

Fish Death Interim Investigation Report

Lower Darling River Fish Death Event, Menindee 2018/19

Executive Summary

A NSW Department of Primary Industries (DPI) investigation has found that it is likely a lack of dissolved oxygen in the Lower Darling River caused large-scale fish deaths in early January and a smaller incident in the same area in December 2018.

DPI scientists consulted with Murray-Darling Basin experts in biochemistry and algal ecology and found that both fish deaths were likely to have been caused by several related and compounding factors resulting in low oxygen in the river, including:

High temperatures and low or no water flow conditions led to thermal stratification. A situation in which warmer surface layer (~1m) of water sat above a cooler deeper layer (2-3m) of water with very low dissolved oxygen. These conditions were conducive to blue-green algal blooms in the surface layers.

Rainfall on December 15 2018 and an associated drop in temperature appears to have mixed water layers, which resulted in very low dissolved oxygen throughout the water column.

Another substantial drop in air temperatures from 46 degrees to 28 degrees on January 4 and 5 associated with cold fronts passing through the region again caused layers of water with different dissolved oxygen levels to mix, reducing the overall dissolved oxygen available.

High algal content in stock and domestic flow releases drawn from Lake Pamamaroo, which increased oxygen demand and consumption, further reduced dissolved oxygen available to fish.

However, it is not possible to determine unequivocally the cause of the fish deaths in Menindee without comprehensive data on the conditions in the Darling River immediately prior to the first sighting of dead fish

DPI will continue to remain on high alert for potential future fish deaths in the Lower Darling River, and have commenced the deployment of aeration devices.

DPI scientists have collected otoliths (ear bones) from some of the Murray Cod, Golden Perch, and Silver Perch that died during the event to improve their knowledge of the species and their future management. Preliminary analysis of the otoliths from individuals collected (127 to 103 cm in length) have been estimated to range from 17 to 25 years old. Future research will use the otolith to examine where the fish may have been born.

DPI is working with other state and federal agencies to deliver improved management for protecting and enhancing our native fish populations in the Murray-Darling Basin, including better water quality and fish monitoring, increased restocking, and improving fish passages to allow fish to move, feed, and breed.

The Lower Darling fish community

The Lower Darling region is important for the breeding and recruitment (growth and survival) of numerous species of native freshwater fish (Gilligan 2005). In particular, recent research has indicated that the Darling River is a particularly important nursery area for Golden Perch (Sharpe 2011). Additionally, in some years Golden Perch spawned in the Darling River have been found to make substantial contributions to Golden Perch populations in the Murray River and associated tributaries (Zampatti *et al.* 2015, 2018).

Prior to the Millennium Drought the fish community of the Lower Darling was generally in a good condition, with robust populations of Murray Cod, Golden Perch and other native fish. During the Millennium Drought numerous fish deaths have occurred in the Lower Darling River and Menindee Lakes, particularly over 2002 - 2004. This included a fish death in Lake Pamamaroo in December 2002 as the lake dried out; three separate fish death events in August 2003 involving thousands of fish dying in the Darling River upstream and downstream of Wilcannia, a fish death at Pamamaroo Lake inlet regulator in November 2003. A significant fish death also occurred along approximately 160 km of the Darling River upstream of Pooncarie in February 2004 involving thousands of Murray Cod. Subsequent to 2004, fish deaths were recorded in the Lake Menindee Outlet in November 2017 and the Lake Menindee Inlet in January 2018 (Figure 1).

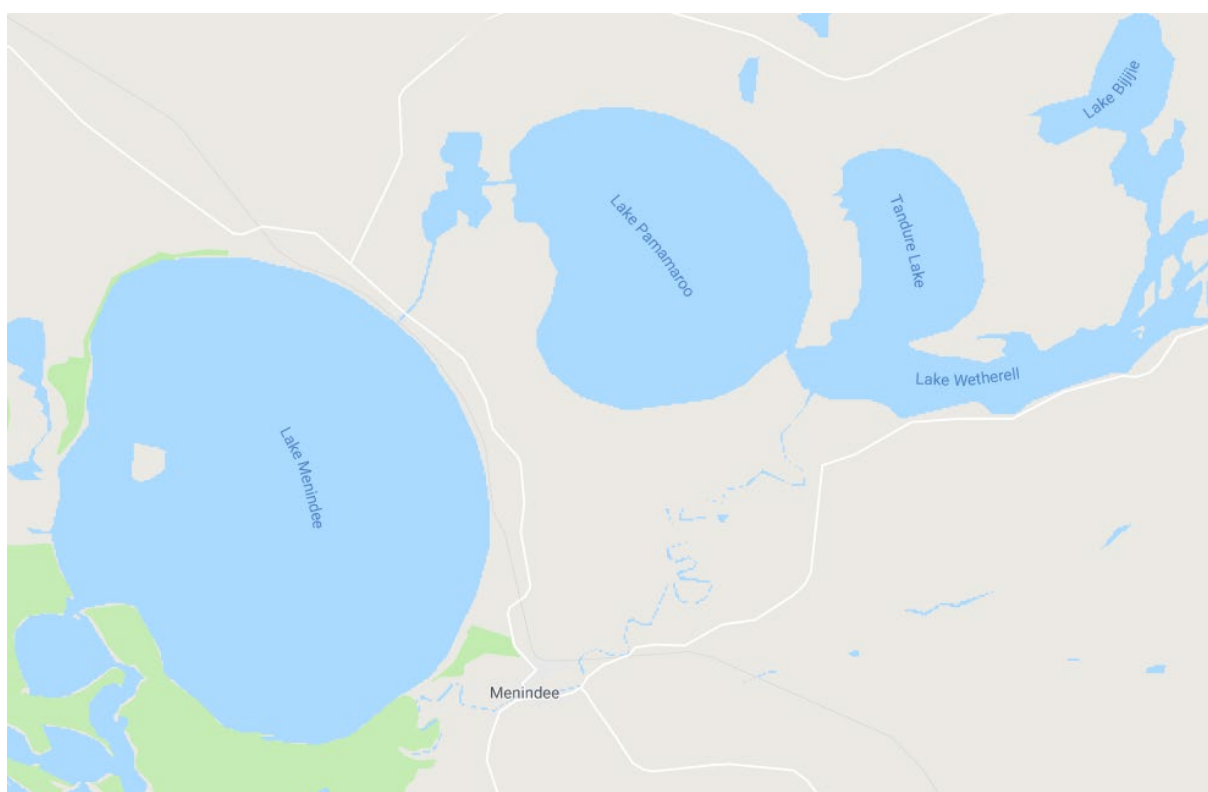


Figure 1: The Lower Darling River and lakes near Menindee (Source: Google Earth).

Timeline of the Menindee 2018/19 fish deaths and associated environmental conditions

On **December 15, 2018** a significant fish death occurred on the Darling River adjacent to the town of Menindee. The affected stretch of river was approximately 30km long, from a point downstream of the Menindee Lakes Main weir to a point upstream of Weir 32 (Figure 2).

Tens of thousands of dead fish were reported by DPI Fisheries staff that inspected the site, with high numbers of dead fish observed in the vicinity of the Old Menindee Weir and Menindee Pump Station.

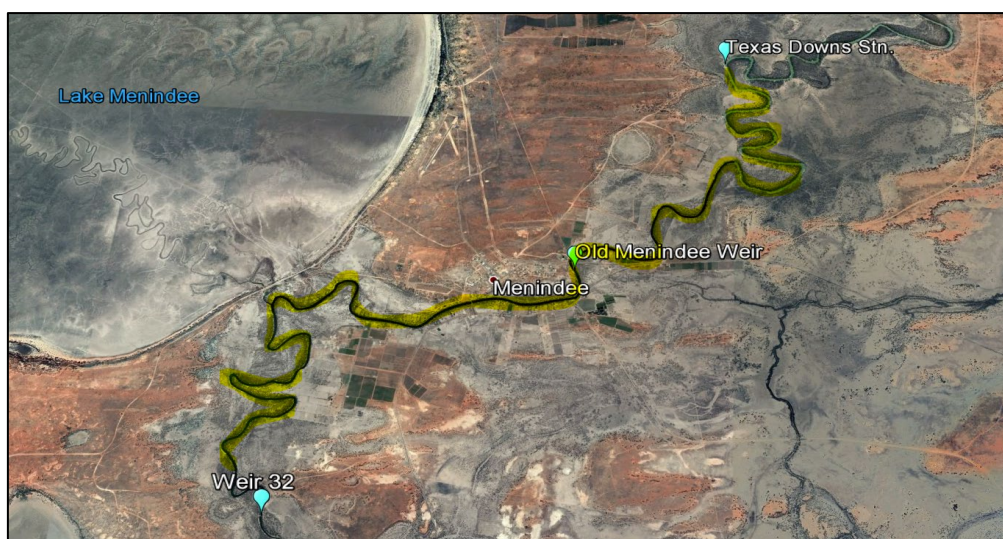


Figure 2: The Lower Darling River near Menindee affected by the Dec 2018/Jan 2019 fish deaths, with the reach estimated to have been affected by the fish deaths highlighted in yellow (Source: Google Earth).

In the lead up to this fish death event the Menindee region experienced very hot and still conditions. Daytime maximum air temperatures were regularly over 35°C, with overnight minimums exceeding 20°C during the week prior to the fish death (Figure 3).

WaterNSW had been making releases to the Lower Darling of 300-350 megalitres a day (gauged at Weir 32) from Lake Pamamaroo since 28 November 2018 to maintain supply for stock and domestic users downstream of Weir 32.

Growth of blue-green algae occurred during the hot, still conditions, with 'red alert' notifications issued by WaterNSW for the Darling River at Menindee and the Menindee Lakes throughout December 2018. Red alert levels represent 'bloom' conditions.

Approximately 19mm of rainfall was recorded in the Menindee region over 14 and 15 December (Figure 3). A substantial decrease in temperature was associated with the rainfall event, with maximum daytime temperature decreasing from 39°C to 19.3°C between December 12 and 14. Minimum air temperature decreased from 24.5°C to 11°C during the same period (Figure 3), whilst water temperature upstream of Weir 32 dropped by approximately 6-7°C (Figure 4).

This rainfall also resulted in localised run-off to the river and a small increase in discharge through the stretch of river adjacent to the town of Menindee (Figure 3). This stretch of

Darling River includes deeper pools upstream of the Old Menindee Weir (a submerged structure) just upstream of the town.

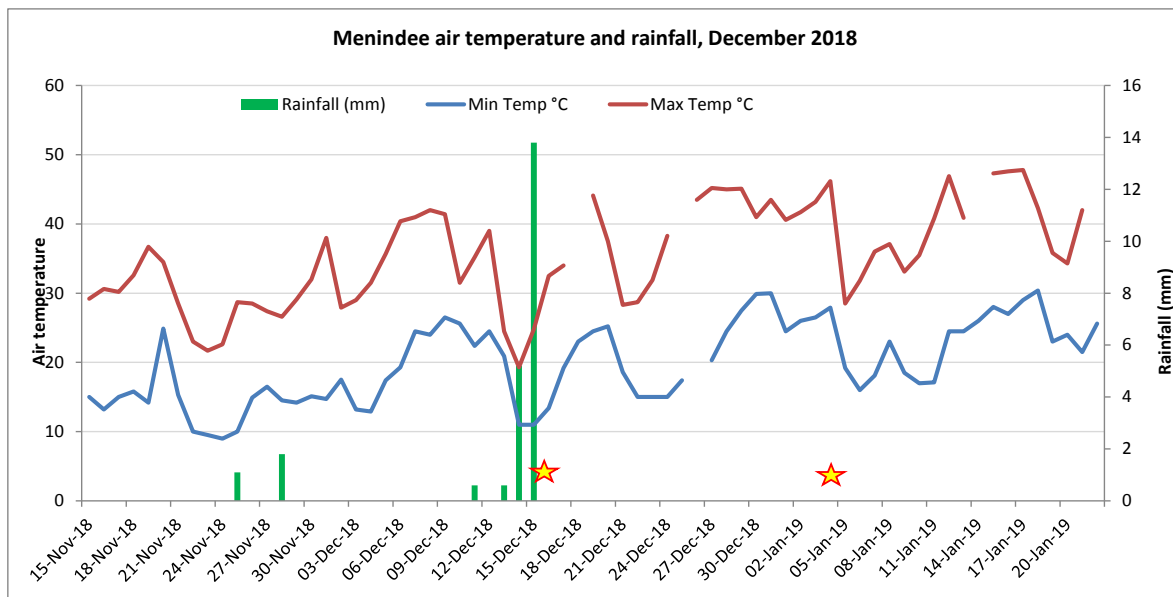


Figure 3: Recorded daily maximum and minimum air temperature and rainfall at Menindee from 15 November 2018 to 20 January 2019 (Source: Bureau of Meteorology). Observed fish death events are indicated by stars. Growth of blue-green algae occurred during the hot conditions, with 'red alert' notifications issued by WaterNSW for the Darling River at Menindee and the Menindee Lakes throughout December 2018.

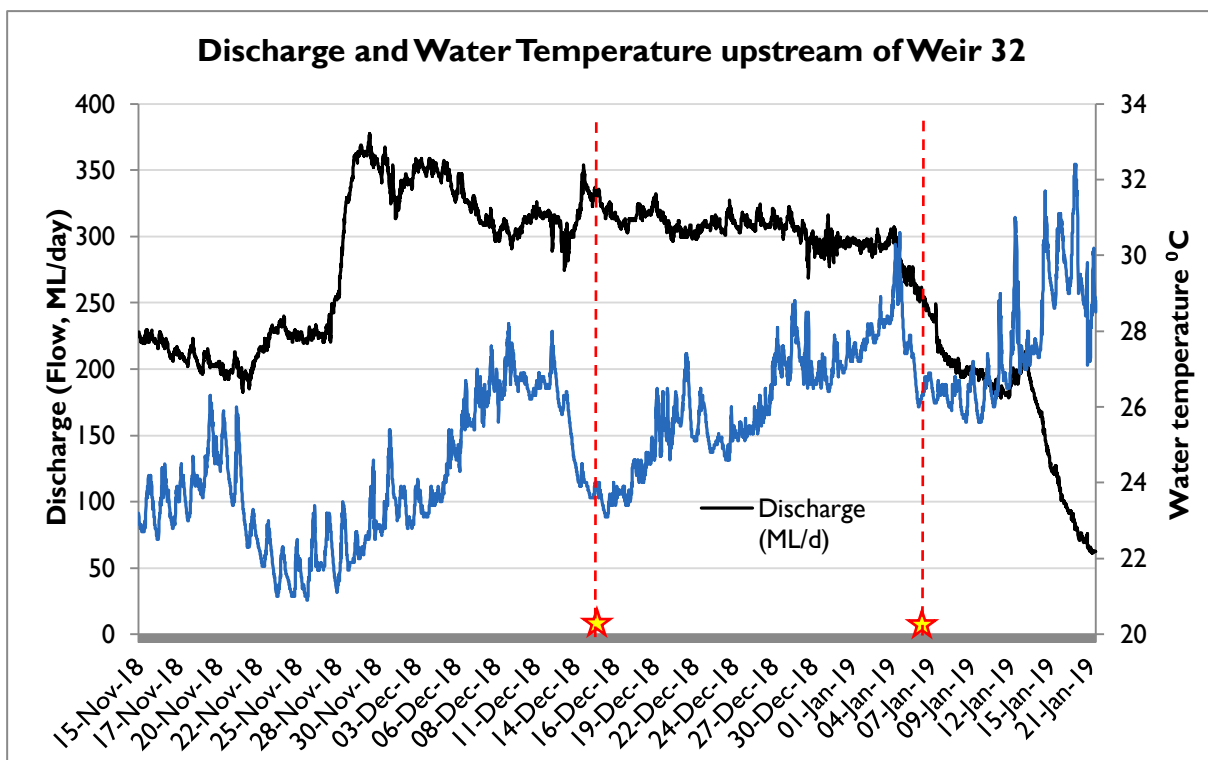


Figure 4: Recorded discharge flow (black line) and water temperature (blue line) upstream of Weir 32 (i.e. in the affected weir pool) from 15 November 2018 to 20 January 2019 (Source: Water NSW). Observed fish death events are indicated by stars.

The rapid decrease in temperature and localised increase in flow coincided with early reports of a fish death in the Weir 32 pool adjacent to Menindee (first reported around 12:30pm on

15 December, 2018). DPI Fisheries staff inspected the site and estimated tens of thousands of dead fish along approximately 300km of river (Figure 5).

Dead fish were predominantly Bony Herring, but also included hundreds of Golden Perch and Silver Perch, as well as dozens of Murray Cod (mostly large adults). Small numbers of dead non-native Carp were also observed. Dead fish ranged in size from 5cm (thousands of juvenile Bony Herring) up to 127cm (mature Murray Cod). At the time of inspection, the water in the affected reach appeared green and discoloured, with clumps of algae scums visible. A strong musty or organic odour was also reported.

A second major fish death in the same stretch of river was reported on the morning of 6 **January 2019**, with fish continuing to die through to January 7, 2019. DPI Fisheries staff who inspected the site estimated **hundreds of thousands of fish died** in the second event along the same stretch of river, with more dead fish downstream toward Weir 32 and fish noticeably gasping (known as aquatic surface respiration) near the Menindee town.

Maximum air temperatures in Menindee were again high from 24 December 2018 through to 4 January 2019 (Figure 3). Blue-green algal red alert notifications were still in place for the Menindee region.

Water releases from Lake Pamamaroo to the Weir 32 pool were being reduced at the time of the second fish death as useable water supply in the lake diminished. This resulted in a gradual decrease in flow in the Darling River at Menindee (Figure 4). A cold front moved through the region on January 5, 2019, with maximum air temperature dropping from 46.2°C to 28.5°C between 4 January and 5 January. Minimum air temperature dropped from 27.9°C on January 4 to 16°C on the morning of 6 January, while water temperature dropped approximately 5°C (Figure 4). These rapid decreases in maximum and minimum temperature directly preceded reports of a second major fish death in the Darling River adjacent to Menindee reported at 9:30am on 6 January 2019. A follow up report at 7am on 7 January 2019 indicated the number of dead fish had increased again overnight (Figure 6).

Again, affected fish were predominantly Bony Herring, with thousands of Golden Perch and Silver Perch, as well as dozens (potentially hundreds) of Murray Cod (mostly large adults) also died. Small numbers of dead Carp were again noted. Dead fish ranged in size from 5cm (thousands of juvenile Bony Herring) up to over 100cm (adult Murray Cod). A sulphur-like smell was also noted on the mornings of 6 and 7 January.



Figure 5: Bony Herring (top left), Murray Cod (top right and bottom left), and Golden Perch (bottom right) that died in the December 2018 fish death adjacent to Menindee. Note the green colour of the water.



Figure 6: Images of fish dead in the 6-7 January 2019 event adjacent to Menindee. Note again the green colour of the water.

Evaluation of likely cause of the Menindee fish deaths

As with any fish death event, it is not possible to unequivocally determine the cause of the fish deaths in Menindee without comprehensive data on the conditions in the Darling River immediately prior to the first sighting of dead fish. However, we can infer the most likely primary cause of the fish death, and other contributing factors, using a multiple lines of evidence approach based on; available environmental data, expert opinion and evidence associated with water quality dynamics in the Lower Darling, evaluation of historical fish death events, and earlier mortality events in the Darling River and other inland lowland rivers in the Murray-Darling Basin.

A number of hypotheses on the cause(s) of the fish deaths in the Darling River have been put forward in the media. These hypotheses are considered in turn.

1. Algal bloom and toxins

For the last several months there has been a major blue-green algal bloom at the red alert level between Menindee Weir 32 and upstream to Menindee Main Weir. WaterNSW lists the dominant species as "Nostocaceae sp"; and this has been confirmed as *Dolichospermum*, previously called *Anabaena sp*. The timing of the formation of the bloom is consistent with previous research that identified that blooms of *Dolichospermum* occur during low flows and thermal stratification (Mitrovic *et al.* 2011). This species produces toxins including saxitoxin; a potent neurotoxin. Saxitoxins are quite stable, water soluble, tasteless, odourless, and can be bioaccumulated in freshwater fish (Galvao *et al.*, 2009). Saxitoxin has been associated with fish deaths and cattle deaths previously. Toxin deaths are expected to be gradual with fish dying over a longer period and smaller fish affected first due to their smaller body weight and thus susceptibility to intoxication. Although it is possible that the fish deaths were caused by (or at least heightened) by algal toxins, given no observed fish deaths prior to mid-December when an algal bloom was in place suggests that exposure to algal toxins was not the principal cause of the fish mortality event. Furthermore, toxicity testing undertaken in Weir 32 were negative for the presence of toxins (pers comms, WaterNSW).

2. "Crash" of Algal Bloom

As reported previously, the first fish mortality event coincided with a cool change in mid-December 2018. It has been proposed in more than one media report that the change in air temperature may have led to a sudden crash in the biomass of the algae. The dead algae would then decompose, which would consume oxygen, and lead to low oxygen in the water column resulting in the fish death event. However, the water temperature data upstream of Weir 32 does not support this hypothesis. While there was a significant drop in air temperature over 12-14 December (Figure 3), the change in water temperature was substantially less. The surface water temperature upstream of Weir 32 on 12 December was 28°C and fell to a low of 23°C by 16 December. These water temperatures are not cool enough to cause any significant changes in blue-green algal biomass. Blue-green algae grow at a range of temperatures and although cooler temperatures lead to slower growth rates this does not usually lead to mass die off, but rather could lead to a gradual change in the type of species if conditions were no longer conducive to growth (Dr Simon Mitrovic, pers. comm.). Therefore, not surprisingly, blue-green algal biomass remained high in the reach after the 16 December with a red alert remaining in place.

3. Breakdown of thermal stratification below the Menindee Main Weir

This appears the most likely principal cause of the fish deaths. In very low or non-flowing water bodies during warm weather, the surface of the waterbody heats up more rapidly than deeper water. The warmer surface water is less dense than the colder bottom water so the temperature differential results in less mixing between the top and bottom. Oxygen levels in the surface water are continually replenished from the atmosphere. However, because the surface water and deeper waters do not mix, oxygen levels in the bottom water are not replenished. Oxygen in the deeper water continues to be consumed through respiration (particularly by microorganisms in the sediment at the bottom of the waterbody) and this can result in vertical stratification - a warm, relatively well oxygenated surface layer and, a colder, oxygen-depleted (hypoxic or even anoxic) bottom layer (Figure 7).

In deep waterbodies like large lakes and reservoirs, where the thermocline is well below the surface, stratification can last for many months - or even indefinitely. In rivers like the Darling, persistent stratification without mixing can occur for weeks or months under the right conditions (Mitrovic *et al.* 2003; 2011). However, in these shallow water bodies, where the thermocline is shallower and the temperature difference between the surface and the bottom is not great, the surface and bottom layers can become easily mixed by climatic events. Strong winds, cooler air temperatures, and inflows from rain events or reservoir releases can all breakdown stratification. As the surface and bottom water mix, the overall water temperature will fall, as will the concentration of dissolved oxygen (Figure 7).

The fish mortality event in mid-December was preceded by a cool change (discussed above) which also included strong winds (at least 24 km/h) on the 13 December and 14 December and rainfall (5 mm on the 14 December and 14 mm on the 15 December) (Figure 3). The second mortality event (in early January 2019) in the same reach coincided with another cool change (with maximum air temperatures falling from 46°C on 4 January to 28.5°C on 5 January (Figure 3). The cool change was also associated with strong winds (24 km/hr on 5 January) and resulted in a substantial fall in water temperature (from above 30°C on 4 January to 26°C on 6 January).

A fall in both temperature and dissolved oxygen preceding both fish death events is consistent with a breakdown in stratification. The effected reach has been shown to undergo periodic thermal stratification in the summer months under flows similar to those occurring in the river through September to January (Mitrovic *et al.*, 2011) and the *Dolichospermum* bloom is consistent with the thermal stratification being in place for a considerable amount of time. Furthermore, breakdown of stratification in pools of the Lower Darling has been previously shown to create catastrophic falls in dissolved oxygen concentrations (Wallace *et al.*, 2008) and has been linked to previous fish mortality events in the Darling River (Ellis and Meredith, 2004).

It should be noted that destratification events do not always lead to fish deaths. If this were the case fish deaths would occur more frequently in every dam in NSW. Mitrovic *et al.* (2003; 2011) noted that previous destratification events in the Darling River have not resulted in fish deaths, or not as extensive as those observed recently. Most importantly, whether deaths will occur is dependent on the proportion and concentration of low oxygen water that mixes into the surface water (and its oxygen concentration). This partly determines the final water column oxygen concentration. If the water becomes low enough in dissolved oxygen (hypoxic) it can create substantial oxygen-stress for fish, which absorb oxygen from the water

through their gills. If dissolved oxygen concentrations fall to stressful levels (i.e. <3 mg/L) for extended periods of time (days) the likelihood of fish deaths, particularly in large, isolated or disconnected water bodies, is increased.

Available data indicated that the Darling River in the Menindee region was stratified during 2018-19 in recent months preceding the fish kill events (Figure 8). There was a decrease in water temperature and dissolved oxygen with increasing depth in the water column just upstream of Menindee Main Weir (i.e. in Lake Wetherell, Figure 1) on 13 December, prior to the first fish kill. Although no depth profile water quality data is available for the Weir 32 pool (Menindee Weir Pool) immediately prior to the fish kills, based on the evidence presented, we expect that similar hypoxic conditions at greater than 1-2 metres deep prevailed along the effected stretch of river prior to both the December 2018 and the January 2019 fish deaths in the river adjacent to Menindee. Observations of fish undertaking aquatic surface respiration after the January fish death event also supports the presence of hypoxic conditions (McNeil and Closs, 2007).

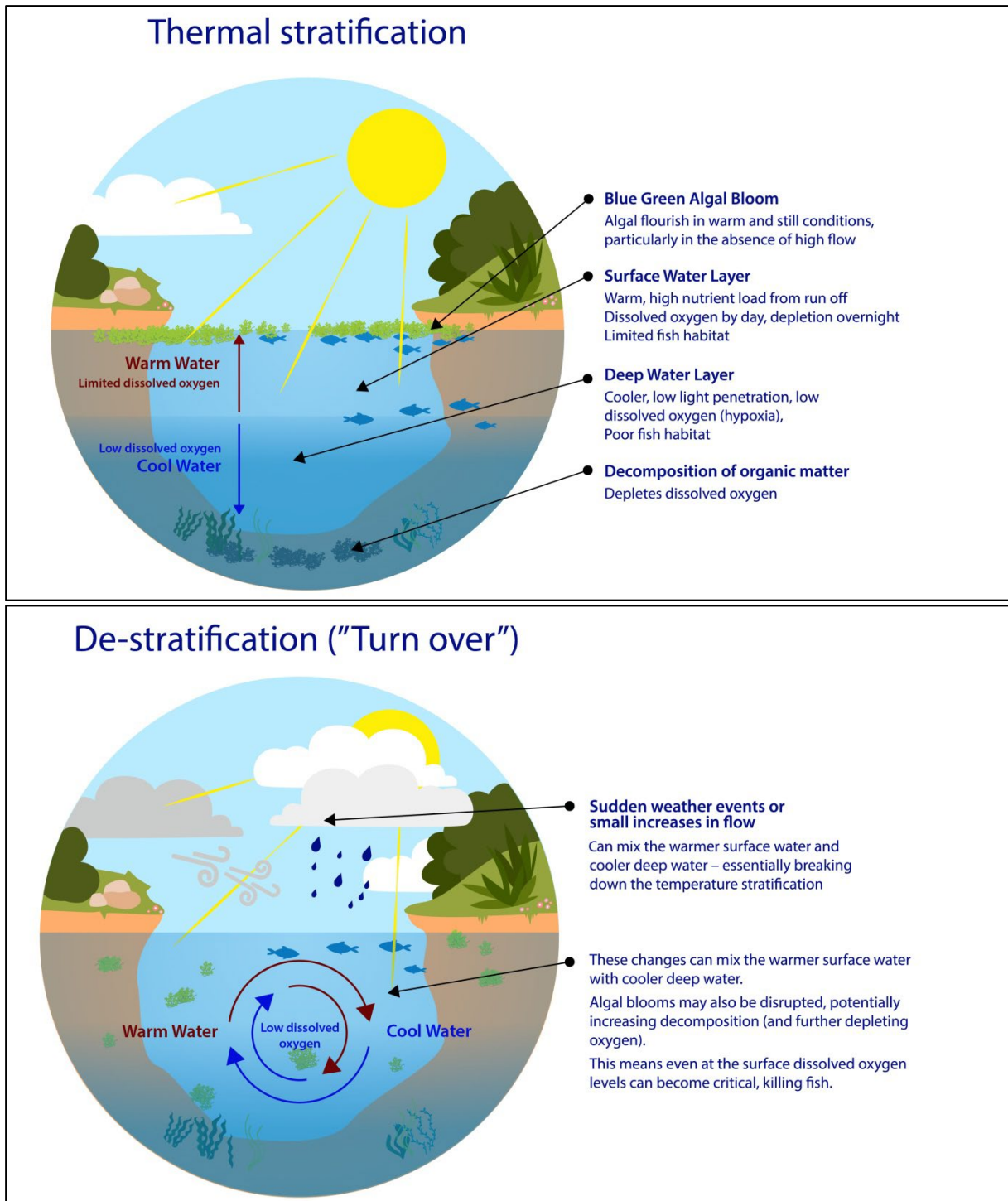


Figure 7: Explanation of thermal stratification and de-stratification processes.

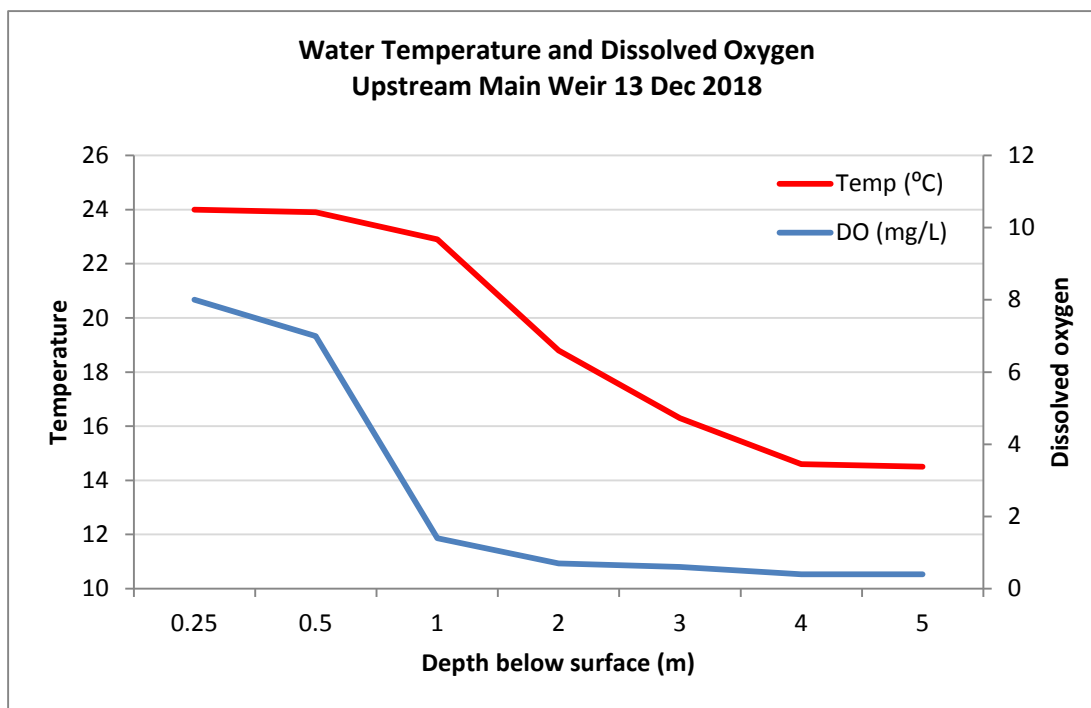


Figure 8: Decreasing water temperature and dissolved oxygen levels with increased depth in the water column upstream of Menindee main weir (i.e. Lake Wetherell), which indicates stratification (source: WaterNSW).

WaterNSW collected depth-profile water quality data in the Menindee Weir pool upstream of Weir 32 on 7 January 2019, soon after the second fish death (Figure 9). At this time, the temperature throughout the whole water column did not indicate a distinct thermocline (change from warm to cool water), suggesting that de-stratification occurred and the water column had become mixed, potentially assisted by water being drawn over the weir with releases occurring at the time. Dissolved oxygen levels were very low throughout the whole water column (< 2mg/L). Most fish are expected to experience extreme oxygen stress at such hypoxic conditions.

Further upstream at Menindee Town on January 7 2019 a thermocline was evident later in the day with dissolved oxygen concentration in surface waters >3mg/L, but very low at depths greater than 1m (Figure 10). The combination of wildly fluctuating dissolved oxygen, including down to extreme lows overnight, and very high water temperature in the surface water, where slightly more favourable dissolved oxygen levels persisted, would have contributed to decreasing condition of native fish and ultimately their death on 6 and 7 January. It is likely that fish stressed over several weeks would have been vulnerable to the January conditions (La and Cook 2010). The observation of fish undertaking aquatic surface respiration in this area on January 7 supports the presence of hypoxic conditions in lower water depths of the system and indicates native fish in a stressed condition.

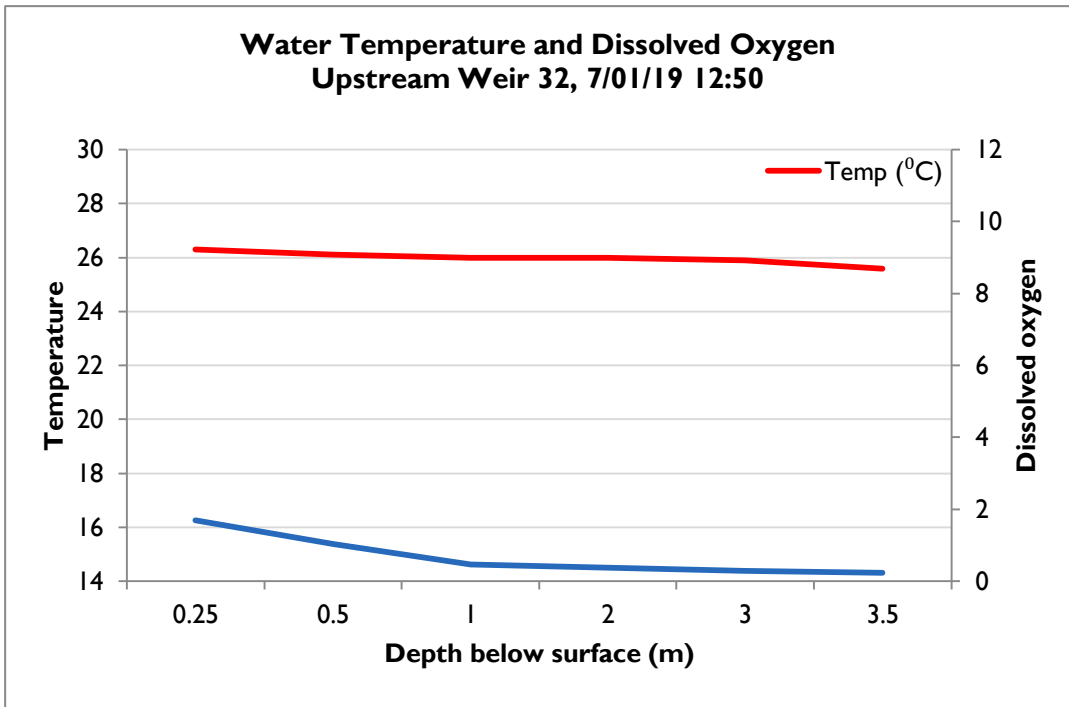


Figure 9: Data showing absence of thermocline and presence of hypoxic conditions throughout the water column upstream of Weir 32 following the January 2019 fish death. (source WaterNSW).

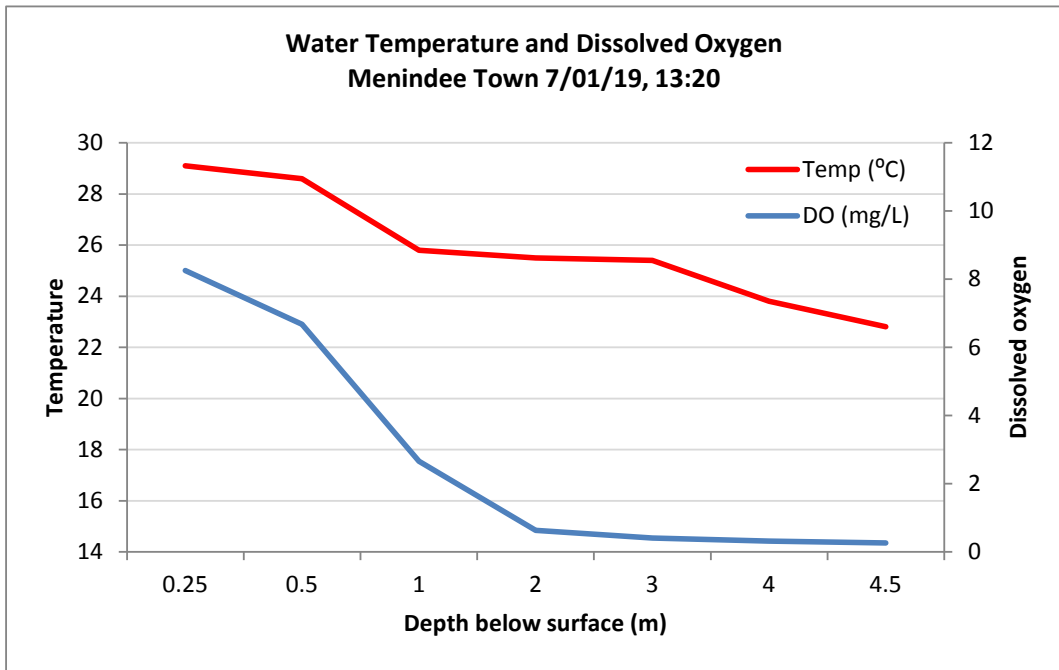


Figure 10: Data showing presence of thermocline and hypoxic conditions at depth greater than 1m adjacent to Menindee town in the afternoon following the January 2019 fish death. (source WaterNSW).

4. Other Contributing Factors

Although a breakdown of stratification is thought to be the primary cause of hypoxic conditions, it is likely that other factors have also contributed to fish deaths. Other oxygen consuming materials such as organic matter washed in (leaves, soil) or algal matter breaking down can further reduce oxygen levels. The sinking and decomposition of fish from the December fish death would also contribute to hypoxic conditions. Algae produce oxygen during photosynthesis, but consume oxygen during respiration. This means that during bloom conditions the dissolved oxygen levels in the surface layer can be quite high, while during the night the levels will fall. The diurnal shifts in oxygen levels can be extreme. Figure 11 shows the dissolved oxygen levels at Burtundy on the Darling River (approximately 150km downstream from this fish death event) for the first two weeks of 2019. Daily dissolved oxygen levels in the surface layer ranged from 2 mg/L (about 25% saturation) to nearly 22 mg/L (nearly 3 times saturation).

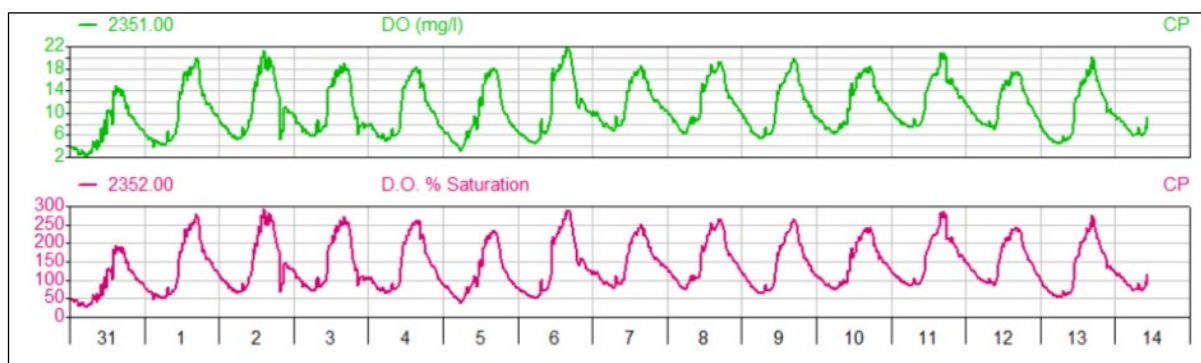


Figure 11: Continuous dissolved oxygen concentrations (top panel) and level of saturation (bottom panel) at Burtundy on the Darling River from 31/12/2018 to 14/1/2019 (source WaterNSW).

At low oxygen concentrations, it will be difficult for the fish to get enough oxygen for respiration. Generally, large bodied native fish begin to show signs of distress at oxygen concentrations of about 4 mg/L (Gehrke 1988) and mortality can begin at sustained exposure to concentrations of 2-3 mg/L (Gehrke 1988; Small *et al.* 2014). Therefore, while toxins from the algal blooms may not directly affect the fish population to a large extent, the algal bloom's impact on oxygen concentration in the surface layer will likely indirectly impact on fish survival.

High temperatures experienced across the region would exacerbate hypoxic conditions. Water temperature in the Darling River above Weir 32 prior to the second fish mortality event reached 30°C, and have subsequently reached above 32°C (WaterNSW online data). Large body natives are ectotherms, and as the water temperature increases, so does their metabolic rate and hence their oxygen requirements. A metastudy (Clarke and Johnston, 1999) suggests that for every 10 degree rise in temperature (between 0 and 30°C) causes a 2.4 times increase in resting oxygen metabolism. Furthermore, resting oxygen metabolism rate increases with body weight. Therefore, the warmer the water (and the bigger the fish) the more oxygen it will require.

What is DPI doing?

DPI continue to remain on high alert for potential future fish deaths in the Lower Darling River in the immediate future as poor water quality and challenging climatic conditions continue to persist in the region, with monitoring and exploration of management options continuing.

Following these deaths, a number of interventions have been proposed for the short-term re-oxygenation of water to provide localised fish refuges and minimise the likelihood of further fish mortalities. A technical group of experts from the public, private and university sectors has been established to evaluate these potential interventions, with particular emphasis on their efficacy, practicality, and potential to cause additional water quality issues.

As an interim measure, DPI Fisheries are coordinating the deployment of aeration devices at certain locations along the Lower Darling River. These devices will create small localised refuges in priority locations where native fish may survive in the event of further fish death events, especially if water quality conditions deteriorate along the reach and climatic conditions remain unfavourable. DPI Fisheries, in collaboration with WaterNSW, will coordinate monitoring of water quality adjacent to the devices to assess their effectiveness, which will help inform future fish death events.

To improve future planning, management and response actions in the Lower Darling River it is recommended that a comprehensive climatic and water quality monitoring and evaluation program be established that focuses on water depth and water quality aspects such as dissolved oxygen and temperature, along the Darling River, including in different source locations of water. A coordinated network would help to show trends over time and space, and allow us to better forecast the likelihood of a fish death event and further understand the system and conditions that may lead to fish death events, including the impact of air temperature and sudden climatic changes.

Whilst the fish deaths to date have been extensive, historical data records suggest strong populations of Murray Cod and Golden Perch persist in the Lower Darling River downstream of the Menindee Lakes. DPI is looking at management actions in the region to protect and recover native fish populations when conditions improve. These actions may include ongoing water quality and fish monitoring, increased restocking efforts, improving fish passage through the region, and working with other state and federal agencies to deliver further management actions to support the movement, breeding, and recruitment of native fish.

Additionally, researchers from DPI Fisheries removed otoliths (ear bones) from 40 to 50 individuals of each of the Silver Perch, Golden Perch, and Murray Cod species that were died during the January fish death event at Menindee to improve our knowledge of these species (Figure 12).

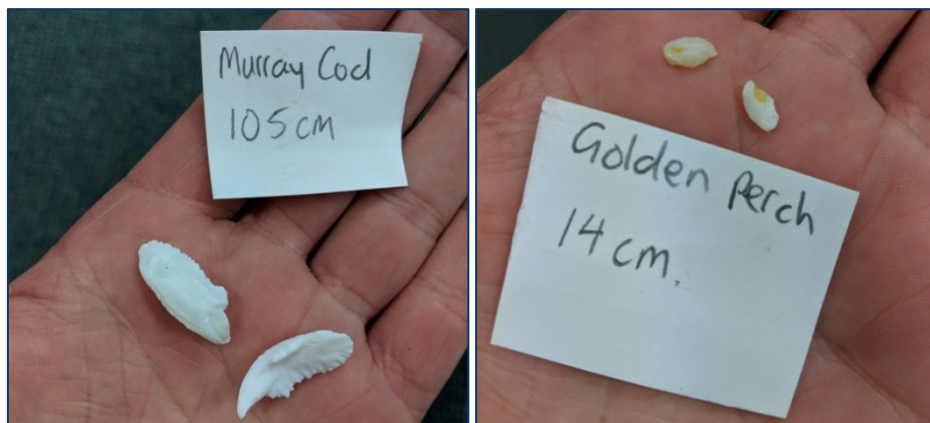


Figure 12: Extracted otoliths from fish died during the recent events in the Lower Darling River near Menindee.

Otoliths allow researchers to work out how old a fish is, and can be used to help establish age and length relationships, as well as potentially unearth other secrets through microchemistry work, including where the fish was born and spent its life.

Ages of the fish can be 'read' from the otoliths by counting the number of seasonal bands (or growth rings), similar to ageing trees. DPI Fisheries scientists are currently ageing these fish and have completed readings of otoliths from a sub-sample of the Murray Cod collected that cover a range of sizes (and ages). The four largest (and most likely oldest) individuals collected (127, 118, 105, and 103 cm in length) have been estimated to range from 17 to 25 years old. Researchers will continue to work through all of the samples collected in the coming weeks to provide age information for all specimens.

In addition, recognising the relatively large spatial scale that these species can cover during the life history, researchers will also examine the microchemistry of the otoliths. This will help determine where these fish were spawned and how long they have been residents of the Lower Darling, providing important information on the recovery potential for the system, and associated management actions to enhance the recovery and protection of native fish in the region.

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