

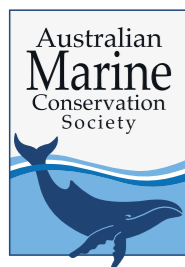


The impacts of bushfires on coastal and marine environments

A review and recommendations for change

A report for the Australian Marine
Conservation Society by Chris Smyth





Australian Marine Conservation Society

Phone: +61 (07) 3846 6777

Freecall: 1800 066 299

Email: amcs@amcs.org.au

PO Box 5815 West End QLD 410

Author: Chris Smyth

Coordinator: Darren Kindleysides

© Australian Marine Conservation Society, February 2020

This report has been prepared for the exclusive use of the Australian Marine Conservation Society (AMCS) by Chris Smyth of Chris Smyth Consulting. The report must only be used by AMCS, or with the explicit permission of AMCS. The matters covered in the report are those agreed to between AMCS and the author. The report does not purport to consider exhaustively all issues related to the impacts of bushfires on coasts and oceans. The author does not accept liability for any loss or damage, including without limitation, compensatory, direct, indirect, or consequential damages and claims of third parties that may be caused directly or indirectly through the use of, reliance upon or interpretation of the contents of the report

Cover photo

Brothers stand together on the beach during 2019/20 Bushfire Crisis. Forster, New South Wales. © Martin Von Stoll

Contents

Executive Summary	4
Key Findings	6
Recommendations	8
The Australian Coast Up in Flames	10
Existing Catchment, Coastal and Marine Research on Bushfire Impacts	14
Current and Future Impacts of the Bushfires on Oceans and Coasts	20
Conclusions and Recommendations	28
References	31
Appendix 1	38

Tables

Table 1 State by state breakdown of fire impacts

Table 2 The impacts of major bushfires in Australia's past

1. Executive summary

When the NSW Rural Fire Season announced that the 2019–2020 bushfire season was to begin one month early in September 2019, it did so because of ‘extreme drought conditions, a forecast of hot, dry weather’ and fires already burning in August.

The announcement marked the beginning of a bushfire season that would be unprecedented. Thousands of fires engulfed all states and territories, with some burning down to the shorelines of estuaries and beaches. The season was a stark piece of evidence that the scale, intensity and frequency of Australia’s bushfires were increasing, exacerbated by the effects of escalating climate change.

The immediate bushfire impacts were clear. Lives were lost, homes and infrastructure destroyed, access into and out of towns cut, smoke and ash turning day into night, power blackouts and food and water shortages. Images emerged of dead, dying and injured wildlife, blackened and charred coastal dunes and cliffs, and suffocating fish in rivers and estuaries.

The economic costs of the bushfire season can be measured in terms of insurance claims and lost income to businesses and tourism, the social costs, sadly, in terms of lost lives and damaged communities. The destruction of terrestrial habitats can be measured in terms of the habitat area burned and the number of animals killed and injured. However, the costs for marine and coastal environments are far more difficult to estimate due to limited data on coastal and marine plants, animals and habitats, and the small amount of research on how they are impacted by bushfires.

This report is the first to focus on bushfire impacts on coastal and marine environments. In its preparation, the available marine and coastal research has been reviewed, along with a larger body of research into bushfire impacts in catchments away from the coast. In combination, these two sources of data provide an insight into what bushfire impacts can be expected in estuaries and other coastal and marine

environments, in the short and longer term, and help with planning for future bushfire events.

The increasing scale, frequency and intensity of bushfires in Australia, and the extensive media coverage of the current season, is causing the community to be more aware that coastal and marine environments are also impacted. Ocean and coastal environments are already struggling against development, pollution, overfishing and global warming. They now face the added burden of escalating bushfire impacts.

Research has shown that when the nutrients, ash, debris, sediments and metals released by bushfires are washed into waterways, they can remove the feeding and breeding areas of aquatic animals, clog the gills of fish, and undermine the breathing of filter feeding animals such as mussels. The contaminated sediment slug can slowly work its way downstream to the coast, harming aquatic life along the way.

Metals such as copper, zinc, lead and mercury, and other contaminants released by the bushfire, could change the physiology and behaviours of marine animals and work their way up the food chain. Harmful algal blooms caused by nutrient enrichment can kill fish and contaminate oyster farms.

Coastal and marine habitats, such as seagrass meadows and mangroves, are already under considerable stress, and the water quality of major estuaries has been in accelerating decline, the impacts of bushfires are adding further pressure. This will likely worsen as the scale, intensity and frequency of bushfires increase as a result of global warming.

To mitigate the impacts of bushfires, which are an increasing problem in many parts of the world, all governments, including Australia, must work together to cut carbon emissions to net zero quickly and effectively. The pathways to achieve this are well known and include replacing the use of fossil fuels by renewable energy sources, electrifying transport, stopping deforestation, regenerating forests and carbon-

rich coastal habitats, and moving away from the use and export of coal, oil and gas.

The Australian, state and territory governments should also work together to develop an integrated, comprehensive and consistent monitoring program for coastal and marine environments. It can be used as an early warning system for environmental changes that may occur after bushfires and other pollution events, and enable swift action to address them. It will also help build a better understanding of bushfire impacts and how they can be avoided or minimised. The program should involve government agencies, research institutions, citizen scientists and community organisations.

Finally, the declining health of estuaries needs to be reversed by governments supporting existing restoration programs and the development of new ones. This will help mitigate the impacts of bushfires and also maintain nature based tourism and commercial and recreational fisheries and the economic and social benefits they bring to coastal communities.

If the recommendations of this report, and those of other organisations concerned about bushfire impacts on coastal and marine environments are acted upon by all levels of government, then Australia can minimise the environmental, cultural, social and economic costs and start recovering and restoring the health of our coastal waterways.

This report reviews academic literature, media reports and various websites to summarise what we know, what we don’t know and what we need to know and do about bushfire impacts on marine and coastal environments. It begins by reviewing existing catchment and coastal research on bushfire impacts, describes some of the impacts of the current bushfire season, and considers a number of restoration projects that can help bushfire recovery. The report ends with a comprehensive listing of references and an appendix that describes the scale of the 2019–2020 bushfire season.

Figure 1: Sea water turned black by ash from wildfires laps onto a beach near Eden, NSW in January, 2020.



© Mark Graham/Bloomberg via Getty Images

Key findings

Intensifying bushfires

The 2019–2020 bushfire season is unprecedented in Australian bushfire history, fuelled by record-breaking hot and dry conditions exacerbated by global warming.

The scale, frequency and intensity of Australian bushfires is increasing and, as leading scientists, meteorologists and fire and rescue chiefs agree, the changes are directly linked to global warming.

The window for hazard reduction burning is narrowing as the climate changes, while the effectiveness of the practice is diminished under increasingly extreme bushfire conditions.

Consequently, there is a greater need to understand and manage the impacts of bushfires on coastal and marine environments.

Research on bushfire impacts

A growing body of research exists on the effects of bushfires on inland catchments, freshwater fish and the quality of water in rivers, creeks, streams and potable water supplies. However, there is insufficient research on the impacts of airborne and waterborne particulates, nutrients, ash, debris, sediments and metals on coastal waterways, beaches and nearshore and open waters. Even so, it identifies past impacts and potential issues, and catchment bushfire research can provide some indication as to what could occur in coastal and marine habitats.

Bushfire impacts on coastal and marine environments

The 2019–2020 bushfire season has devastated coastal habitats in many locations, led to fish kills in estuaries and forced the closure of oyster farms in New South Wales estuaries.

Bushfire impacts on coastal and marine environments stem from habitat destruction, water pollution from ash and other bushfire debris, and the emergence of harmful algal blooms.

The sediment and nutrient slugs formed by bushfire debris can move many kilometres downstream, impacting aquatic life along the way.

Smoke and ash from fires contain contaminants such as copper, zinc, lead and mercury that could change the physiology and behaviours of marine animals and work their way up aquatic and terrestrial food chains.

The ash and debris entering waterways during bushfires and after rain can remove the feeding and breeding areas of aquatic animals, clog the gills of fish, and undermine the breathing of filter feeding animals such as mussels.

Smoke and ash from fires increase the levels of nutrients such as nitrogen and phosphorus in waterways and can lead to the growth of phytoplankton and harmful algal blooms.

Seagrass meadows, mangrove forests and rocky and coral reefs are already under increasing pressure from climate change, coastal development, overfishing and declining water quality. Ash, smoke and debris are an added burden and one that could worsen over time as Australia's bushfires increase in scale, intensity and severity.

Fire retardants used in fire suppression activities can be harmful to aquatic animals when directly or indirectly applied to waterways.

Increased or repeated hazard reduction burning could cause local impacts on coastal environments, such as increased erosion and longer recovery times.

The bushfire impacts on estuaries and other coastal waterways could take months or longer to materialise, making it imperative to establish comprehensive and ongoing monitoring programs as soon as practicable.

Economic, social and cultural impacts of bushfires on coastal and marine users

When ash and debris enter estuaries and other coastal waterways, they reduce water quality and can harm seagrass meadows and mangroves, threatening the future of commercial and recreational fishing (and related tourism) and aquaculture. Damage to these habitats would also reduce their potential for storing blue carbon, with implications for global warming.

The impacts on fisheries of bushfire-related water pollution may resemble those caused by catchment clearing, coastal development and draining. These latter impacts may provide a sense of scale for the potential losses to economically and culturally important fisheries and ecosystem functions caused by bushfires.

Cost estimates for bushfires often focus on the financial costs that can be measured in dollars and largely ignore the costs to environmental, social and cultural values.

The 2019–2020 bushfires are likely to damage coastal and marine sacred sites of Indigenous culture.

Recovery and restoration programs

The pollutants, ash and debris washed into waterways during and after bushfires has put at risk the survival of many threatened freshwater fish species.

Rescue, recovery and restoration programs will be essential to minimise bushfires impacts on threatened species and coastal and marine habitats.

The restoration of estuaries, already required due to their long-term decline in health, could also help them recover from bushfire impacts, benefit fisheries production and provide economic benefits to communities dependent on fishing and associated tourism.

The monitoring and analysis of the impacts of bushfires on marine and coastal environments needs urgent expansion and should be ongoing if adaptation is considered a primary strategy to manage increasing bushfire weather.

Figure 2: Burnt out waterway in northeastern New South Wales, January 2020.



© Jo Sparks

Recommendations

The following recommendations, if acted upon, would improve our understanding and enable Australia to effectively respond to and better mitigate bushfire impacts on our coastal and marine environments. It is imperative that the Australian, state and territory governments work together to deliver these recommendations.

Research

1. Establish a comprehensive research program to address serious knowledge shortfalls of the impacts of bushfires on coastal and marine environments to enable adaptation and mitigation to be effective.
2. Ensure continued and adequate funding to the Bushfire and Natural Hazards CRC. Additional funding should be granted to enable the widespread use of the CRC's Value Tool which allows managers to estimate the value of intangibles, such as biodiversity protection, when making management decisions.
3. Map the extent and severity of the bushfires along the coast to determine the nature and extent of the damage to their natural values.
4. Identify and map areas and catchments most at risk from bushfire runoff, and where impacts are likely to be highest, to assist in the targeting of revegetation and sediment control.

Monitoring

5. Immediately develop an integrated, comprehensive and consistent monitoring program for coastal and marine environments to build an understanding of bushfire impacts and how they can be avoided or minimised. This should engage local governments, citizen scientists, research institutions and government agencies in a nationally funded program to enable accurate and consistent measurement of environmental change from bushfires and other impacts.

6. Establish ongoing water quality monitoring programs for phytoplankton, bacteria, nutrients and metals to provide early-warning systems for poor water quality in coastal waterways.
7. Identify key indicators for water quality and ecological health and ensure that they are consistently monitored nationally across coastal waterways and nearshore waters using best-practice technologies and methodologies.
8. Ensure monitoring programs gather data on seagrass meadows, seaweeds, mangroves, as well as on fish, including key commercial and recreational fish species, birds, mammals, shellfish and other invertebrates reliant on healthy coastal and marine environments in fire-prone regions.

Management

9. Ensure that national and state agencies charged with assessing and responding to the bushfire impacts on wildlife, habitats and ecosystems are tasked with and sufficiently resourced to include marine and coastal plants, animals and habitats in their assessments and responses.
10. Ensure coastal environmental management plans, such as local government or agency plans, work to reduce the runoff from agriculture and coastal development entering coastal waterways.
11. Ensure coastal aquaculture operations are adaptive and resilient to the increasing scale, frequency and intensity of bushfires.
12. Ensure management of inshore fisheries is adaptive to account for the reduced or altered stocks of targeted fish after bushfires and that the increased frequency, scale and intensity of bushfires is factored into long-term fisheries management plans.
13. Establish protected buffer zones around burnt and impacted coastal areas to provide refuge for surviving coastal and marine wildlife.

Recovery and restoration

14. Identify the coastal and marine species and populations at risk from the current and future bushfires and develop and implement protection, recovery and restoration programs.
15. Re-establish riparian vegetation along coastal waterways flowing into estuaries, lagoons, lakes and nearshore waters to reduce water temperatures and to restrict the entry of sediment loads. All riparian vegetation should be fenced, where necessary, to prevent access by livestock.
16. Install sediment barriers and other erosion control measures to reduce the runoff of ash and bushfire debris into coastal waterways.
17. Support, promote and resource the various projects initiated by academic institutions, government agencies and community groups that are restoring, seagrass meadows, oyster reefs, underwater forests of seaweed and other coastal and marine habitats. Some of the organisations have the expertise but not necessarily the capacity – greater investment in their efforts should be a priority.
18. Increase the allocated funds to the Bushfire recovery package for wildlife and their habitat to include the restoration and protection of damaged coastal and marine environments.

Protection and Mitigation

19. Strengthen nature conservation and environmental laws to protect and build the resilience of communities and ecosystems vulnerable to bushfire impacts.
20. Reduce domestic carbon emissions to net zero swiftly and effectively, and show strong leadership in supporting and encouraging other nations to reduce emissions.

2. The Australian coast goes up in flames

An unprecedented bushfire season

Black Saturday. Black Sunday. Black Tuesday. Red Tuesday. Ash Wednesday. Black Friday. Black Christmas. These are the names given to major bushfires from Australia's past. Each devastated the regions they burnt. However, as their names imply, they reached their peak on a particular day. The unprecedented 2019–2020 bushfire season demonstrates that the fires are increasing in scale, intensity, frequency – and longevity.

On the first day of September 2019, the NSW Rural Fire Service repeated what it had done for only the first time in September 2018, and called the official start of the bushfire season one month early. It did so because of 'extreme drought conditions and a forecast of hot, dry weather ahead'; firefighters had already been fighting fires in August. And it ushered in an unprecedented bushfire season that would engulf all states and territories.

Thousands of fires burnt across Australia during the 2019–2020 bushfire season, some down to the shores of estuaries and the ocean. On 15 November, Port Macquarie, about 400 kms north of Sydney, was recorded as having the world's worst air pollution with an Air Quality Index reading of 1739. On the same day New Delhi was 817, Lahore 549 and Beijing 192. An index reading of 200 is considered hazardous. School closures, airport cancellations and delays, and increased admissions to hospitals for asthma and breathing problems were further signs of the bushfire season's social impacts².

The bushfires have devastated coastal towns, their residents and visitors. During what was planned to be a pleasant summer holiday break, they became bushfire refugees, evacuated from their homes and camp sites, huddled on beaches, and cut off from their every-day worlds. The immediate bushfire impacts were clear. Lives were lost, homes and infrastructure destroyed, access in and out of towns

cut off, smoke and ash turned day into night, and there were also power blackouts and food and water shortages. Images emerged of dead, dying and injured wildlife, vegetation on coastal dunes and cliffs blackened and charred, and suffocating fish in rivers and estuaries.

Australia's marine and coastal environments are where many Australians choose to live or spend their holidays. Seagrass meadows, mangrove forests and rocky and coral reefs provide many ecosystem services such as nutrient cycling, shoreline protection and food and shelter for many fish species targeted by commercial and recreational fishers. These are habitats that are already under increasing pressure from climate change, coastal development, land clearing, overfishing and declining water quality. Ash, smoke and debris are an added burden and one that could increase over time as Australia's bushfires increase in scale, intensity and severity.

The stark images of bushfire impacts beamed around the world on news websites and social media are compelling – bushfires do impact coastal and marine environments – but the evidence is mostly anecdotal. A growing body of research does exist on the effects of bushfires on inland catchments, freshwater fish and the quality of water in rivers, creeks, streams and potable water supplies. However, there is little research on the impacts of airborne and waterborne particulates, nutrients, ash, debris, sediments and metals on coastal waterways, beaches and nearshore and open waters.

Australia remains in the grip of the 2019–2020 bushfire season. Although recent rains have doused many of the blazes and allowed firefighters to get others under control, the official fire season has weeks to run through the typically hot months of February and March. It will then be followed by the 2020–2021 season beginning in September or October.

The increasing scale, frequency and intensity of bushfires in Australia, and the extensive media coverage, is making the community more aware that bushfires impact coastal and marine environments. Although there is very little scientific information to build community understanding, inland and catchment research can provide helpful insight on what to expect now and in the future. Australians will have to get used to longer fire seasons disrupting their lives, while ocean and coastal environments, already

struggling against development, pollution, overfishing and climate change, will face the added burden of bushfires and their impacts.

This report reviews academic literature, media reports and various websites to summarise what we know, what we don't know and what we need to know and do about bushfire impacts on marine and coastal environments. It begins by reviewing the scale, intensity, extent and cause of the 2019–2020 bushfire season.

Figure 3: Aerial view of New South Wales mid north coast, Summer 2019.



Thousands of fires burnt across Australia during the 2019–2020 bushfire season, some down to the shores of estuaries and the ocean. © Ash Hogan

1. NSW Rural Fire Service 2019, '2019–20 fire season starts early; Fire permit suspended', NSW Rural Fire Service, 1 September 2019, <<https://www.rfs.nsw.gov.au/about-us/our-districts/cudgegong/latest-news/2019-20-fire-season-starts-early-fire-permit-suspended>>.

2. Rubbo L and Wellauer K 2019, 'Waves of ash wash up on NSW beaches, Port Macquarie records world's dirtiest air as bushfires burn', *ABC Mid North Coast*, 16 November 2019, <<https://www.abc.net.au/news/2019-11-15/nsw-bushfires-make-port-macquarie-most-polluted-place/11708612>>.

Figure 4: (top and bottom): Burrum Coast near Bundaberg, Queensland, November 2019.



Bushfires burn to the coast during the 2019–2020 bushfire season. © Michael Harwood

The cause of the bushfire crisis

Australia's catastrophic 2019–2020 bushfire season has sparked debate about whether the increasing scale, frequency and intensity of fires have any link to climate change. Some commentators have blamed arsonists, while others have said that Australia has had major fires in the past and the 2019–2020 bushfire season is little different.

Sir David Attenborough said 'it is "palpable nonsense" to suggest that Australia's bushfire crisis has nothing to do with climate change as

he warned "the moment of crisis" has arrived'³. As to the claim that arson was the driving cause of the fires, ABC News reported on 18 January that just 1% of NSW fires had been deliberately lit, in Victoria the figure was lower, and in Queensland it was 3% and South Australia zero⁴.

Scientists, former fire and rescue chiefs and the Australian Meteorological Bureau have all drawn the clear link between the current bushfires and climate change.

More than 440 Australian and international climate, weather and fire scientists on 7 February 2020 released 'An open letter on the scientific basis for the links between climate change and bushfires in Australia'. The letter stated that: 'Scientific evidence unequivocally links human-caused climate change to the increasing risk of frequent and severe bushfires in the Australian landscape. That same science tells us these extreme events will only grow worse in the future without genuine concerted action to reduce global emissions of greenhouse gases. Further lengthening of the fire season and more frequent and more extreme fire-weather are expected into the future due to ongoing human-caused climate change'⁵.

Former Australian fire and rescue chiefs established Emergency Leaders for Climate Action in early 2019. One of its members, former NSW fire and rescue commissioner, Greg Mullins, told news.com.au in April 2019 that 'emergency services are on the frontline of climate change and are witnessing devastating consequences first-hand'. He added that those 'emergency services are facing an escalating crisis. In the last year we've seen unseasonal fires in Tasmania, Victoria, New South Wales, Queensland and Western Australia, floods and twin cyclones in parts of northern Australia, longer bushfire danger periods and fires burning in rainforests.

Rising greenhouse gas pollution from the burning of coal, oil and gas is worsening extreme weather and putting people in danger'⁶.

According to the Australian Bureau of Meteorology: 'The combination of prolonged record heat and drought led to record fire weather over large areas throughout the year, with destructive bushfires affecting all states, and multiple states at once in the final week of the year. Many fires were difficult to contain in regions where drought has been severe, such as northern NSW and southeast Queensland, or where below average rainfall has been persistent, such as southeast Australia. The Forest Fire Danger Index, a measure of fire weather severity, was the highest on record for December 2019, and the highest for any month when averaged over the whole of Australia'⁷.

Climate change has exacerbated the conditions that have driven the 2019–2020 bushfire season – 2019 was the hottest and driest year on record⁸. Australia's annual mean temperature was 1.52°C above the 1961–90 average of 21.8°C – well above the previous hottest year (2013) at 1.33°C. The national area average rainfall was the lowest on record going all the way back to 1900⁹.

There has been no other bushfire season like this one:

- there have been many fires burning at the same time and across a broad area;
- there has been an absence of the El Nino conditions usually associated with severe fires;
- individual fires have covered vast areas and, in once case along the Victorian NSW border, joined to create what has been dubbed a 'megafire';
- habitats have burned that usually don't burn, including rainforests and wet eucalypt forests;
- capital cities have been shrouded in smoke for days on end.

3. Taylor J 2020, 'David Attenborough calls Australia's bushfires "the moment of crisis" to address climate change', *The Guardian*, 17 January 2020, <<https://www.theguardian.com/tv-and-radio/2020/jan/17/david-attenborough-calls-australias-bushfires-the-moment-of-crisis-to-address-climate-change>>.
4. Nguyen N et al. 2020, 'The truth about Australia's fires – arsonists aren't responsible for many this season', ABC News, 18 January 2020, <<https://www.abc.net.au/news/2020-01-11/australias-fires-reveal-arson-not-a-major-cause/11855022>>.
5. Australian Bushfires and Climate Change 2020, 'An open letter on the scientific basis for the links between climate change and bushfires in Australia', Australian Bushfires and Climate Change, 4 February 2020, <<https://australianbushfiresandclimatechange.com>>.

6. Bedo S 2019, 'Former fire chiefs warn of more catastrophic weather events', news.com.au, 10 April 2019, <<https://www.news.com.au/technology/environment/climate-change/former-fire-chiefs-warn-of-more-catastrophic-weather-events/news-story/b050f578a4dce8ced68604db20cb39a8>>.
7. Jones D, Braganza K and Tobin S 2020, 'Weather bureau says hottest, driest year on record led to extreme bushfire season', *The Conversation*, 9 January 2020, <<https://theconversation.com/weather-bureau-says-hottest-driest-year-on-record-led-to-extreme-bushfire-season-129447>>.
8. Jones D, Braganza K and Tobin S 2020.
9. Doyle K 2020, '2019 was Australia's hottest and driest year on record', *ABC Weather*, 2 January 2020, <<https://www.abc.net.au/news/2020-01-02/2019-was-australias-hottest-and-driest-year-on-record/11837312>>.

3. Existing catchment, coastal and marine research on bushfire impacts

Primary scientific research on the impacts of bushfires on marine and coastal environments is limited, both in Australia and in other parts of the world where wildfires are prevalent. The available literature is reviewed in this section, along with examples drawn from a much larger body of research on bushfire impacts in catchments away from the coast. The inland catchment research analyses the impacts that the pollutants, ash and debris released by bushfires have on rivers and streams and their aquatic life including fish and invertebrates. Similar impacts including eutrophication and harmful algal blooms can occur in coastal waterways polluted by bushfire ash and debris. Together, the inland and coastal research provides some insight into what the future holds for marine and coastal environments impacted by bushfires.

Water pollution from bushfire ash and debris

Bushfires destroy riparian vegetation, reducing shade and increasing water temperatures. The bushfire debris washed into rivers and streams contains ash, leaves, trees, rocks and soil that increase turbidity and can reduce the ability of aquatic plants to photosynthesise. Bushfire debris can also change the shape of the river bed, fill holes that are preferred fish habitats and close gaps between pebbles where fish lay eggs and where water bugs find food. The stream's course could also be altered by landslides that may follow heavy rains.

The sludge formed by the debris can clog the gills of fish. It will also contain contaminants that may work their way up the food chain. Increased nutrients can encourage the growth of bacteria and algae that consume oxygen and lead to the suffocation of fish and aquatic invertebrates.

After January 2020 rains fell in bushfire-hit areas of the Murray-Darling, there were numerous reports of fish kills after ash and charcoal washed into the river system and reduced oxygen levels. Red alerts were sounded across the basin warning of blue-green algal blooms¹⁰.

Bushfire ash contains nutrients such as carbon, nitrogen and phosphorous, as well as metals that include copper, mercury and zinc, and synthetic and manufactured materials. In areas where houses have been destroyed, the ash could contain asbestos and other carcinogens, as well as the remnants of cars, couches and building materials.

Scientist Erin Kelly was studying mercury levels in lakes near Jasper, Canada, in 2000¹¹. She found that after fires, the nitrogen levels in the lakes doubled and phosphorous levels increased four-fold, along with a five-fold increase in mercury in the fish. Mercury had been released from soils and moved up the food chain, first to macroinvertebrates, then rainbow trout and finally to lake trout, the top predator. In response to Erin Kelly's findings, a government health warning was issued on the consumption of fish from the lakes¹².

Australian bushfire smoke may contain lead from legacy deposits of leaded petrol. In a study of bushfires sites near Sydney, Hobart and Adelaide during the 2012-2013 fire season, Liqin Wu, Mark Taylor and Heather Handley found historic lead from petrol representing up to 73% of the lead in ash. They concluded that the 'remobilisation of legacy industrial Pb [lead] depositions by wildfires in ash results in it being a persistent and problematic contaminant in contemporary environmental systems because of its known toxicity'¹³.

In a study of bushfire impacts on East Gippsland waterways, Bruce Chessman sampled five river basins in East Gippsland, including the Cann and Genoa rivers, during drought and after extensive fires. The burnt proportions of the Cann and Genoa rivers catchments were higher than the other sampled basins and had higher peak turbidity, suspended solids and phosphorus. Chessman noted that the samples taken from the two rivers 'indicated high sediment yields and moderate to high phosphorus yields ... by comparison with other Australian data'¹⁴.

Unprecedented algal blooms developed in the Gippsland Lakes after fires in 2003 and 2006-2007 that respectively burned 9% and 32% of the catchment. Intense rainfall and floods in June and July 2007 led to 'large increases in loads of suspended sediment, nitrogen and phosphorus from background levels', with the actual loads of phosphorus and nitrogen the 'highest of any year where measurements were available (over 30 years)¹⁵. The researchers also noted that climate change could lead to an increase in the severity of fire weather and of the Forest Fire Danger Index (a function of relative humidity, air temperature, wind speed and a drought factor - the number of days since rain and evapotranspiration) and this could increase the risk of 'severe water quality events' in the Gippsland Lakes.

Iraima Verkaik and others reported in 2013 that the richness, composition, function, and resilience of aquatic macroinvertebrates, which include midges, black flies, stone flies and caddis flies, declined after fires in northern Victoria. A similar study of three streams in the US by John Rinne found that the 1990 Dude Fire in Arizona

killed off local populations of brook trout and rainbow trout, while aquatic macroinvertebrate densities 'declined to near zero within a month after the fire, recovered to only 25-30% of prefire density in two of the streams 1 year later, and continued to fluctuate postfire'¹⁶. Also in the US, ash-laden runoff after heavy rainfall was reported to have suffocated 80% of the fish in Colorado's Animas River in June 2018¹⁷.

Ash and debris washed into rivers and streams can form sediment slugs that can travel great distances downstream, affecting aquatic life along the way. Sediment slugs fill the river and seabed habitats of invertebrates and fish, clog fish gills and damage or destroy the breathing apparatus of filter feeders such as mussels, sponges, and corals. Avoidance behaviour, if possible, could take animals away from their preferred feeding and breeding grounds into areas where they are outcompeted by the existing wildlife.

In 2008, Jarod Lyon and JP O'Connor reported that a sediment slug following the 2003 fires in Australia's alpine region travelled 200 km¹⁸. As the slug moved downstream and passed monitoring sites in the upper reaches, fish abundance fell between 95 and 100%. Twelve months later fish numbers were still depressed and signs of recovery did not appear until 24 months after the slug had passed. The scientists suggested that for the long-term survival of threatened species in these circumstances, translocation may be required.

Fires in 2006 and 2007 wiped out 45% of the population of the barred galaxias, a nationally endangered freshwater fish endemic to the Goulburn River in north-central Victoria. Those

10. Murray Darling Basin Authority 2020, 'Relief of rain brings expected water quality challenges', Media Release, 30 January 2020, Murray Darling Basin Authority, Canberra.

11. Struzik E 2018, 'How wildfires are polluting rivers and threatening water supplies', *Yale e360*, 2 October 2018, <<https://e360.yale.edu/features/how-wildfires-are-polluting-rivers-and-threatening-water-supplies>>.

12. Struzik E 2018.

13. Wu L, Taylor M and Handley H 2017, 'Remobilisation of industrial lead depositions in ash during Australian wildfires', *Science of the Total Environment*, 599-600, 1233-1240, <<https://doi.org/10.1016/j.scitotenv.2017.05.044>>.

14. Chessman B 1986, 'Impact of the 1983 wildfires on river water quality in East Gippsland, Victoria', *Australian Journal of Marine and Freshwater Research*, 37(3) 399-420.

15. Cook P, Holland D and Longmore A 2008, *Interactions between phytoplankton dynamics, nutrient loads and the biogeochemistry of the Gippsland Lakes*, A report prepared for the Gippsland Lakes Taskforce, Water Studies Centre, Monash University, Clayton.

16. Rinne J 1996, 'Short-term effects of wildfire on fishes and aquatic macroinvertebrates in the South Western United States', *North American Journal of Fisheries Management* 16: 653-658, 1996.

17. Kim A 2019, 'A wildfire killed 80% of fish in a Colorado river', *CNN*, 24 September 2019, <<https://edition.cnn.com/2019/09/24/us/colorado-fish-death-animas-river-wildfire-trnd/index.html>>.

18. Lyon J and O'Connor J, 2008, 'Smoke on the water: Can riverine fish populations recover following a catastrophic fire-related sediment slug?', *Austral Ecology* (2008) 33, 794-806.

that remained were again affected by fire in 2009. Daniel Stroessel, Renae Ayres and Tarmo Raadik found that fire-affected streams 'suffer from sedimentation and infilling, causing fish death, reduced fish recruitment by reducing available spawning habitat, and killing eggs'¹⁹.

Students from the University of California Santa Barbara used their scheduled mid-December 2017 research voyage in the Santa Barbara Channel to gather data on the marine impacts of ash from the Thomas Fire. The fire began on 4 December 2017, burnt for 40 days and destroyed more than 1000 buildings. The students sampled the ash for its chemical components and the water for phytoplankton and bacteria on Day 10 of the fire. The trace metals from the fire had little effect on concentrations in the water because background levels were already high²⁰. However, the researchers believed that were the aerosols to reach the open waters of the Pacific Ocean, and the less nutrient-dense waters to the south, then phytoplankton booms or busts could result. The metal concentrations they measured were more than 10 times those found in the Pacific Ocean.

The results of the students' research were limited because sampling occurred on only one day in the early progress of the Thomas Fire. Rachel Kelly, one of the researchers said that 'looking back, I would have loved to sample the Santa Barbara Basin a week to a month after the fire. I think it is very important for future studies that are similar to ours to sample consistently after a burn event to see how the coastal marine community may respond' (Rachel Kelly pers. comm.).

Lizabeth Bowen and other scientists were

scheduled to monitor sea otters off the coast of Big Sur in California when the Basin Complex Fire struck in 2008²¹. Thirty-nine sea otters were captured in 2008 (27) and 2009 (12), respectively three months and 15 months after the fire was brought under control. Gene sampling of the 2008 otters revealed 'reactions to organic exposure, malignant transformation, and decreased ability to respond to pathogens'²². Samples from the 2009 group suggested that the otters were detoxifying, which can be costly in physiological terms because nutrients and energy have to be reallocated. This could reduce their reproductive capacity and make them more susceptible to disease. The scientists concluded that although 'the long-term population level effects of exposure to fire generated hydrocarbon products remain to be seen, evidence exists for continued altered immune states in affected sea otters'²³.

Using a lab-based experiment, Gabriel Gonino and others found that bushfire ash could change the feeding and resting behaviour of the Iberian barbel, a freshwater fish, and lead to a decline in fish health²⁴. In another study, Gonino and others found that the ash from the burning of sugarcane caused liver damage and death in native fish populations in Brazil's Parana River basin²⁵ and would likely lead to their replacement by introduced fish species.

Roi Durano-Medrano and others report that the movement of ash downstream has affected marine ecosystems along the Galicia coast in Spain, where mussels, hake and clams are landed by the fishing fleet²⁶. They noted that 'soil erosion in burnt areas close to the coast

followed by rainfalls results in soil particles and ashes being dragged to the sea and impacting on the marine ecosystems'. The 'maritime wildlife (especially the mussels and clams) is affected and the local economies depending on these resources suffer important losses'²⁷. However, the 'focus usually is on suppressing fires, while little is said about the post-fire scenarios and restoration dynamics'²⁸.

Runoff from burnt areas can also impact beaches. In Malibu, California, the Woolsey Fire in 2018 caused a sharp decline in water quality at beaches in Malibu. Researchers reported that: 'Major wildfires have a significant effect on water quality because the blazes damage sewage infrastructure and increase the amount of runoff into the ocean because of vegetation loss, especially when they burn along the coast'²⁹.

Bushfire haze and smoke

Zeehan Jaafar and Tse-Lynn Loh have warned that haze from bushfires fires could decrease sunlight and undermine photosynthesis in marine ecosystems, including coral reefs, mangroves and seagrasses.³⁰ Smoke particles may also make droughts worse. In 2005, Yongqiang Liu found smoke particles from bushfires absorbed solar radiation, led to reduced rainfall and enhanced drought in the US³¹.

By mid-January, smoke from the Australian bushfires had circumnavigated the globe³². New Zealand glaciers turned brown with ash that had blown in from the Australian bushfires, prompting Professor Andrew Mackintosh,

Figure 5: Smoke billows from the Kangaroo Island bushfire and out across the ocean.



© NASA Earth Observatory.

the head of the school of earth, atmosphere and environment at Monash University, to predict that it could lead to a 20–30% increase in glacial melt, already receding due to climate change³³. The accumulating ash reduces the reflection of heat from the ice, encouraging more absorption. Such a connection was found by Yongwon Kim and others when modelling the potential effects of ash from boreal wildfires on Alaska's Arctic and glacial landscapes, surmising that it could lead to reduced albedo and an increase in the summer melt of glaciers³⁴. Increased glacial melt has implications for the rate of sea level rise.

19. Stoessel D, Ayres R and Raadik T 2012, *Improving spawning success for barred galaxias (Galaxias fuscus) in streams affected by bushfire – an aid to recovery*, Black Saturday Victoria 2009 - Natural Values Fire Recovery Program, Department of Sustainability and Environment, Heidelberg, Victoria.

20. These had been sourced from the atmosphere, river discharges, upwellings from the continental shelf and in coastal currents.

21. Bowen L et al. 2015, 'Effects of wildfire on sea otter (*Enhydra lutris*) gene transcript profiles', *Marine Mammal Science*, 31(1): 191–210 (January 2015).

22. Bowen L et al. 2015.

23. Bowen L et al. 2015.

24. Gonino G et al. 2019b, 'Short-term effects of wildfire ash exposure on behaviour and hepatosomatic condition of a potamodromous cyprinid fish, the Iberian barbel *Luciobarbus bocagei* (Steindachner, 1864)', *Science of the Total Environment*, 665 (2019) 226–234.

25. Gonino G 2019a, 'Fire increases the productivity of sugarcane, but it also generates ashes that negatively affect native fish species in aquatic systems', *Science of the Total Environment*, 664 (2019) 215–221.

26. Duran-Medrano R 2017, 'Valuation of terrestrial and marine biodiversity losses caused by forest wildfires', *Journal of Behavioral and Experimental Economics*, 71 (2017) 88–95.

27. Duran-Medrano R 2017.

28. Duran-Medrano R 2017.

29. Fry H 2019, 'Beach pollution surges after massive wildfires and heavy rains, report finds', *LA Times*, 26 June 2019, <<https://www.latimes.com/local/lanow/la-me-ln-beach-report-card-20190626-story.html>>.

30. Zeehan Jaafar and Tse-Lynn Loh 2014, 'Linking land, air and sea: potential impacts of biomass burning and the resultant haze on marine ecosystems of Southeast Asia', *Global Change Biology*, 2014; DOI: 10.1111/gcb.12539.

31. Liu Y 2005, 'Enhancement of the 1988 northern US drought due to wildfires', *Geophysical Research Letters*, vol.32, L10806, doi:10.1029, 2005GL022411, 2005.

32. The Weather Channel, 'Australian bushfire smoke circumnavigates the Earth', The Weather Channel, 15 January 2020, <<https://weather.com/news/weather/news/2020-01-15-australia-bushfire-smoke-circumnavigates-entire-earth>>.

33. Roy E 2020, 'New Zealand glaciers turn brown from Australian bushfires' smoke, ash and dust', *The Guardian*, 2 January 2020, <<https://www.theguardian.com/world/2020/jan/02/new-zealand-glaciers-turn-brown-from-australian-bushfires-smoke-ash-and-dust>>.

34. Kim Y et al. 2005, 'Possible effect of boreal wildfire soot on Arctic sea ice and Alaska glaciers', *Atmospheric Environment*, 39 (2005) 3513–3520.

Water pollution and seagrasses, mangroves and coral reefs

Seagrasses meadows and mangrove forests provide very important ecosystem services in Australia's estuaries including nutrient cycling, sediment stabilisation, shoreline protection and shelter and food for many fish species targeted by commercial and recreational fishers. However, they are highly vulnerable to poor water quality, which will be worsened by bushfire debris washed down coastal rivers and streams.

Robert Orth and others in 2006 described a global crisis for seagrass ecosystems that is driven by climate change, declining regional water quality and the 'more localised impacts due to increased loading of sediment, contaminants, and nutrients'³⁵. They found that in 'all regions, the environmental effects of excess nutrients or sediments are the most common and significant causes of seagrass decline, and result in small to very large areas of seagrass being lost'³⁶.

Mangroves rely on pneumatophores or breathing roots to extract oxygen from the air to survive in muddy shorelines. Climate change and coastal development are their major threats but they can also be impacted by the smothering of their roots by increased sediments, algal blooms and seagrass wrack³⁷, all of which could increase after bushfires in the catchment.

When ash and the other smoke particles settle on the surface of inshore and offshore waters, they can impact coral reefs. Australian National University researchers discovered that smoke from 'fires raging through tropical forests near coastal reefs can cause an algal bloom capable of killing virtually all coral and fish for hundreds of kilometres'. They made the discovery when

analysing nutrients in the 1997 Indonesian fires. The smoke released almost 11,000 tonnes of iron into the atmosphere, which fertilised the phytoplankton and the algal bloom. The reef system was suffocated across an area equivalent to 25% of the Great Barrier Reef³⁸.

Potential impacts of fire retardants

The use of fire retardants, often dropped from large low-flying aircraft, has become a highly visible feature of fire suppression operations in Australia and other parts of the world. Houses, cars, roads and vegetation can be stained pink after the aircraft has flown past. Although the use of retardants has increased, there has been little analysis of their environmental impacts, especially in waterways and on fish and other aquatic life.

Fire retardants contain fertilisers as well as corrosion inhibitors and ammonia. Toxicity tests have shown that where fire retardants are directly applied to streams containing rainbow trout, they need to be diluted in the range of 100–1750 times to avoid fish death³⁹.

Fish have also been shown to avoid areas of fire retardant, which could 'affect the habitat negatively, altering aquatic ecosystems and causing significant biological and economic injury to natural resources'⁴⁰. According to a review by Kostas Kalabokidis, fire retardants can also lead to eutrophication and fish kills if applied incorrectly⁴¹. The use of retardants also increases the amount of smoke and airborne particulates, although these are relatively small when compared to the smoke generated by the fire itself.

Hazard reduction burning: impacts and effectiveness

Increased hazard reduction burning is being seen by some as the solution for preventing future fires of the magnitude of the 2019–2020 bushfire season. Although Mitch Tulau and Sally McInnes-Clarke found very little literature on the impacts of hazard reduction burning, there were cases where nutrient loss and reduced rates of nutrient cycling could occur, along with increased runoff and erosion⁴². They also reported on overseas research that suggested the cumulative impacts of repeated hazard reduction burning may lead to longer recovery times, while surmising that any reductions in water flows could be compounded by climate change.⁴³

When interviewed by *ABC News*, the head of the NSW Rural Fire Service said that there was a 'shrinking window of opportunity' for hazard reduction burning and that it is 'absolutely an important factor when it comes to fire management and managing fire in the landscape but it is not the panacea. When you're running fires under severe, extreme or worse conditions, hazard reduction has very little effect at all on fire spread'⁴⁴.

In their open letter on bushfires on climate change, 446 scientists said that 'Fire management measures such as hazard reduction burning are of diminishing effectiveness under extreme wildfire conditions. The future availability of suitable hazard reduction burning days is highly uncertain'⁴⁵.

Abbie Rogers and others from the University of Western Australia and the Bushfire and Natural Hazards CRC stress the importance of measuring the intangible values, 'often neglected in decision making', that may be impacted by bushfire mitigation strategies such as hazard reduction burning. They have developed a 'Value Tool' that 'identifies the types of intangible values that might be affected by bushfires or their mitigation, in terms of health, environmental and social effects'⁴⁶. The tool could be used by a bushfire manager to 'identify the types of intangible values that might be affected by a prescribed burning plan, such as protecting wildlife and minimising distress to local communities, and find dollar estimates for each of these values'⁴⁷.

35. Orth R et al. 2006, 'A global crisis for seagrass ecosystems', *BioScience*, December 2006, DOI: 10.1641/0006-3568(2006)56[987:AGCFSE]2.0.CO;2.

36. Orth et al. 2006.

37. OzCoasts, 'Changes in mangrove areas', <https://ozcoasts.org.au/indicators/biophysical-indicators/mangrove_areas/>.

38. Fresh Science 2003, 'Fire: The new threat to coral reefs', *Fresh Science*, <<https://freshscience.org.au/2003/fire-the-new-threat-to-coral-reefs/>>.

39. Gimenez A et al. 2004, 'Long-term forest fire retardants: A review of quality, effectiveness, application and environmental considerations', *International Journal of Wildland Fire*, 2004, 13, 1-15.

40. Gimenez A et al. 2004.

41. Kalabokidis K 2000, 'Effects of wildfire suppression chemicals on people and the environment – A review', *Global Nest Journal*, vol. 2, No 2, pp 129-137, 2000.

42. Tulau M and McInnes-Clarke S 2015, *Fire and soils. A review of the potential impacts of different fire regimes on soil erosion and sedimentation, nutrient and carbon cycling, and impacts on water quantity and quality*, NSW Office of Environment and Heritage, Sydney.

43. Tulau M and McInnes-Clarke S 2015.

44. AAP 2020.

45. Australian Bushfires and Climate Change 2020.

46. Rogers A et al. 2017, 'Including the intangible benefits of bushfire mitigation in economic analyses: a "value tool" for informed decision making', In M. Rumsewicz (ed.), *Research Forum 2017: proceedings from the Research Forum at the Bushfire and Natural Hazards CRC & AFAC Conference*. Melbourne: Bushfire and Natural Hazards CRC, Melbourne.

47. Rogers A et al. 2017.

4. Current and future impacts of the bushfires on oceans and coasts

Without a comprehensive monitoring program in place, identification of the current and future impacts of bushfires for coastal and marine environments is largely based on anecdotal evidence from the current and past fires, and the results of bushfire research conducted on inland waterways and catchments. This section summarises some of the impacts of the 2019–2020 bushfire season on Australia’s marine and coastal environments, as well as projects seeking to mitigate or minimise those impacts.

Water pollution from bushfire ash and debris

Smoke and ash may have long-term impacts on marine life when the particulates and contaminants descend into coastal and nearshore waters or when smoke haze persists. For example, smoke haze could reduce sunlight and undermine photosynthesis in marine habitats.

In a recent statement on bushfire impacts from the Sydney Institute of Marine Science (SIMS), Shauna Murray, team leader of the Marine Microbial Biotoxins Facility, said that an ‘ash layer might shade the water column, and lead to an inability of phytoplankton to access sunlight. This might lead to die offs of phytoplankton, which in turn might lead to a low level of oxygen in the water. A low level of oxygen can lead to the deaths of marine life, i.e. fish, as they basically suffocate. The addition of ash might lead to a large nutrient input to the water column. This could lead to greatly increased growth of certain ‘weed’ microalgal species. This is called a “harmful algal bloom” (HAB), and they are increasingly common around the world. Some HABs are directly caused by nutrient inputs, i.e. fertilisers. An addition of ash might have this same effect⁴⁸.

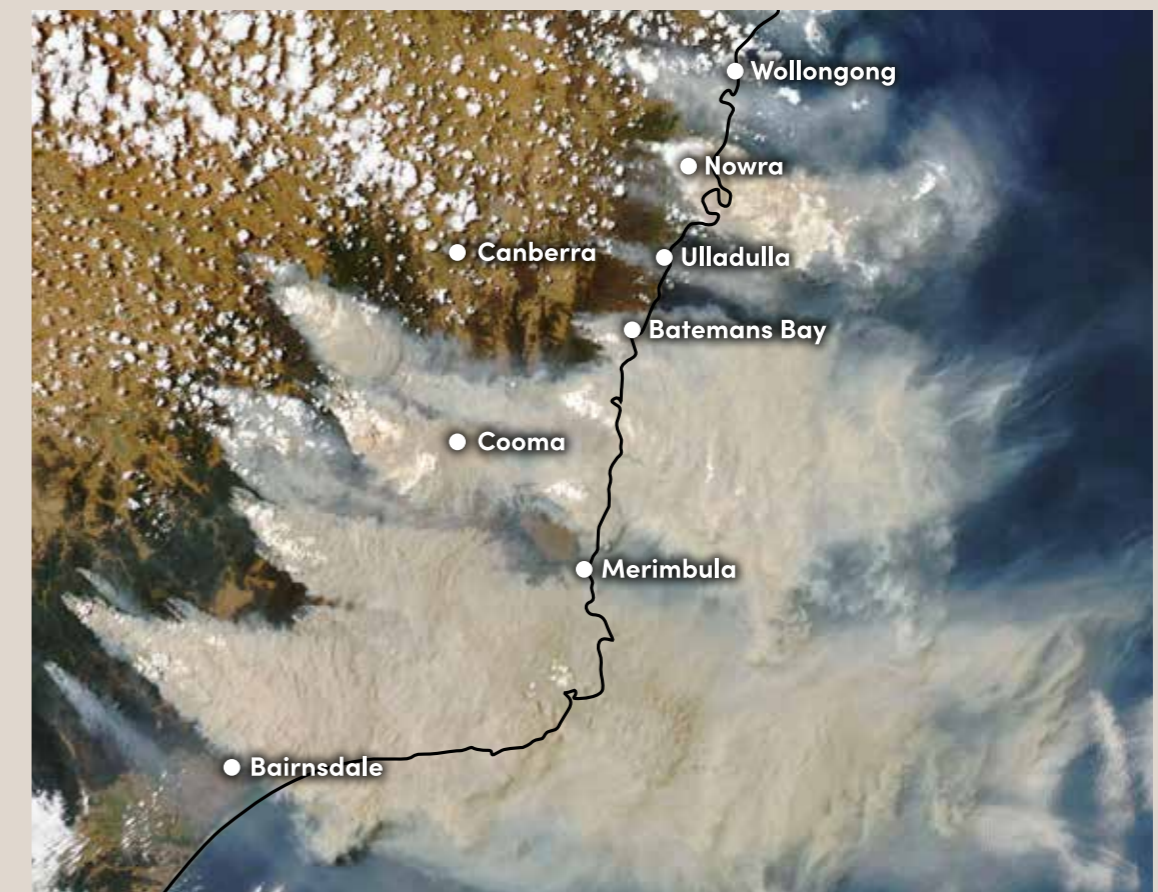
Heavy rains and thunderstorms in late January 2020 washed large volumes of ash and debris into the Tambo River, killing eels. The Tambo River flows into the Gippsland Lakes, where there are concerns that the depleted stocks of black beam will also be impacted⁴⁹. Eels live in freshwater, but in one of the world’s great migration stories, they leave the rivers and travel up the east coast to the Coral Sea where they spawn and likely die. If eels were to be lost in large numbers, as many coastal rivers and streams have been affected by fires, the annual spawning migration could be impacted.

In early February 2020, heavy rains along the east coast were a welcome relief for firefighters and communities in the bushfire areas but also generated warnings of flash flooding, falling trees, water contamination by ash and silt and ‘possible land slips in areas near fire grounds cleared of vegetation⁵⁰. Byron Bay received 280mm in 24 hours that caused flooding and a mudslide. The NSW government’s Beachwatch program gave every Sydney beach the highest (worst) pollution grade⁵¹.

In NSW, the fish kills website of the Department of Primary Industries reported that coastal lakes and lagoons are ‘likely to experience fish kills this summer with increasing water temperatures, stratification and no or low flow⁵². The website reported fire-affected fish kills in coastal catchments upstream of Moruya, at Tilba Lake and Sportsmans Creek (on the Clarence River). At Tilba Lake one witness estimated there were approximately 2000 dead flathead and bream, 100 mullet and also tens of eels and crabs⁵³.

Hundreds of thousands of fish were reported

Figure 6: Forecasters accurately predicted extreme fire conditions in southeastern Australia for the weekend of January 4–5, 2020, when this satellite image was captured. It shows the east Australian coastline from Wollongong on the NSW coast, south to the Corner Inlet in Victoria.



© NASA Earth Observatory

dead along a 70-kilometre stretch of the Macleay River upstream from Kempsey in mid-January 2020, after rain washed in ash and debris⁵⁴ and reduced oxygen levels. Australian bass, freshwater mullet and eel-tailed catfish were the main species killed⁵⁵. Freshwater ecologist Lee Baumgartner has said ‘there was a precedent for understanding the long-term

impacts of an event such as this: major bushfires in 1939 had caused ash to run into the Lachlan River, and “the fish never recovered”⁵⁶.

The affected section of the Macleay River is popular with recreational fishers. Assisted by flooding rains, the sediment could potentially move downstream and discharge into the Macleay estuary.

48. Sydney Institute of Marine Science 2020, ‘Potential impacts of bushfires on our marine environment: Potential impacts of bushfire smoke and ash to Sydney and surrounds’, <<https://www.sims.org.au/news/94/bushfire-impact-statement>>.

49. McNaughton J 2020, ‘Bushfire debris turns Gippsland’s Tambo River to sludge, suffocating eels’, *ABC Gippsland*, 23 January 2020, <<https://www.abc.net.au/news/2020-01-23/eels-found-dead-in-polluted-tambo-river/11893646>>.

50. Chappell B 2020, ‘Australia’s east gets drenched by rain and flood warnings replace fire alerts’, *NPR*, 7 February 2020, <<https://www.npr.org/2020/02/07/803748216/australias-east-gets-drenched-by-rain-and-flood-warnings-replace-fire-alerts>>.

51. Bundgard M and Hannam P 2020, ‘Widespread beach closures expected as erosion fears mount’, *Sydney Morning Herald*, 7 February, 2020, <<https://www.smh.com.au/environment/weather/widespread-beach-closures-expected-as-erosion-fears-mount-20200207-p53yv9.html>>.

52. Department of Primary Industry, ‘Fish kills in NSW’, Department of Primary Industry, <<https://www.dpi.nsw.gov.au/fishing/habitat/threats/fish-kills>>.

53. Barnzey 2020, posted 13 January 2020 on *Fish Raider*, <<https://www.fishraider.com.au/topic/90445-dead-fish/>>.

54. Redfearn G 2020, ‘Hundreds of thousands of fish dead in NSW as bushfire ash washed into river’, *The Guardian*, 18 January 2020, <<https://www.theguardian.com/world/2020/jan/17/hundreds-of-thousands-of-fish-dead-in-nsw-as-bushfire-ash-washed-into-river>>.

55. Hannam P 2020, ‘Revealed: Widespread species devastation following “unprecedented” fires’, *Sydney Morning Herald*, 18 January 2020, <<https://www.smh.com.au/environment/conservation/revealed-widespread-species-devastation-following-unprecedented-fires-20200117-p53siy.html>>.

56. Redfearn G 2020.

Figure 7: Fires burnt down to the shoreline and estuaries along many of our coasts and waterways.



Aerial view of NSW mid north coast, Summer 2019. © Ash Hogan

Emma Johnston, from the University of New South Wales, said in an interview with *National Geographic* that the unprecedented fires and images of ash-laden waves along beaches 'indicate that there is a very high density in the water column, so that is likely to have localised effects in those areas'⁵⁷. She also said that 'while few studies have looked at the impact of charcoal and ash on marine organisms and possible toxins generated by bushfires, it's certainly possible they could be detrimental, and the influx of nutrients into the ocean may also cause algal blooms there'⁵⁸.

In the SIMS statement about bushfire impacts on marine environments, Katherine Dafforn, Deputy Director of its Sydney Harbour Research

Program said 'bushfires remove vegetation which increases soil mobilisation and so we'd expect more soil runoff into waterways resulting in murkier waters. This increased sediment load and reduced light in the water column could have impacts on productivity. Similarly metals in high concentrations can impact on marine life by causing death through toxicity or affecting reproduction and growth rates'⁵⁹.

William Glamore from the SIMS Scientific Advisory Committee said in the statement that acidic groundwater, caused by the drainage of coastal floodplains in the 1960s and 1970s and worsened by drought, could leach into coastal ecosystems. After rains the acidic water will combine with ash, toxic metals and high turbidity

to further impact already drought-stressed coastal ecosystems and lead to major fish kills in 'blackwater' events. He said that 'urgent action is required to restore high priority acidic sites to reduce acid generation, limit acid discharges and recreate intertidal ecosystems that sequester carbon'⁶⁰.

Members of the SIMS Postdoctoral Group said in the statement that should a reduction in 'light availability be prolonged this could impact important sub-tidal habitats including seagrass and kelp beds, which provide refuge and nursery habitats for commercially and recreationally important species, improve water quality and provide protection to coastal zones from erosion'⁶¹.

Jason Alexandra from RMIT and Max Finlayson from Charles Sturt University, in a January 2020 paper, warned that 'exposed, ash enriched soils are highly erodible, especially on steeper slopes'⁶². They urged that the 'protection and restoration of catchments and waterways' be a priority in bushfire recovery programs, that monitoring be increased and that agencies identify 'important habitat areas and at-risk populations of threatened species of fish that could be protected through catchment treatment or sustained through a captive breeding program, until stream water quality stabilises'⁶³.

In response to the bushfire impacts in NSW estuaries, the NSW Minister for Local Government announced a \$5million grants program to 'mitigate the effects of the recent bushfires on sensitive estuary ecosystems'⁶⁴. The Minister said at the time that the 'effects of the bushfires have the potential to degrade coastal waterways by impacting water quality and coastal ecosystems which in turn has the potential to impact estuary environments and local industries such as tourism and aquaculture'⁶⁵.

Oyster farms in estuaries closed due to water quality concerns

The plight of south coast NSW oyster farmers during the 2019–2020 bushfire season has highlighted the environmental as well as the economic costs of bushfires along the coast. Some of the estuaries have been closed to oyster harvesting due to concerns that bushfire debris could contaminate oysters and pose a threat to human health. Road closures kept tourists away and prevented the farmers from getting their product to the market during what is usually their busiest sales period. They also prevented farmers at Wonboyn from getting their required weekly water quality measurements to government agencies and, as a result, their farms had to be closed (Shauna Murray, UTS, pers. comm.).

57. Pickrell J 2020a, 'Australia's raging fires will create big problems for fresh drinking water', *National Geographic*, 10 January 2020, <<https://www.nationalgeographic.com/science/2020/01/australian-fires-threaten-to-pollute-water/>>.

58. Pickrell J 2020.

59. Sydney Institute of Marine Science 2020, 'Potential impacts of bushfires on our marine environment: Contaminants and toxic effects of ash to marine ecosystems', <<https://www.sims.org.au/news/94/bushfire-impact-statement>>.

60. Sydney Institute of Marine Science 2020, 'Potential impacts of bushfires on our marine environment: Drought and fire impacts in estuaries', <<https://www.sims.org.au/news/94/bushfire-impact-statement>>.

61. Sydney Institute of Marine Science 2020, 'Potential impacts of bushfires on our marine environment: Unprecedented fires require crucial research for future monitoring of coastal environments', <<https://www.sims.org.au/news/94/bushfire-impact-statement>>.

62. Alexandra J and Finlayson C 2020, 'Floods after bushfires: rapid responses for reducing impacts of sediment, ash, and nutrient slugs', *Australasian Journal of Water Resources*, <<https://doi.org/10.1080/13241583.2020.1717694>>.

63. Alexandra J and Finlayson C 2020.

64. NSW Department of Planning, Industry and Environment 2020, '\$5 million for bushfire affected coastal waterways', <<https://www.environment.nsw.gov.au/news/5-million-for-bushfire-affected-coastal-waterways>>.

65. NSW Department of Planning, Industry and Environment 2020.

Oyster harvesting has also been closed in The Shoalhaven, Clyde River, Tuross Lake and Narooma estuaries due to high readings of algae and other contaminants⁶⁶. As of February 2020, it was a waiting game for the 80 oyster farms between The Shoalhaven and the Victorian border to see whether ash and debris flows down the rivers into the estuaries, causes algal blooms that suck oxygen from the water and suffocate oysters⁶⁷.

Andrew Myers from Ocean Watch was concerned that 'the impact on water quality may take months/years to play out. In the short term, slowly flushed estuaries could see algal blooms ... whereas in the mid/long term following rain we could see run-off impacts including low pH, heavy metals, low DO [dissolved oxygen], suspended sediments, and more organic loading leading to more algal blooms. Each estuary is going to respond differently and depend on rainfall patterns, soil chemistry & structure, flushing rates etc'⁶⁸.

The Food Agility CRC, NSW Department of Primary Industry and the University of Technology Sydney have been regularly monitoring water quality in 13 of the estuaries where oysters are grown, with an emphasis on phytoplankton and algal blooms. This will allow them to identify any changes to estuary health caused by the bushfires.

At least 10 estuaries have been affected (Shauna Murray, pers. comm.). In the longer term, there could be a slow drip-feed of nutrients into the estuaries over months and years, and this could lead to harmful algal blooms that are toxic to marine life.

Commercial fisheries: the added bushfire burden of habitat loss and water pollution

The most immediate and dramatic impact of the 2019–2020 bushfire season on fisheries was the destruction of the Mallacoota Abalone Cooperative buildings and processing facilities, the main employer in the town. Coastal lakes, estuaries lagoons and seagrass meadows are spawning grounds for economically important fish including flathead, whiting, bream, mulloway, prawns and shellfish.

Although the direct bushfire impacts on marine and coastal environments are poorly described, the negative local impacts on fishery production from water pollution caused by agricultural and coastal development have had serious effects on the fisheries. Bushfire-related runoff and its pollutants, ash and debris would exacerbate these impacts.

Colin Creighton and others in 2015 reported that more than '75% of commercial fish catch in Australia, and in some regions up to 90% of all recreational angling catch, spend part of their life cycle within estuaries and inshore wetlands'⁶⁹. They went on to state that reduced fish populations are 'likely to be due first to limitations to recruitment, growth and productivity due to loss of habitat and changes in tidal and freshwater flow regimes. Second massive water quality-induced kills are likely to have had an effect on total biomass, the almost total loss of some species (e.g. Sydney rock oysters and mud oysters, *Ostrea angasi*, from many NSW floodplain estuaries) and possibly overall species composition of estuary fish populations. Much of the water-quality decline ... is due to the draining of the critical estuarine habitats, the floodplain wetlands, salt marshes and accompanying sea-grass-lined channels'⁷⁰.

Given the critical nature of these habitats to fisheries, and their sensitivity to water pollution, the bushfires could have a significant impact on them and should be monitored.

Recreational fisheries: the social and economic costs of bushfires

East Gippsland and the south coast of NSW are summer holiday playgrounds for many Australians. But this summer the bushfires have caused forced evacuations and holiday cancellations, with estimates of losses for the tourism industry ranging from hundreds of millions of dollars⁷¹ to more than \$4 billion⁷² if the loss of international tourists is included.

For many Australians, summer is the time to go fishing and they patronise tackle shops, petrol stations, charter fishing operators and camping grounds. The impacts forecast for commercial fisheries will also be felt by the many recreational fisheries that catch the same species. On its website, the recreational fishing organisation OzFish, has highlighted the 'record numbers of fish kills, widespread habitat loss plus poor water quality. There are also still places with little to no water where many precious native fish have simply suffocated. The situation is getting referred to as the 'triple whammy' in media reports. We've seen one of our worst droughts on record, devastating bushfires and now severe rain events. This will impact our fish like never before'⁷³.

The economic loss to local businesses due to the absence of recreational fishers is yet to be quantified but the overall impact on coastal

tourism has been huge. Acknowledging the importance of recreational fishing to regional economies, which has been estimated at \$600million each year in north-eastern Victoria and Gippsland⁷⁴, the Victorian Government has released tagged fish into the state's waterways. If a tagged fish is caught, the lucky fisher could win up to \$10,000. Tagged black bream, dusky flathead and king george whiting have been released in East Gippsland, and murray cod, brown trout and rainbow trout in the state's north east. The government hopes that recreational fishers will return to coastal and inland towns affected by the fires, including Mallacoota, Cann River, Marlo, Lakes Entrance and Lake Tyers.

Rescue, recovery and restoration after bushfires

Threatened species, already struggling with the loss of habitat, reduced numbers and restricted range, were hard hit by the fires. University of Queensland researcher, Michelle Ward, used NASA satellite images and range maps for threatened species to estimate that 70 species had lost more than half their known habitat. In total, 272 threatened plant, bird, mammal, reptile and fish species lost habitat, including 25 that are critically endangered⁷⁵.

The federal Environment Minister has established the Wildlife and Threatened Species Bushfire Recovery Expert Panel. It has identified the following priority activities to guide immediate recovery activities:

66. Boys C 2020, 'South Coast oyster harvests suspended due to bushfires', *Good Food*, 11 January 2020, <<https://www.goodfood.com.au/eat-out/news/south-coast-oyster-harvests-suspended-due-to-bushfires-20200110-h1kyk0>>.

67. Boys C 2020.

68. Myers A 2020, Ocean Watch Facebook page, 10 January 2020

69. Creighton C et al. 2015, 'Repairing Australia's estuaries for improved fisheries production – what benefits, at what cost?', *Marine and Freshwater Research*, 66(6), 493–507.

70. Creighton C et al. 2015.

71. Butler B and Wahlquist C 2020, 'Australian bushfire crisis predicted to cost tourism industry hundreds of millions', *The Guardian*, 3 January 2020, <<https://www.theguardian.com/australia-news/2020/jan/03/australian-bushfire-crisis-predicted-to-cost-tourism-industry-hundreds-of-millions>>.

72. SBS News 2020, 'Tourism strategy promised after bushfires cost the industry \$4.5 billion', *SBS News*, 17 January 2020, <<https://www.sbs.com.au/news/tourism-strategy-promised-after-bushfires-cost-the-industry-4-5-billion>>.

73. OzFish, 'The current triple whammy on our native fish', *OzFish*, 13 February 2020, <<https://ozfish.org.au/2020/02/the-current-triple-whammy-on-our-native-fish/>>.

74. Victorian Government 2020, 'Golden tags to lure fishers back to fire affected areas', Victorian Government Media Release, 5 February 2020, <<https://www.premier.vic.gov.au/golden-tags-to-lure-fishers-back-to-fire-affected-areas/>>.

75. Deacon B and Carbonell R 2020, 'Inside the race to protect 250 threatened species hit by bushfire', *ABC News*, 20 January 2020, <<https://www.abc.net.au/news/2020-01-19/inside-the-race-to-protect-threatened-species/11877990>>.

- protecting unburnt areas within or adjacent to recently burnt ground that provide refuges;
- feral predator and herbivore control to reduce the pressure on native species where appropriate;
- emergency salvage of plant and animal species for ex-situ conservation or wild-to-wild translocation;
- rapid on-ground assessment for species and communities of concern;
- supplementary shelter, food, and water for animals where appropriate⁷⁶.

The images of wildlife rescuers combing burnt areas for surviving animals have featured heavily in the Australian and international media. At the same time, wildlife agencies and community organisations are initiating rescue and translocations of species. This could become a feature of threatened species in bushfire seasons.

James Todd from the Victorian Department of Environment, Land, Water and Planning (DELWP) said that there were 'some native fish in Gippsland whose entire range had burned in the fires and after heavy rain there could be fish kills'⁷⁷. 'One of the key actions that we need to look at for a range of species, including those fishes, [is] whether we need to pull those fish and other species out and salvage them until their habitat is suitable for them to return'⁷⁸.

DELWP has identified 35 potential species for possible extraction, including 12 species of freshwater fish. Macquarie perch were extracted from the Buffalo River⁷⁹ and will be returned once water quality improves. In NSW, breeding programs are being established for the stocky galaxias and the Macquarie perch, nine of which rescued from the Mannus Creek in southern NSW⁸⁰. It is part of the 'biggest fish rescue project the NSW government has ever attempted'⁸¹. Unfortunately, on returning to rescue more Macquarie perch a week later, the rescuers were confronted by the water having turned 'to a river of black porridge'.

Estuary and other marine habitat restoration projects could also help mitigate the impacts of bushfires. In 2015, Colin Creighton and others detailed the decline in the health of Australia's estuaries, and as a result, the decline of fish populations targeted by commercial and recreational fishers⁸². They argued the need for major restoration projects in Australia's estuaries, which will become even more imperative after the bushfires, and listed five key repair themes or estuaries:

1. restore connectivity by removing obstructions such as barrages and causeways;
2. rehabilitate coastal floodplains;
3. re-establish mussel and oyster reefs;
4. protect and re-establish seagrass meadows;
5. maintain adequate freshwater flows into the estuaries.

The restoration of estuaries, already required due to their long-term decline in health, could also help them recover from bushfire impacts, benefit fisheries production and provide economic benefits to communities dependent on fishing and associated tourism. There are a number of organisations already dedicated to the recovery of coastal and marine habitats and their expertise should be used to assist in the recovery of marine and coastal habitats in fire-affected areas.

Bushfire impacts on Indigenous culture

Coastal and marine environments are sea country to Indigenous communities who have been part of the response to the bushfires and their aftermath in catchments and coastal areas. For example: 'When the rain began in the Central Coast region of New South Wales, members of the Darkinjung, a local Aboriginal land council, set up barriers to keep the deluge of silt- and ash-filled water out of the region's rivers, lakes, and estuaries'⁸³.

Traditional Owners have lived in their sea country for thousands of years and established an intimate connection with marine and coastal environments. According to Kelvin Johnson, a senior land manager with the Darkinjung, 'Australia's Indigenous peoples use sacred songlines—a complex mix of celestial references, songs, oral history, and physical and cultural landmarks—to navigate terrestrial and aquatic routes. Though it's too early to know the extent of the damage, if the fires harm oysters, crustaceans, flathead, or mullet, that would mark a loss of these cultural touchstones'⁸⁴.

76. Legge S et al. 2020, 'Rapid analysis of impacts of the 2019–20 fires on animal species, and prioritisation of species for management response – preliminary report', Report prepared for the Wildlife and Threatened Species Bushfire Recovery Expert Panel, 9 February 2020, <<https://www.environment.gov.au/biodiversity/bushfire-recovery/research-and-resources>>.

77. Deacon B and Carbonell R 2020.

78. Deacon B and Carbonell R 2020

79. Eddie R 2020.

80. Gorman N 2020, 'Native fish rescued after bushfires, rainfall and predators threaten their survival', *ABC Riverina*, 12 February 2020, <<https://www.abc.net.au/news/2020-02-12/native-fish-rescued-from-bushfires-in-kosciuszko-national-park/11953776>>.

81. Redfearn G 2020, 'A moment of complete despair': last population of Macquarie perch wiped out in NSW river carnage', *The Guardian*, 15 February 2020, <<https://www.theguardian.com/environment/2020/feb/15/last-population-macquarie-perch-nsw-river-carnage-bushfire-ash-fish-species>>.

82. Creighton C et al. 2015, 'Repairing Australia's estuaries for improved fisheries production – what benefits, at what cost?', *Marine and Freshwater Research*, <http://dx.doi.org/10.1071/MF14041>.

83. Fox A 2020, 'Australia's marine ecosystems imperiled by fires', *The Hill*, <<https://thehill.com/changing-america/sustainability/environment/479628-australias-fires-will-damage-the-countrys-marine>>.

84. Johnson D 2020.

5. Conclusions and recommendations

In the preparation of this report, the available marine and coastal research has been reviewed, along with a larger body of research into bushfire impacts in catchments away from the coast. In combination, these two sources of data provide a guide to what bushfire impacts can be expected in estuaries and other coastal and marine environments in the short and longer term. However, the full consequences of the current bushfire season remain to be seen.

Australians will experience longer fire seasons disrupting their lives, while coastal and marine environments, already struggling against development, pollution, overfishing and climate change, will face the added burden of bushfires and their impacts. The following recommendations, if acted upon, would improve our understanding and enable Australia to effectively respond to and better mitigate bushfire impacts on our coastal and marine environments. It is imperative that the Australian, state and territory governments work together to deliver these recommendations.

Research

1. Establish a comprehensive research program to address serious knowledge shortfalls of the impacts of bushfires on coastal and marine environments to enable adaptation and mitigation to be effective.
2. Ensure continued and adequate funding to the Bushfire and Natural Hazards CRC. Additional funding should be granted to enable the widespread use of the CRC's Value Tool which allows managers to estimate the value of intangibles, such as biodiversity protection, when making management decisions.
3. Map the extent and severity of the bushfires along the coast to determine the nature and extent of the damage to their natural values.
4. Identify and map areas and catchments most at risk from bushfire runoff, and where impacts are likely to be highest, to assist in the targeting of revegetation and sediment control.

Monitoring

5. Immediately develop an integrated, comprehensive and consistent monitoring program for coastal and marine environments to build an understanding of bushfire impacts and how they can be avoided or minimised. This should engage local governments, citizen scientists, research institutions and government agencies in a nationally funded program to enable accurate and consistent measurement of environmental change from bushfires and other impacts.
6. Establish ongoing water quality monitoring programs for phytoplankton, bacteria, nutrients and metals to provide early-warning systems for poor water quality in coastal waterways.
7. Identify key indicators for water quality and ecological health and ensure that they are consistently monitored nationally across coastal waterways and nearshore waters using best-practice technologies and methodologies.
8. Ensure monitoring programs gather data on seagrass meadows, seaweeds, mangroves, as well as on fish, including key commercial and recreational fish species, birds, mammals, shellfish and other invertebrates reliant on healthy coastal and marine environments in fire-prone regions.

Management

9. Ensure that national and state agencies charged with assessing and responding to the bushfire impacts on wildlife, habitats and ecosystems are tasked with and sufficiently resourced to include marine and coastal plants, animals and habitats in their assessments and responses.
10. Ensure coastal environmental management plans, such as local government or agency plans, work to reduce the runoff from agriculture and coastal development entering coastal waterways.
11. Ensure coastal aquaculture operations are adaptive and resilient to the increasing scale, frequency and intensity of bushfires.
12. Ensure management of inshore fisheries is adaptive to account for the reduced or altered stocks of targeted fish after bushfires and that the increased frequency, scale and intensity of bushfires is factored into long-term fisheries management plans.
13. Establish protected buffer zones around burnt and impacted coastal areas to provide refuge for surviving coastal and marine wildlife.

Figure 8



Aerial view of NSW mid north coast, Summer 2019. © Ash Hogan

Recovery and restoration

14. Identify the coastal and marine species and populations at risk from the current and future bushfires and develop and implement protection, recovery and restoration programs.
15. Re-establish riparian vegetation along coastal waterways flowing into estuaries, lagoons, lakes and nearshore waters to reduce water temperatures and to restrict the entry of sediment loads. All riparian vegetation should be fenced, where necessary, to prevent access by livestock.
16. Install sediment barriers and other erosion control measures to reduce the runoff of ash and bushfire debris into coastal waterways.
17. Support, promote and resource the various projects initiated by academic institutions, government agencies and community groups that are restoring, seagrass meadows, oyster reefs, underwater forests of seaweed and other coastal and marine habitats. Some of the organisations have the expertise but not necessarily the capacity – greater investment in their efforts should be a priority.
18. **Increase the allocated funds to the Bushfire recovery package for wildlife and their habitat to include the restoration and protection of damaged coastal and marine environments.**

Protection and Mitigation

19. Strengthen nature conservation and environmental laws to protect and build the resilience of communities and ecosystems vulnerable to bushfire impacts.
20. Reduce domestic carbon emissions to net zero swiftly and effectively, and show strong leadership in supporting and encouraging other nations to reduce emissions.

6. References

Research papers

- Abram N et al 2003, 'Coral reef death during the 1997 Indian Ocean Dipole linked to Indonesian wildfires', *Science*, vol. 301, 15 August 2003, pp.952–955.
- Adams R and Simmons D 1999, 'Ecological effects of fire fighting foams and retardants', Conference Proceedings, Australian Bushfire Conference, Albury, July 1999, <http://life.csu.edu.au/bushfire99/contents.html>
- Alexandra J and Finlayson C 2020, 'Floods after bushfires: rapid responses for reducing impacts of sediment, ash, and nutrient slugs', *Australasian Journal of Water Resources*, <https://doi.org/10.1080/13241583.2020.1717694>
- Blake W, Wallbrink P and Droppo I 2009, 'Sediment aggregation and water quality in wildfire-affected river basins', *Marine and Freshwater Research*, 2009, 60, 653–659, p.658.
- Bowen L et al. 2015, 'Effects of wildfire on sea otter (*Enhydra lutris*) gene transcript profiles', *Marine Mammal Science*, 31(1): 191–210 (January 2015).
- Chessman B 1986, 'Impact of the 1983 wildfires on river water quality in East Gippsland, Victoria', *Australian Journal of Marine and Freshwater Research* 37(3) 399–420.
- Creighton C et al. 2015, 'Repairing Australia's estuaries for improved fisheries production – what benefits, at what cost?', *Marine and Freshwater Research*, <http://dx.doi.org/10.1071/MF14041>
- Duran-Medrano R 2017, 'Valuation of terrestrial and marine biodiversity losses caused by forest wildfires', *Journal of Behavioral and Experimental Economics*, 71 (2017) 88–95.
- Gill M, Stephens S and Cary G 2013, 'The worldwide "wildfire" problem', *Ecological Applications*, 23(2), 2013, pp. 438–454 by the Ecological Society of America
- Gimenez A et al. 2004, 'Long-term forest fire retardants: A review of quality, effectiveness, application and environmental considerations', *International Journal of Wildland Fire*, 2004, 13, 1–15.
- Gonino G 2019a, 'Fire increases the productivity of sugarcane, but it also generates ashes that negatively affect native fish species in aquatic systems', *Science of the Total Environment*, 664 (2019) 215–221.
- Gonino G et al. 2019b, 'Short-term effects of wildfire ash exposure on behaviour and hepatosomatic condition of a potamodromous cyprinid fish, the Iberian barbel *Luciobarbus bocagei* (Steindachner, 1864)', *Science of the Total Environment*, 665 (2019) 226–234.
- Jaafar Z and Loh T-L 2014, 'Linking land, air and sea: potential impacts of biomass burning and the resultant haze on marine ecosystems of Southeast Asia', *Global Change Biology*, 2014; DOI: 10.1111/gcb.12539.
- Kalabokidis K 2000, 'Effects of wildfire suppression chemicals on people and the environment – A review', *Global Nest Journal*, vol. 2, No 2, pp 129–137, 2000.
- Kelly R 2018, 'Thomas Fire: Analysis of metals in aerosols, coastal waters, and flood waters', University of Southern California, Poster.
- Kelly R et al (working manuscript), 'Thomas Fire: Analysis of metals in aerosols, coastal waters, and flood waters'.
- Kim Y et al. 2005, 'Possible effect of boreal wildfire soot on Arctic sea ice and Alaska glaciers', *Atmospheric Environment*, 39 (2005) 3513–3520.
- Liu Y 2005, 'Enhancement of the 1988 northern US drought due to wildfires', *Geophysical Research Letters*, vol.32, L10806, doi:10.1029, 2005GL022411, 2005.
- Lyon J and O'Connor J, 2008, 'Smoke on the water: Can riverine fish populations recover following a catastrophic fire-related sediment slug?', *Austral Ecology* (2008) 33, 794–806.
- Nunes et al 2017, 'Off-site impacts of wildfires on aquatic systems – Biomarker responses of the mosquitofish *Gambusia holbrooki*', *Science of the Total Environment*, 581–582 (2017) 305–313.

Rinne J 1996, 'Short-term effects of wildfire on fishes and aquatic macroinvertebrates in the South Western United States', *North American Journal of Fisheries Management* 16: 653–658, 1996.

Rogers A et al. 2017, 'Including the intangible benefits of bushfire mitigation in economic analyses: a "value tool" for informed decision making', In M. Rumsewicz (ed.), *Research Forum 2017: proceedings from the Research Forum at the Bushfire and Natural Hazards CRC & AFAC Conference*. Melbourne: Bushfire and Natural Hazards CRC, Melbourne.

Thompson M et al 2017, 'A review of challenges to determining and demonstrating efficiency of large fire management', *International Journal of Wildland Fire* 2017, 26, 562–573 <http://dx.doi.org/10.1071/WF16137>

Turetsky M et al 2006, 'Wildfires threaten mercury stocks in northern soils', *Geophysical Research Letters*, vol. 33, L16403, doi:10.1029/2005GL025595, 2006.

Verkaik I 2013, 'Effects of bushfire on macroinvertebrate communities in south-east Australian streams affected by a megadrought', *Marine and Freshwater Research* 65(4) 359–369 <https://doi.org/10.1071/MF13039>

Wu L, Taylor M and Handley H 2017, 'Remobilisation of industrial lead depositions in ash during Australian wildfires', *Science of the Total Environment*, 599–600 (2017) 1233–1240.

Government agency websites and reports

Barkley Y, 'Wildfire and its effects on streams and rivers', <<https://ucanr.edu/sites/postfire/files/248232.pdf>>.

California Department of Fish and Wildlife, 'Science: Wildfire Impacts Overview', <<https://wildlife.ca.gov/Science-Institute/Wildfire-Impacts>>.

CoastAdapt 2017, 'Coastline a refuge for threatened animals', <<https://coastadapt.com.au/coastline-refuge-threatened-animals>>.

Cook P, Holland D and Longmore A 2008, *Interactions between phytoplankton dynamics, nutrient loads and the biogeochemistry of the Gippsland Lakes*, A report prepared for the Gippsland Lakes Taskforce, Water Studies Centre, Monash University, Clayton.

Department of Primary Industry, 'Fish kills in NSW', <https://www.dpi.nsw.gov.au/fishing/habitat/threats/fish-kills>.

Food Agility, 'Food safety in the NSW Oyster industry', Food Agility, <https://www.foodagility.com/projects/food-safety-in-the-oyster-industry>.

Legge S et al. 2020, *Rapid analysis of impacts of the 2019–20 fires on animal species, and prioritisation of species for management response – preliminary report*, Report prepared for the Wildlife and Threatened Species Bushfire Recovery Expert Panel, 9 February 2020, <https://www.environment.gov.au/biodiversity/bushfire-recovery/research-and-resources>.

Liu Y 2005, 'Enhancement of the 1988 northern US drought due to wildfires', *Geophysical Research Letters*, vol.32, L10806, doi:10.1029/2005GL022411, 2005.

Murray Darling Basin Authority 2020, 'Relief of rain brings expected water quality channels', Media Release, 30 January 2020, Murray Darling Basin Authority, Canberra.

NSW Department of Planning, Industry and the Environment 2020, '\$5 million for bushfire affected coastal waterways', NSW Government, 28 January 2020, <https://www.environment.nsw.gov.au/news/5-million-for-bushfire-affected-coastal-waterways?fbclid=IwAR0yCGWGwtmA4GMdKJJERSHaTUQCIIHRH0b4Xlcr3PjqcCnNRcbldJCzHOs>

NSW Department of Primary Industries 2020, 'Bushfire impacts on native fish', NSW DPI, <https://www.dpi.nsw.gov.au/fishing/habitat/threats/fish-kills/bushfire-impacts-on-native-fish>.

NSW Rural Fire Service 2019, '2019–20 fire season starts early; Fire permit suspended', NSW RFS, 1 September 2019, <https://www.rfs.nsw.gov.au/about-us/our-districts/cudgegong/latest-news/2019-20-fire-season-starts-early-fire-permit-suspended>

Stoessel D, Ayres R and Raadik T 2012, *Improving spawning success for Barred Galaxias (Galaxias fuscus) in streams affected by bushfire – an aid to recovery*, Black Saturday Victoria 2009: Natural Values Fire Recovery Program, Department of Sustainability and Environment, Heidelberg, Victoria.

Tulau M and McInnes-Clarke S 2015, *Fire and soils. A review of the potential impacts of different fire regimes on soil erosion and sedimentation, nutrient and carbon cycling, and impacts on water quantity and quality*, NSW Office of Environment and Heritage, Sydney.

University websites

Jones N 2017, 'Stark evidence: A warmer world is sparking more and bigger wildfires', *Yale e360*, 2 October 2017, <<https://e360.yale.edu/features/the-evidence-is-clear-a-warmer-world-means-more-wildfires>>.

Struzik E 2018, 'How wildfires are polluting rivers and threatening water supplies', *Yale e360*, 2 October 2018, <<https://e360.yale.edu/features/how-wildfires-are-polluting-rivers-and-threatening-water-supplies>>.

Sydney Institute of Marine Science 2020, 'Potential impacts of bushfires on our marine environment: Potential impacts of bushfire smoke and ash to Sydney and surrounds', <<https://www.sims.org.au/news/94/bushfire-impact-statement>>.

Sydney Institute of Marine Science 2020, 'Potential impacts of bushfires on our marine environment: Drought and fire impacts in estuaries', <<https://www.sims.org.au/news/94/bushfire-impact-statement>>.

Sydney Institute of Marine Science 2020, 'Potential impacts of bushfires on our marine environment: Contaminants and toxic effects of ash to marine ecosystems', <<https://www.sims.org.au/news/94/bushfire-impact-statement>>.

Sydney Institute of Marine Science 2020, 'Potential impacts of bushfires on our marine environment: Unprecedented fires require crucial research for future monitoring of coastal environments', <<https://www.sims.org.au/news/94/bushfire-impact-statement>>.

University of New South Wales 2020, 'More than one billion animals killed in Australian bushfires', UNSW website, 8 January 2020, <<https://sydney.edu.au/news-opinion/news/2020/01/08/australian-bushfires-more-than-one-billion-animals-impacted.html>>.

Community

Australian Bushfires and Climate Change 2020, 'An open letter on the scientific basis for the links between climate change and bushfires in Australia', Australian Bushfires and Climate Change, 4 February 2020, <<https://australianbushfiresandclimatechange.com>>.

Barnzey 2020, posted 13 January 2020 on *Fish Raider*, <<https://www.fishraider.com.au/topic/90445-dead-fish/>>.

Boat Sales 2020, 'Victoria calls in army to save bushfire-hit fish', *Boat Sales*, 24 January 2020, <<https://www.boatsales.com.au/editorial/details/victoria-calls-in-army-to-save-bushfire-hit-fish-122574/>>.

Centre for Disaster Philanthropy 2020, '2019–2020 Australian Bushfires', February 4, 2020', <<https://disasterphilanthropy.org/disaster/2019-australian-wildfires/>>.

Environmental Investigation Agency 2019, 'Watching the world burn – fires threaten the planet's tropical forests and millions of people', *EIA*, 18 September 2019, <<https://eia-international.org/news/watching-the-world-burn-fires-threaten-the-worlds-tropical-forests-and-millions-of-people/>>.

Myers A 2020, Ocean Watch Facebook page, 10 January 2020.

Operation Crayweed, 'Restoring Sydney's underwater forests', <<http://www.operationcrayweed.com/>>.

Operation Posidonia, 'Restoring underwater meadows', <<https://www.operationposidonia.com>>.

Ozfish, 'Fishers for coastal habitat', <<http://ozfish.org.au/programs/fishers-for-coastal-habitat/>>.

Recfishwest 2019, 'Creating seagrass pastures anew for Cockburn Sound', Recfishwest, 28 November 2019, <<https://recfishwest.org.au/news/creating-seagrass-pastures-anew-for-cockburn-sound/>>.

The Nature Conservancy, 'Rebuilding Australia's lost shellfish reefs', <<https://www.natureaustralia.org.au/what-we-do/our-priorities/provide-food-and-water-sustainably/food-and-water-stories/restoring-shellfish-reefs/>>.

Media

AAP 2020, 'Hazard reduction burns are not a "panacea" for bushfire risk, RFS boss says', *The Guardian*, 8 January 2020, <<https://www.theguardian.com/australia-news/2020/jan/08/hazard-reduction-is-not-a-panacea-for-bushfire-risk-rfs-boss-says>>.

Abram S 2017, 'Are Southern California wildfires a threat to local marine life? Scientists aim to find out', *Daily News*, 26 December 2017, <<https://www.dailynews.com/2017/12/26/are-southern-california-wildfires-a-threat-to-local-marine-life-a-new-study-aims-to-find-out/>>.

Bolton C 2018, 'The sky is falling', *Hakai Magazine*, 26 February 2017, <<https://www.hakaimagazine.com/news/the-sky-is-falling/>>.

Boys C 2020, 'South Coast oyster harvests suspended due to bushfires', *Good Food*, 11 January 2020, <<https://www.goodfood.com.au/eat-out/news/south-coast-oyster-harvests-suspended-due-to-bushfires-20200110-h1kyk0>>.

Brewer P 2020, 'Anxious wait as Moruya prepares for possible firefront', *Canberra Times*, 8 January 2020, <<https://www.canberratimes.com.au/story/6572397/anxious-wait-as-moruya-prepares-for-possible-firefront>>.

Bundgard M and Hannam P 2020, 'Widespread beach closures expected as erosion fears mount', *Sydney Morning Herald*, 7 February, 2020, <<https://www.smh.com.au/environment/weather/widespread-beach-closures-expected-as-erosion-fears-mount-20200207-p53yv9.html>>.

Butler B and Wahlquist C 2020, 'Australian bushfire crisis predicted to cost tourism industry hundreds of millions', *The Guardian*, 3 January 2020, <<https://www.theguardian.com/australia-news/2020/jan/03/australian-bushfire-crisis-predicted-to-cost-tourism-industry-hundreds-of-millions>>.

Butt C and McManus J 2020, ' "It's a sorry sight": Dead birds wash up on Mallacoota's beaches', *The Age*, 7 January 2020, <<https://www.theage.com.au/national/victoria/it-s-a-sorry-sight-dead-birds-wash-up-on-mallacoota-s-beaches-20200107-p53plm.html>>.

Casben L 2020, 'NSW bushfires: Batemans Bay fire front was like no other bushfire for me', *ABC News*, 1 January 2020, <<https://www.abc.net.au/news/2020-01-01/nsw-bushfires-batemans-bay-fire-like-no-other-new-years-eve/11836136>>.

Chang C 2020, 'Forever fires: How the Australia bush fires compare to other disasters', *New Zealand Herald*, 7 January 2020, <https://www.nzherald.co.nz/world/news/article.cfm?c_id=2&objectid=12298682>.

Chappell B 2020, 'Australia's east gets drenched by rain and flood warnings replace fire alerts', *NPR*, 7 February 2020, <<https://www.npr.org/2020/02/07/803748216/australias-east-gets-drenched-by-rain-and-flood-warnings-replace-fire-alerts>>.

CNN 2020, 'Australia's deadly wildfires are showing no signs of stopping. Here's what you need to know', *CNN*, 1 January 2020, <<https://edition.cnn.com/2020/01/01/australia/australia-fires-explainer-intl-hnk-scli/index.html>>.

Cox L 2020, ' "Massive relief": torrential rain douses bushfires across parts of Australia', *The Guardian*, 7 February 2020, <<https://www.theguardian.com/world/2020/feb/07/massive-relief-torrential-rain-douses-bushfires-across-parts-of-australia>>.

Dawes S and Thorne L 2020, 'Bushfire contamination of waterways may lead to fish deaths and algal blooms, CSIRO warns', *ABC Mildura-Swan Hill*, 25 January 2020, <<https://www.abc.net.au/news/2020-01-25/bushfire-ash-in-waterways-could-affect-murray-quality/11896592>>.

Deacon B and Carbonell R 2020, 'Inside the race to protect 250 threatened species hit by bushfire', *ABC News*, 20 January 2020, <<https://www.abc.net.au/news/2020-01-19/inside-the-race-to-protect-threatened-species/11877990>>.

Doyle K 2020, '2019 was Australia's hottest and driest year on record', *ABC Weather*, 2 January 2020, <<https://www.abc.net.au/news/2020-01-02/2019-was-australias-hottest-and-driest-year-on-record/11837312>>.

Doyle K and Slezak M 2019, 'More records tumble as heatwave rolls on, scientists point finger at climate change', *ABC Weather*, 20 December 2019, <<https://www.abc.net.au/news/2019-12-20/finger-pointed-at-climate-change-as-heatwave-smashes-records/11817884>>.

Duxfield F 2013, 'Oyster farmers struggle with bushfires', *ABC Rural*, 18 January 2013, <<https://www.abc.net.au/news/rural/2013-01-18/oyster-farmers-struggle-with-bushfires/6298078>>.

Eddie R 2020, 'Delicate rescue to save threatened wildlife from bushfire zone', *The Age*, 13 February 2020, <<https://www.theage.com.au/national/victoria/delicate-rescue-to-save-threatened-wildlife-from-bushfire-zone-20200207-p53yms.html>>.

Fresh Science 2003, 'Fire: The new threat to coral reefs', *Fresh Science*, <<https://freshscience.org.au/2003/fire-the-new-threat-to-coral-reefs>>.

Fry H 2019, 'Beach pollution surges after massive wildfires and heavy rains, report finds', *LA Times*, 26 June 2019, <<https://www.latimes.com/local/lanow/la-me-ln-beach-report-card-20190626-story.html>>.

Fox A 2020, 'Australia's marine ecosystems imperiled by fires', *The Hill*, <<https://thehill.com/changing-america/sustainability/environment/479628-australias-fires-will-damage-the-countrys-marine>>.

Gorman N 2020, 'Native fish rescued after bushfires, rainfall and predators threaten their survival', *ABC Riverina*, 12 February 2020, <<https://www.abc.net.au/news/2020-02-12/native-fish-rescued-from-bushfires-in-kosciuszko-national-park/11953776>>.

Hall B and Hannam P 2020, 'Leaked report lays bare environmental devastation of Victorian fires', *The Age*, 10 January 2020, <<https://www.theage.com.au/national/victoria/leaked-report-lays-bare-environmental-devastation-of-victorian-fires-20200110-p53qep.html>>.

Hannam P 2020, 'Revealed: Widespread species devastation following "unprecedented" fires', *Sydney Morning Herald*, 18 January 2020, <<https://www.smh.com.au/environment/conservation/revealed-widespread-species-devastation-following-unprecedented-fires-20200117-p53siy.html>>.

Hannam P and Bungard M 2020, 'Forecasters warn of potentially "life-threatening flash-flooding" in Sydney', *Sydney Morning Herald*, 8 February 2020, <<https://www.smh.com.au/environment/weather/one-extreme-to-the-other-flood-risks-for-nsw-and-sydney-20200207-p53yt1.html>>.

Herbert L 2020, 'Oyster bounty from South Coast waters unlikely to be affected by ash', *About Regional*, 10 January 2020, <<https://aboutregional.com.au/will-ash-from-the-fires-affect-our-pristine-waters-and-beautiful-bounty-not-so-much/>>.

Heyden D 2017, 'California wildfires are impacting the ocean and a team of researchers want to study it', *The Inertia*, 21 December 2017, <<https://www.theinertia.com/surf/california-wildfires-are-impacting-the-ocean-and-a-team-of-researchers-want-to-study-it/>>.

Jansen H 2019, '5 unexpected ways that wildfires affect wildlife, ecosystems of forests', *Accuweather*, 6 July 2019, <<https://www.accuweather.com/en/weather-news/five-effects-wildfire-west-forests-wildlife-ecology-animals-plants/432552>>.

Johnson D 2020, 'Australia's marine animals will be the fires' unseen victims', *Hakai Magazine*, 22 January 2020, <<https://www.hakaimagazine.com/news/australias-marine-animals-will-be-the-fires-unseen-victims/>>.

Jones D, Bettio L and Tobin S 2019, 'Last summer was Australia's hottest on record – here's what this means', *The Conversation*, 7 March 2019, <<https://www.weforum.org/agenda/2019/03/2018-19-was-australia-s-hottest-summer-on-record-with-a-warm-autumn-likely-too>>.

Jones D, Braganza K and Tobin S 2020, 'Weather bureau says hottest, driest year on record led to extreme bushfire season', *The Conversation*, 9 January 2020, <<https://theconversation.com/weather-bureau-says-hottest-driest-year-on-record-led-to-extreme-bushfire-season-129447>>.

Khalil Shaimaa 2020, 'Australia fires: "Apocalypse" comes to Kangaroo Island', *BBC News*, 17 January 2020, <<https://www.bbc.com/news/world-australia-51102658>>.

Kim A 2019, 'A wildfire killed 80% of fish in a Colorado river', *CNN*, 24 September 2019,

Leahy S 2016, 'Canada wildfire - what are the environmental impacts?', *The Guardian*, 11 May 2016, <<https://www.theguardian.com/environment/2016/may/11/canada-wildfire-environmental-impacts-fort-mcmurray>>.

McDermott A, 2017, 'Wildfires aren't just a land thing. Smoke and ash can choke the ocean too', *Oceana*, 9 October 2017, <<https://oceana.org/blog/wildfires-aren-t-just-land-thing-smoke-and-ash-can-choke-ocean-too>>.

McInerney P, Rees, G and Joehnk H 20120, 'The sweet relief of rain after bushfires threatens disaster for our rivers', *The Conversation*, 13 January 2020, <<https://theconversation.com/the-sweet-relief-of-rain-after-bushfires-threatens-disaster-for-our-rivers-129449>>.

McKenzie B 2019, 'Water catchments are covered in bushfire ash, what will happen when it rains?', *ABC North Coast*, 6 December 2019, <<https://www.abc.net.au/news/2019-12-06/ash-rain-threatens-quality-of-drinking-water-and-aquatic-life/11774076>>.

McNaughton J 2020, 'Bushfire debris turns Gippsland's Tambo River to sludge, suffocating eels', *ABC Gippsland*, 23 January 2020, <<https://www.abc.net.au/news/2020-01-23/eels-found-dead-in-polluted-tambo-river/11893646>>.

Martin P 2020, 'In fact, there's plenty we can do to make future fires less likely', *The Conversation*, 8 January 2020, <<https://theconversation.com/in-fact-theres-plenty-we-can-do-to-make-future-fires-less-likely-129341>>.

Morton A 2019, 'Yes, Australia has always had bushfires: but 2019 is like nothing we've seen before', *The Guardian*, 25 December 2019, <<https://www.theguardian.com/australia-news/2019/dec/25/factcheck-why-australias-monster-2019-bushfires-are-unprecedented>>.

Nguyen N et al. 2020, 'The truth about Australia's fires - arsonists aren't responsible for many this season', *ABC News*, 18 January 2020, <<https://www.abc.net.au/news/2020-01-11/australias-fires-reveal-arson-not-a-major-cause/11855022>>.

Offer K 2019, '4000 forced into ocean in darkness as fire hits Victorian holiday town', *Australian Financial Review*, 31 December 2019, <<https://www.afr.com/policy/energy-and-climate/4000-forced-into-ocean-in-darkness-as-fire-hits-victorian-holiday-town-20191231-p53nto>>.

Pickrell J 2020a, 'Australia's raging fires will create big problems for fresh drinking water', *National Geographic*, 10 January 2020, <<https://www.nationalgeographic.com/science/2020/01/australian-fires-threaten-to-pollute-water/>>.

Pickrell J 2020b, 'Australian fires have incinerated the habitats of up to 100 threatened species', *Science News*, 13 January 2020, <<https://www.sciencenews.org/article/australian-fires-incinerated-habitats-threatened-species-ecological-disaster>>.

Read P and Dennis R 2020, 'With costs approaching \$100 billion, the fires are Australia's costliest natural disaster', *The Conversation*, 7 January 2020, <<https://theconversation.com/with-costs-approaching-100-billion-the-fires-are-australias-costliest-natural-disaster-129433>>.

Redfearn G 2020, 'Hundreds of thousands of fish dead in NSW as bushfire ash washed into river', *The Guardian*, 18 January 2020, <<https://www.theguardian.com/world/2020/jan/17/hundreds-of-thousands-of-fish-dead-in-nsw-as-bushfire-ash-washed-into-river>>.

Resnick B, Irfan U and Samuel S 2020, '8 things everyone should know about Australia's wildfire disaster', *Vox*, 22 January 2020, <<https://www.vox.com/science-and-health/2020/1/8/21055228/australia-fires-map-animals-koalas-wildlife-smoke-donate>>.

Roy E 2020, 'New Zealand glaciers turn brown from Australian bushfires' smoke, ash and dust', *The Guardian*, 2 January 2020, <<https://www.theguardian.com/world/2020/jan/02/new-zealand-glaciers-turn-brown-from-australian-bushfires-smoke-ash-and-dust>>.

Rubbo L and Wellauer K 2019, 'Waves of ash wash up on NSW beaches, Port Macquarie records world's dirtiest air as bushfires burn', *ABC Mid North Coast*, 16 November 2019, <<https://www.abc.net.au/news/2019-11-15/nsw-bushfires-make-port-macquarie-most-polluted-place/11708612>>.

SBS News 2020, 'Tourism strategy promised after bushfires cost the industry \$4.5 billion', *SBS News*, 17 January 2020, <<https://www.sbs.com.au/news/tourism-strategy-promised-after-bushfires-cost-the-industry-4-5-billion>>.

Smee B 2020, 'Malua Bay fire: survivors tell how 1,000 people lived through a night of flames on NSW beach', *The Guardian*, 1 January 2020, <<https://www.theguardian.com/australia-news/2020/jan/01/malua-bay-fire-survivors-tell-how-1000-people-lived-through-a-night-of-flames-on-nsw-beach>>.

Taylor J 2020, 'David Attenborough calls Australia's bushfires "the moment of crisis" to address climate change', *The Guardian*, 17 January 2020, <<https://www.theguardian.com/tv-and-radio/2020/jan/17/david-attenborough-calls-australias-bushfires-the-moment-of-crisis-to-address-climate-change>>.

Thomas K and Kidd J 2020, 'NSW bushfires sparks mass fish kill at Macleay River on Mid-North Coast', *ABC News*, 16 January 2020, <<https://www.abc.net.au/news/2020-01-16/nsw-bushfire-ash-leads-to-mass-fish-kill-in-macleay-river/11872372>>.

Thomson B 2020, '40kg Murray cod among thousands of fish killed in Upper Murray', *Great Lakes Advocate*, 24 January 2020, <<https://www.greatlakesadvocate.com.au/story/6596147/fire-sparks-massive-upper-murray-fish-kill/?cs=9397>>.

Towell N 2020, 'Race to save birds from fires', *The Age*, 9 February, 2020.

Towell N and Millar R 2020, 'Fish stocks now threatened by bushfire run-off', *The Age*, 20 January, 2020, <<https://www.theage.com.au/national/victoria/fish-stocks-now-threatened-by-bushfire-run-off-20200120-p53t34.html>>.

Wiggins N 2020, 'Hundreds of people in the New South Wales coastal town of Eden have faced the choice of defending their homes or fleeing as authorities warn a massive fire is moving towards the area', *ABC News*, 5 January 2020, <<https://www.abc.net.au/news/2020-01-05/fires-nsdiamonw-eden-evacuation-ordered-as-blaze-poses-imminent-risk/11841864>>.

Woodward A, 'Australia's fires are 46% bigger than last year's Brazilian Amazon blazes. There are at least 2 months of fire season to go', *Business Insider Australia*, 3 January 2020, <<https://www.businessinsider.com.au/australia-fires-burned-twice-land-area-as-2019-amazon-fires-2020-1/amp/?r=US&IR=T>>.

Zaczek Z 2020, 'The bay engulfed by fire: Devastating photos taken hours apart show how a picturesque national park has been destroyed by bushfires', *Nine News*, 11 November 2019, <<https://www.msn.com/en-au/news/australia/the-bay-engulfed-by-fire-devastating-photos-taken-hours-apart-show-how-a-picturesque-national-park-has-been-destroyed-by-bushfires/ar-BBWzT2M>>.

ZME Science 2020, 'Australia is burning and deniers are changing tactics. Here's how', <<https://www.zmescience.com/science/australia-is-burning-and-deniers-are-changing-tactics-heres-how/>>.

Appendix 1. The Australian 2019–2020 bushfire crisis: an overview

The loss of life and properties, the social and economic impacts and the impacts on wildlife dominated the media. As at 4 February 2020, the 2019–2020 bushfire statistics were:

- Estimated insurance cost (at 16 January): \$1.34billion;
- Total cost estimated by economists: \$3.5billion;
- Area burnt (ha): 18.6million ha;
- Lives lost: 36;
- Wildlife lost: 1billion animals (this does not include insects etc, that could number in the trillions);
- Homes lost: 3000 (plus several thousand other buildings);
- Estimated charitable fundraising (at 31 January): \$157.7million⁸⁵.

The above cost estimates only include the financial costs to tangible assets, not social, environmental and health costs, which for the Ash Wednesday fires were estimated to be 9% of the total losses and 71% for the 2005–2006 Grampians fires. Paul Read and Richard Dennis have said that the ‘cost of intangibles can peak years after a disaster and continue to take tolls for decades, if not generations. Deloitte put the tangible costs of the Black Saturday fires at A\$3.1 billion in 2015 dollars and the intangible costs at more than that again: A\$3.9 billion, producing a total of A\$7 billion, which would be A\$7.6 billion in today’s dollars’⁸⁶.

Chris Dickman estimate that 800 million animals had been killed in NSW, and nationally one billion⁸⁷. But this number does not include bats, frogs or invertebrates (95% of species). The number of invertebrate loss could be in the trillions⁸⁸. In Victoria, government documents leaked in early January showed that ‘31 per cent of the state’s rainforests had already gone up in flames, as well as 24 per cent of wet or damp forests, and 34 per cent of lowland forests. Of more concern was the increasing severity and regularity of fire seasons, with many of the areas that have already burnt or which are predicted to burn in 2020 being ravaged as recently as 2014’⁸⁹.

All Australian states and territories have been impacted by the 2019–2020 bushfire season. Table 1 summarises the area burnt, lives lost and homes destroyed in each state and territory since September 2019 and up until 4 February 2020. Table 2 provides a snapshot of the historical impacts of fires in Australia since 1851.

Table 1 State by state breakdown of fire impacts

State	5.26million	Lives lost	Homes lost
NSW	5.26million	25	2176 (plus 200 facilities and 3744 outbuildings)
South Australia	485,600	3	151
Victoria	1.5million	5	396 and 400 other buildings
Queensland	2.5million	0	48
Western Australia	2.2million	0	1 and 12 structures
Australian Capital Territory	35,800	1	n/a
Tasmania	36,000	0	2
Northern Territory	6.8million	0	5

Source: Centre for Disaster Philanthropy 2020, ‘2019–2020 Australian Bushfires’, February 4, 2020, <<https://disasterphilanthropy.org/disaster/2019-australian-wildfires/>>.

Table 2 The impacts of major bushfires in Australia’s past

Fire	Area burnt (ha)	Lives lost	Homes lost
Black Thursday, 1851 (Victoria)	5 mill acres (1/ 4 Victoria)	12	n/a
Red Tuesday, 1898 (Victoria)	260,000 ha	12	2000 buildings
Black Sunday, 1926 (Victoria but fires also in NSW, ACT and Qld)	400,000ha	60	1000 buildings
Black Friday 1939 (Victoria)	2million ha	71	1000
Black Sunday 1955 (South Australia)	40,000ha	2	
Black Tuesday 1967 (Tasmania)	264,270ha	62	1293
Australia 1974–75 summer	117million ha	3	n/a
Ash Wednesday 1983 (Victoria and South Australia)	150,000 (VIC) 160,000ha (SA)	75	1000s
Black Christmas, 2001 (NSW and ACT)	753,314ha	0	109
Canberra 2003	160,000ha	4	488
Black Saturday 2009 (Victoria)	450,000ha	173	3000

Source: Chang C 2020, ‘Forever fires’: How the Australia bushfires compare to other disasters’, New Zealand Herald, 7 January 2020, https://www.nzherald.co.nz/world/news/article.cfm?c_id=2&objectid=12298682; <<https://knowledge.aidr.org.au/resources/bushfire-black-friday-victoria-1939/>>; <<https://www.communitybushfireconnection.com.au/1926-fires/>>.

85. Centre for Disaster Philanthropy 2020, ‘2019–2020 Australian Bushfires’, February 4, 2020, <<https://disasterphilanthropy.org/disaster/2019-australian-wildfires/>>.

86. Read P and Dennis R 2020, ‘With costs approaching \$100 billion, the fires are Australia’s costliest natural disaster’, The Conversation, 7 January 2020, <<https://theconversation.com/with-costs-approaching-100-billion-the-fires-are-australias-costliest-natural-disaster-129433>>.

87. University of New South Wales 2020, ‘More than one billion animals killed in Australian bushfires’, UNSW website, 8 January 2020, <<https://sydney.edu.au/news-opinion/news/2020/01/08/australian-bushfires-more-than-one-billion-animals-impacted.html>>.

88. Pickrell J 2020b, ‘Australian fires have incinerated the habitats of up to 100 threatened species’, Science News, 13 January 2020, <<https://www.sciencenews.org/article/australian-fires-incinerated-habitats-threatened-species-ecological-disaster>>.

89. Hall B and Hannam P 2020, ‘Leaked report lays bare environmental devastation of Victorian fires’, The Age, 10 January 2020, <<https://www.theage.com.au/national/victoria/leaked-report-lays-bare-environmental-devastation-of-victorian-fires-20200110-p53qep.html>>.

Bushfire comparisons

The extent of the fires led to comparisons with those that have burnt overseas and in Australia's past. Figure 7 reveals the stark difference between the current Australian bushfire season with recent Californian, Siberian, and Amazon fires, and Victoria's 2009 Black Saturday fires (Note that the area burnt in Australia's current fire season has almost doubled to 18.6million ha since this graphic was created). And like here in Australia, bushfire characteristics are changing in other parts of the globe. In California the size and intensity of fires have also increased and 15 of the '20 largest wildfires in California history have occurred since 2000, and ten of the most costly and destructive fires to life and property in the state have occurred since 2015⁹⁰. In 2017, Greenland was experiencing significant fires, Siberia its worst in 10,000 years, and fire regimes are changing in Alaska, Canada and the Mediterranean⁹¹. See Figure 8 for the widespread nature of fire across the globe.

Figure 9



NASA satellite map on 22 January 2020, showing fires over previous seven days. Source: Resnick B, Irfan U and Samuel S 2020, '8 things everyone should know about Australia's wildfire disaster', Vox, 22 January 2020, <<https://www.vox.com/science-and-health/2020/1/8/21055228/australia-fires-map-animals-koalas-wildlife-smoke-donate>>.

Figure 10: Bushfire scales compared



Source: Chang C 2020.

Figure 11: World map of fire hotspots: 1 December 2019 to 11 February 2020



Source: Global Forest Watch 2020.

90. California Department of Fish and Wildlife, 'Science: Wildfire impacts overview', <<https://wildlife.ca.gov/Science-Institute/Wildfire-Impacts>>.

91. Jones N 2017, 'Stark Evidence: A Warmer World Is Sparking More and Bigger Wildfires', Yale e360, 2 October 2017, <<https://e360.yale.edu/features/the-evidence-is-clear-a-warmer-world-means-more-wildfires>>.

Figure 12: Burnt leaves and debris washed up on Bar Beach, Narooma, NSW.



© Cat Leach, Catfish Creative.

Figure 13: Wyaliba North, eastern NSW



© Jo Sparks.

