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The impacts of the 2019–20 wildfires on marine species and ecosystems

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Summary

Context and challenges

- There has been little previous appreciation of, or research on, the impacts of wildfire on marine systems.
- Due to the limited data, this chapter considers Australian and international research (before and after the fires), and anecdotal observations in media reports and by coastal communities who contributed to an OceanWatch Australia survey.
- We consider a broad definition of marine ecosystems to include nearshore (subtidal and surf zone) and offshore waters (pelagic, water column and benthic components), estuaries, intertidal zones (beaches, mangroves, and saltmarsh), sand dunes and the mouths of coastal streams.

Main findings

- Anecdotal evidence and some recently published data indicate that the 2019–20 wildfires impacted marine species and ecosystems. However, the extent and duration of that impact are unknown.
- The impacts of the wildfires could continue as wildfire-derived sediments slowly flow down waterways and reach estuaries long after the 2019–20 wildfire season.
- Australia lacks a comprehensive and systematic monitoring of impacts on marine species and ecosystems generally, and by wildfires specifically.
- There is inadequate funding of marine research generally, and more specifically inclusive of wildfire impacts.
- The 2019–20 wildfires showed the strong connections between terrestrial, freshwater and marine ecosystems, with terrestrial and freshwater impacts having consequences for the marine environment.

- Marine, terrestrial and freshwater research often provides only a snapshot in time with no longitudinal data collection, and this limits the assessment of wildfire impacts. This is largely a feature of short-term funding provided by government programs.
- Marine research is often focused on commercial and recreational target species or large charismatic species (e.g. cetaceans, turtles, sharks) rather than building a broader knowledge of how marine ecosystems work and how marine species interact within those ecosystems. This is very limiting for building an understanding on how marine ecosystems are affected by wildfires.

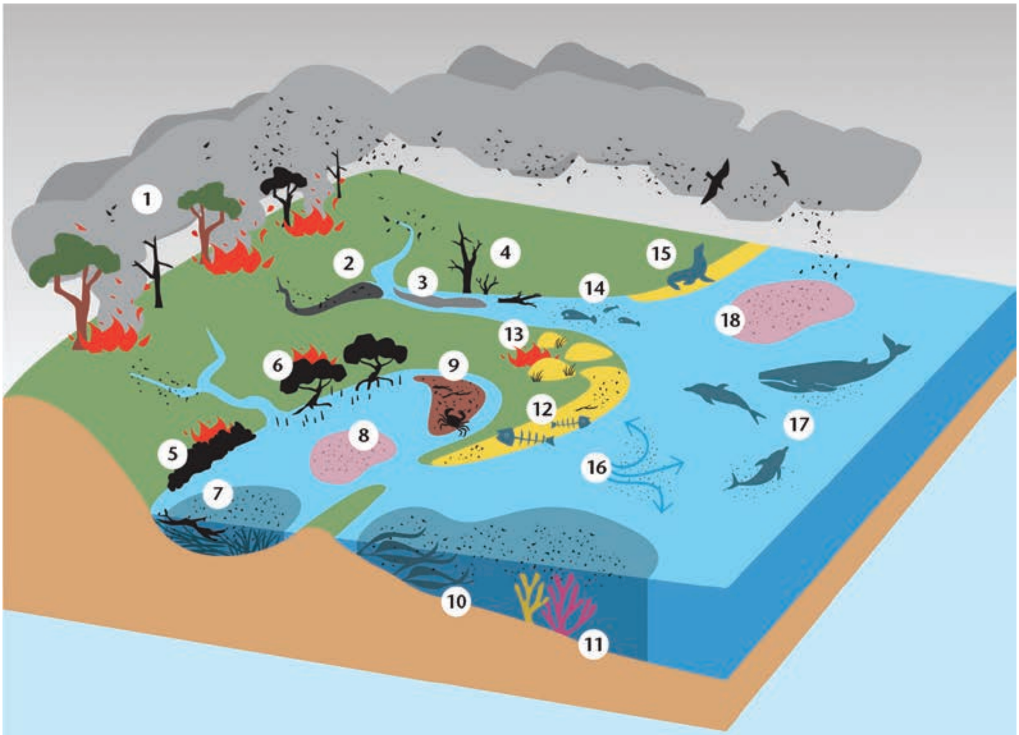
Introduction

The scale and intensity of the 2019–20 wildfires have been linked to climate change and a prolonged drought (Abram *et al.* 2021). Their impacts were exacerbated by subsequent storms and rainfall, which led to widespread severe flooding with ash, debris, nutrients, metals and chemicals flowing into streams and down into estuaries, onto beaches and out to sea. However, the nature and full extent of the wildfire impacts on marine species and ecosystems is largely unknown. The main reasons for this are:

1. During and in the immediate aftermath of the wildfires, access roads were closed and entry to fire grounds was restricted due to safety concerns. Post-fire storms and floods and then the emergence of the COVID-19 pandemic also delayed and then limited the scope of fieldwork in marine environments.
2. The majority of government, academic and citizen scientists work on terrestrial and freshwater species and ecosystems, with research funding directed accordingly.
3. Australia lacks a comprehensive and systematic monitoring framework for marine species and ecosystems that could have been used to establish baselines and report on change in response to the wildfires.
4. The focus of wildfire recovery projects were animals and plants on threatened species lists, which skew towards terrestrial species, in large part due to point 2.
5. There is a long-held belief that dynamic oceans dilute pollution and any impacts from wildfire ash, debris, nutrients, metals and chemicals will be short-lived, of little concern and beyond human intervention.

Even so, anecdotal observations, coincidental research, water-quality monitoring in fire-impacted estuaries, and Australian and international research into past fires can provide some insight into their impacts on marine species and ecosystems (Fig. 7.1). Freshwater research can also aid understanding due to some similarities in species and ecological processes (see Chapter 6). However, determining impacts of fire may be complex, in part due to compounding factors. One of the future research challenges will be to separate the impacts of wildfires from those caused by drought, climate change and floods, as well as from coastal development, pollution, over-harvesting and other stressors.

In this chapter, we describe three mechanisms for wildfire impacts on marine species and ecosystems: death and injury from incineration, smoke inhalation and radiant heat; run-off laden with ash, debris, nutrients, metals and chemicals; and wildfire smoke settling in estuarine and offshore waters. We also report on two case studies (Boxes 7.2 and 7.3) and one survey that compiled anecdotal observations on marine impacts of the 2019–20 wildfires (Box 7.1).



Key

1 Smoke containing ash, nutrients, metals and chemicals released to atmosphere, impacting coastal birdlife.

2 Ash and debris including nutrients, metals and chemicals run off into waterways after rains.

3 Sediment slug moves downstream, killing fish and reducing invertebrate habitats.

4 Riparian vegetation burnt, removing habitat and reducing shade – water temperatures increase.

5 Saltmarsh burnt, removing habitat and reducing shoreline protection.

6 Mangroves burnt, removing habitat and reducing shoreline protection.

7 Seagrass smothered by ash and debris. Turbid water reduces light and impacts seagrass photosynthesis.

8 Algal bloom leads to deoxygenation and death of fish.

9 Mudflats covered in ash and debris, killing mud crabs and removing food source for shorebirds.

10 Subtidal reefs and kelp beds smothered by ash and debris.

11 Coral reef smothered by ash and debris. Turbid water reduces photosynthesis.

12 Beaches covered by ash, debris and dead fish.

13 Sand dunes burnt, leading to erosion.

14 Fish that migrate upstream during life cycle killed by ash and debris.

15 Seals accumulate toxic PFAS from fire retardants.

16 Tides, currents and winds disperse ash and debris and spread the impact in surf zone and nearshore waters.

17 Whales and dolphins affected by inhaling wildfire smoke.

18 Smoke particles fall out of smoke plume, settling on water and causing algal blooms.

Fig. 7.1. Summary of possible wildfire impacts to marine ecosystems. (Figure created by Chris Tsernjavski, with permission from University of Melbourne)

Mechanisms of wildfire impacts on marine systems

Death and injury from incineration, smoke inhalation and radiant heat

Although evidence is limited, the OceanWatch Australia survey (see Box 7.1) received reports of burnt mangroves, wetlands, saltmarshes and sand dunes (Santori and Rowe 2021), which probably led to the immediate injury or death of plants and less-mobile animals such as molluscs and crabs. The loss of vegetation cover has flow-on effects, including the loss of nursery habitat, reduced carbon storage and the destabilisation of stream banks and shorelines.

Box 7.1. OceanWatch Australia survey of wildfire impacts on marine wildlife, habitats and water quality, and socio-economic consequences

Methodology

As part of an investigation into the impacts of the 2019–20 fires on marine wildlife, habitats, water quality and industry, OceanWatch Australia conducted an online public survey to record anecdotal observations from people who lived or worked near the affected areas. The focus of the survey (and its advertising for participants) was on six fire grounds: Kangaroo Island (South Australia), East Gippsland (Victoria), northern Tasmania, the south and north coasts of New South Wales, and south-east Queensland. The survey was built on the ESRI Survey123 platform and ran from December 2020 to June 2021 (Santori and Rowe 2021).

Results

A total of 45 surveys that included 82 observations in the marine environment were submitted to the survey either by the public or by OceanWatch Australia staff who had interviewed stakeholders. Observations that the respondents were only 'slightly confident' about or 'not confident at all', and observations related to terrestrial or freshwater systems, were excluded from this analysis.

Observations from the survey respondents were not equally distributed among the six focus regions (Fig. 7.2):

- north and south coasts of New South Wales: 67 wildfire impact observations, including two 'no impact' observations);
- south-eastern Queensland: six, including three 'no impact' observations;
- East Gippsland: one (the burning of Mallacoota's abalone processing plant);
- Kangaroo Island: four, and two 'no impact' observations;
- coastal Western Australia: two.

Most impact observations (number of observations in brackets) were of impacts to water quality (29), followed by socio-economic impacts (22), habitat (15) and marine wildlife (9). Seven surveys were returned reporting no impacts observed. The impacts were mostly observed from November 2019 to February 2021. Most impacts were reported as 'not recovered' (23), followed by 'partially back to pre-fire conditions' (20), while 20% (15) of the impacts reported were 'fully back to pre-fire conditions' at the time of submission.

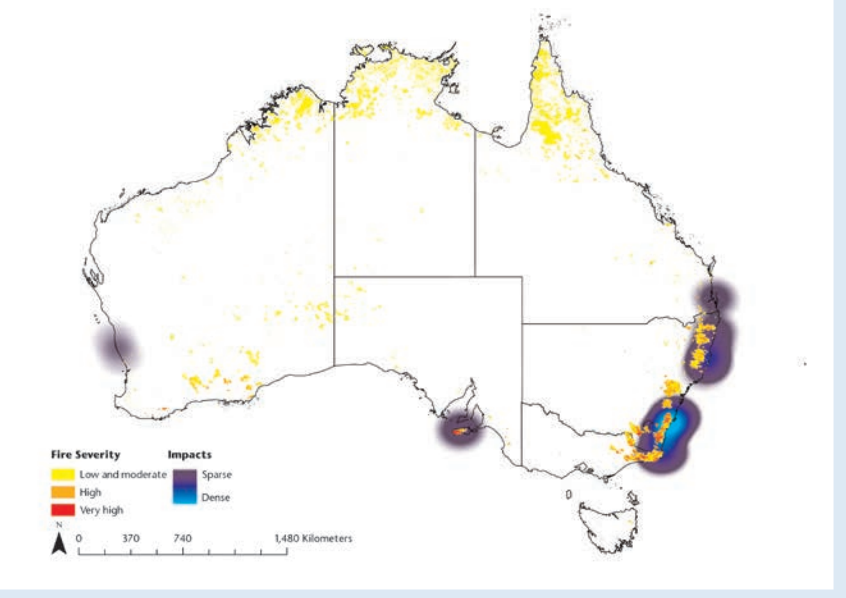


Fig. 7.2. Density of wildfire impact observations around mainland Australia (Australian Bureau of Statistics 2011) collected by OceanWatch Australia, relative to fire severity (the classes 'unburnt' and 'no data' are not displayed; New South Wales Department of Planning, Industry and Environment 2020).

Eight respondents reported observing a negative wildfire impact on marine wildlife, while one reported a positive impact (increase in numbers of big eye tuna and prawns, 6–7 months post wildfires). Five reports were about dead oysters; however, other dead animals observed were mullet, abalone, grouper, crabs, lobsters and 'fish'. Respondents reported that they knew or were uncertain that no action had been taken to address eight out of the nine animal impacts.

Water quality impacts dominated the observations, with most respondents reporting ash in the water (25) among the causal factors, followed by debris (18). Fifty-nine per cent of respondents (17) reported that water quality had not recovered or had only partially recovered from the wildfire impacts, over the survey period. Respondents reported that they either knew or were uncertain that no action had been taken to treat 21 out of the 29 water quality impacts, while actions such as estuary openings and clean-ups were reported for six of the impacts, with mixed success.

Most observations of habitat impacts included habitat destruction (10) followed by habitat degradation (5). The habitat most affected was mangroves (8) followed by wetland (5), saltmarsh (5) and seagrass (4). The main causes identified were fire itself, and ash and debris. Eight respondents stated that the habitat did not recover and six stated that it had only partially recovered. Moreover, respondents reported that to their knowledge no measures had been implemented to treat the impact in 60% (9) of 15 habitat impact observations. However, one respondent reported that coir logs were used to reduce sedimentation of waterways to safeguard seagrass.

Socio-economic impacts observed by the survey respondents covered businesses reliant on marine environments (e.g. aquaculture, fishing), marine-based tourism (e.g. loss of aesthetic appeal and visitor numbers), local use of marine environments (e.g. impeded access), or wellbeing of coastal communities. The most reported impact was impeded access to water resources (9), followed by loss of stock (8) and damage or loss of infrastructure (7). Twenty-three per cent (5) of the socio-economic impact observations reported were classified as not recovered, while 32% (7) were reported as fully back to pre-fire conditions. Respondents reported that to their knowledge no measures had been implemented to treat the socio-economic impact in 11 cases, while for eight of the impacts, respondents were unsure.

Survey limitations

One of the major limitations of this survey is the time that passed between the wildfires and the survey launch, which in many cases was more than 1 year. Moreover, access to online surveys can be difficult for communities that are remote or limited in their digital literacy. Nevertheless, given the paucity of Australian-based scientific information on the effects of wildfires on aquatic environments, collecting anecdotal observations from people who live along the Australian coast and work in Australian waters has built an understanding of post-wildfire impacts. However, it is important to consider that wildfire impacts can be subtle, difficult to attribute to a specific cause, or could be inaccurately reported due to the time passed between the fires and the survey. For example, the impact of the wildfires was exacerbated by the drought that preceded them, as well as the extraordinary summer heat. The 2019–20 wildfires were then followed by significant flooding in many of the affected areas. The impacts reported by survey participants might have been attributed to wildfires when in fact they could have been the result of the combined impacts of these events. As a result, these observations should be treated as hypotheses to be tested, and a first attempt to understand the impacts that wildfires have on marine environments at a regional and national scale.

Where riparian vegetation is burnt, the radiant heat and the loss of shade (Water Quality Australia 2018) can increase water temperature and lead to the death of fish and macroinvertebrates in impacted coastal streams. For example, the richness, composition, function and resilience of aquatic macroinvertebrates, which include midges, black flies, stoneflies and caddisflies, declined after the 2013 fires in northern Victoria (Verkaik *et al*. 2015).

In Mallacoota, hundreds of birds from 25 bird species were found dead on Tip Beach during the 2019–20 wildfires, including lorikeets, cockatoos, honeyeaters and robins, possibly due to smoke inhalation and exhaustion as they tried to escape out to sea (Butt and McManus 2020).

Not all marine and coastal animals in the path of the fires and smoke will die. However, injured animals and those that have lost their habitat may eventually succumb to disease, predation and competition with other surviving wildlife. Moreover, marine habitats altered by wildfires take time to recover and might be unable to support returning fauna.

Post-fire changes to floral composition, age class and density are common and were observed during the 2019–20 wildfires. During a tour of fire grounds in February 2021, two of the authors observed that the dominant foredune canopy species of banksia were killed and not regenerating at Noosa Heads, in south-eastern Queensland, with little evidence of seedling propagation. In the South Coast of New South Wales (NSW), along the Clyde River, Mogendoura Creek and Wonboyn Lake, grey and river mangroves, which

Fig. 7.3. Dead grey mangroves (*Avicennia marina*) along the Clyde River, likely killed by radiant heat due to the 2019–20 wildfires. (Photo: OceanWatch Australia)

are rarely affected by wildfires, were likely killed by radiant heat along hundreds of metres of shoreline (Fig. 7.3; Santori and Rowe 2021).

Run-off laden with ash, debris, nutrients, metals and chemicals

Wildfires do not just burn the 'wild'. They can also engulf houses, factories, furniture, machinery and vehicles, creating a toxic cocktail of ash, carbon dioxide, debris, nutrients (phosphorus, nitrogen and potassium), metals (copper, zinc, lead and mercury), synthetics and fire-retardant chemicals that can be washed into waterways and down to estuaries and river mouths. Wildfires can mobilise industrial and leaded petrol depositions (Wu *et al.* 2017) as well as soil mercury, which can move up the food chain from macroinvertebrates to top-order predators (Turetsky *et al.* 2006; Struzik 2018). Metals in high concentrations can be toxic to marine life and affect reproduction and growth rates (Sydney Institute of Marine Science 2020).

Seagrasses meadows, kelp beds and mangrove forests provide very important ecosystem services in Australia's estuaries, including nutrient cycling, sediment stabilisation, water quality improvement and shoreline protection. They also provide refuge and nursery habitats for the flathead, whiting, bream, mulloway, prawns and shellfish targeted by commercial and recreational fishers. However, they are highly vulnerable to poor water quality, which is worsened by wildfire debris washed down coastal rivers and streams.

Mangroves rely on pneumatophores or breathing roots to extract oxygen from the air to survive in muddy shorelines and can be impacted by the smothering of their roots by sediments, algal blooms and seagrass wrack (OzCoasts 2007), all of which could increase after wildfires in the catchment.

After the 2019–20 wildfires, fire-affected waterways were described as fluid mud, sludge, inky black or resembling cake mix. Wave, wind and tidal action eventually cleared blackened beaches of ash, some of it floating into nearshore waters and the surf zone, before breaking down or sinking to the seabed and subtidal reefs. Ash was also observed underwater at North Solitary Island off the New South Wales coast near Coffs Harbour.

Along the coast and in estuaries between the Hawkesbury River and Botany Bay (NSW), monitoring by the Abyss Project showed that climate change and drought, in combination with the wildfires and subsequent severe storms and floods, had led to significant marine impacts to depths of eight metres (The Abyss Project 2020) and could lead to ecological change.

The Abyss Project had been monitoring the area for 12 years and found that changes in water quality (and ocean chemistry) following the 2019–20 wildfires had impacted soldier crabs, sea urchins, kelp, turban snails, soft sponges and coral-like bryozoan invertebrates. The post-fire recovery of some species was faster than others, and invasive species were spreading into impacted areas where they could out-compete indigenous species.

NSW Government scientists monitored dissolved oxygen levels in seven estuaries during the 2019–20 wildfire season. In the Wonboyn River estuary, this monitoring showed that dissolved oxygen declined from 4.3 mg/L to 0 mg/L in 2 weeks during February 2020, the result of the excess nutrients and accompanying phytoplankton blooms (Manjalay 2020). Lowered water levels during drought had also prevented the estuary entrance from opening, concentrating the ash and debris from catchment run-off and increasing estuary vulnerability.

Excess phosphorus, nitrogen and potassium flowing into Australia's estuaries, which are generally low in nutrients, can lead to algal blooms that, when decomposing, reduce oxygen in the water and kill fish and other marine animals. Along with the immediate wildfire impacts, there is likely to be a long-term and gradual drip-feed of nutrients into estuaries over months and years; these nutrients may accumulate and lead to algal blooms well after the fire events.

In a Before-After-Control-Impact study, Barros *et al.* (2022) demonstrated substantial impacts of the 2019–20 wildfires on estuarine habitat. Where fires were of high intensity and burnt to the estuary edge (i.e. with no protective buffer), sedimentation from burnt areas led to higher silt content and increased concentrations of nutrients and metals in estuarine benthic habitats.

Unprecedented algal blooms that developed in the Gippsland Lakes (Victoria) after fires in 2006–07 were followed by floods that led to large increases in loads of suspended sediment, nitrogen, and phosphorus above background levels (Cook *et al.* 2008). Heavy rains and thunderstorms following the 2019–20 wildfires in late January 2020 washed large volumes of ash and debris into the Tambo River in Gippsland, killing eels, commonly regarded as the hardiest of animals (McNaughton 2020). The Tambo River flows into the Gippsland Lakes, where a scientific audit is now underway to assess the impacts of the fires on the Ramsar-listed coastal lagoons (Ley and Chester 2021).

The water column and seabed can be filled or covered by ash and debris, smothering habitats and clogging the gills of fish and the feeding structures of filter feeders. Increased turbidity can reduce sunlight and hinder the ability of aquatic plants, including seagrasses, to photosynthesise. The OceanWatch Australia survey (see Box 7.1) received reports of dead luderick, flathead, mullet, bream, abalone, rock oysters, rock lobsters and mud crabs on beaches and in estuaries. The NSW Department of Primary Industries reported that at the Tilba Lake estuary there were ~2000 dead flathead and bream, 100 mullet and tens of eels and crabs (see forum post by Barnzey 2020).

Sedimentation in fire-affected streams fills habitat spaces needed by invertebrates, kills fish and impacts their recruitment (Stoessel *et al*. 2012). Ash and debris can also form sediment slugs that slowly move downstream over what can be years, impacting animals and plants along the way and potentially entering a river mouth or estuary (see Box 7.2). A sediment slug that formed in an alpine waterway after Victoria's 2003 fires travelled 200 km downstream, and reduced fish abundance by 95–100%. Signs of recovery did not appear until 2 years later (Lyon and O'Connor 2008). 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.

Fire suppression activities also have the potential to harm marine life. Fire retardants contain fertilisers, corrosion inhibitors, ammonia, and chemicals such as per- and poly-fluoroalkyl substances (PFAS). Fish have been shown to avoid areas of fire retardants (Giménez *et al*. 2004), which can also lead to eutrophication and fish kills if applied incorrectly (Kalabokidis 2000). PFAS have been found in Australian fur seals (*Arctocephalus pusillus doriferus*) on Phillip Island, Victoria, and could be responsible for a significant decline in local seal numbers (Taylor *et al*. 2021). Researchers suggest that seal pups likely received the chemicals in gestation or in their mother's milk, while juvenile and adult seals could have accumulated them from the fish, crustaceans, octopus and squid they eat (Taylor *et al*. 2021).

Box 7.2. Potential long-term threats from wildfires in Kangaroo Island waters

Kangaroo Island, 10 km off the South Australian coast, was devastated by the 2019–20 wildfires. More than 200 000 ha or 46% of the island was burnt between December 2019 and February 2020 (National Parks & Wildlife Service South Australia 2020).

Heavy rain began to fall on 1 February 2020, with 55 mm recorded in 1 day, which was the daily record for 2020 (Bureau of Meteorology 2021). Although the rain helped firefighting efforts, it had the potential to severely impact marine ecosystems. Many of the island's estuary systems are not permanently open to the sea, so the water could remain stagnant while being contaminated by sediments and chemicals. Then the forced opening of estuaries as wildfire run-off accumulated within them could cause nearshore turbid plumes and affect estuarine and coastal fish communities.

As soon as it was safe, University of Adelaide scientists began collecting data on water quality, metal contaminants, stable isotopes and fish. Their aims were to:

- estimate the area burnt per catchment;
- evaluate the spatial extent of turbid river plumes washing into the island's coastal areas;
- assess water quality changes due to local fluxes of wildfire-mobilised solutes and sediment run-off; and
- investigate the effects on the composition and abundance of fish species over time (Gillanders and Reis-Santos 2020).

At time of writing, data analysis was continuing. However, detrimental impacts on biota and changes in water quality have been observed, with nutrient enrichment and low dissolved oxygen in several estuarine sites, along with fish die-offs (tens to hundreds of individuals) in the aftermath of the wildfires at Middle River, Harriet River and Stun'Sail Boom, and localised mortality during 2020 (P. Reis-Santos, *pers. comm*).

Like many studies on the marine impacts of wildfires, the Kangaroo Island research was constrained by the lack of pre-fire baseline data on water quality and fish community composition. This makes it difficult to determine if/when water conditions and fish communities will return to pre-fire conditions. Nevertheless, the ability to link sediment run-off, loads and impacts on water quality will be key, and ongoing monitoring critical, in appraising the long-term marine impacts of the 2019–20 wildfires on estuaries and coastal waters. The risk of degraded water remains as wildfire-related sediments are likely to remobilise or enter estuarine systems in future run-off (P. Reis-Santos, *pers. comm.*).

Wildfire smoke settling in estuarine and offshore waters

The smoke generated by wildfires contains ash, nutrients, metals and chemicals that are released into the atmosphere and eventually settle on land, inland waterways, estuaries and distant oceans (Fig. 7.4). For example, smoke from the 2019–20 wildfires was recorded in New Zealand where it had increased atmospheric particles to 150 parts per billion in early December 2019 (normal levels are 60 parts per billion; National Institute of Water and Atmospheric Research 2019).

Haze from wildfires can decrease sunlight and undermine photosynthesis in coral reefs, mangroves and seagrasses (Jaafar and Loh 2014) and lead to a die-off of phytoplankton, a reduction in oxygen and the death of marine life (Murray and Ajani 2020). Moreover, inhaling smoke may be harmful for air-breathing marine animals such as dolphins and whales, which could suffer from lung diseases and a compromised immune system as a result (Basu 2020).

Where nutrients are at naturally high levels, there may be little response from marine life when the particles in wildfire smoke settle in seawater. In contrast, nutrient-deficient waters that receive a significant influx of nutrients can experience algal blooms (Sundarambal *et al*. 2010). This occurred in 1997 off the island of Sumatra, Indonesia, and smothered coral reefs over an area one-quarter the size of the Great Barrier Reef (Abram *et al*. 2003). Offshore algal blooms were also caused by the iron-rich smoke particles from Australia's 2019–20 wildfires, as the next case study (Box 7.3) outlines.

Box 7.3. Wildfire smoke particles cause algal bloom in the South Pacific

While coastal impacts were more visible and relatively better understood, the 2019–20 wildfires also affected marine ecosystems as far as the South Pacific Ocean (Li *et al.* 2021) by releasing iron-rich aerosol plumes into the atmosphere.

The waters of the South Pacific Ocean are limited in their iron content. This restricts the growth of phytoplankton, which require iron for photosynthesis (Boyd *et al.* 2007). The iron-rich smoke particles eventually settled on these iron-limited waters, triggering a strong response by the phytoplankton (Tang *et al.* 2021). An algal bloom appeared around October 2019 and lasted for more than four months (Tang *et al.* 2021).

The bloom in the South Pacific Ocean exceeded the size of the Australian continent, reaching the highest concentrations ever observed by the European Space Agency's Ocean Colour Climate Change Initiative, although its consequences remain unclear (Tang *et al*. 2021). It acted as a sink for the CO_2 emitted by the wildfires, absorbing 680 million t of carbon dioxide: most of the 715 million t released by the wildfires from November 2019 to January 2020 (Tang *et al*. 2021; Lu 2021). However, it could have significantly impacted fish populations by reducing dissolved oxygen in the water as the bloom decomposed, and the carbon sequestration may be only temporary (Lu 2021).

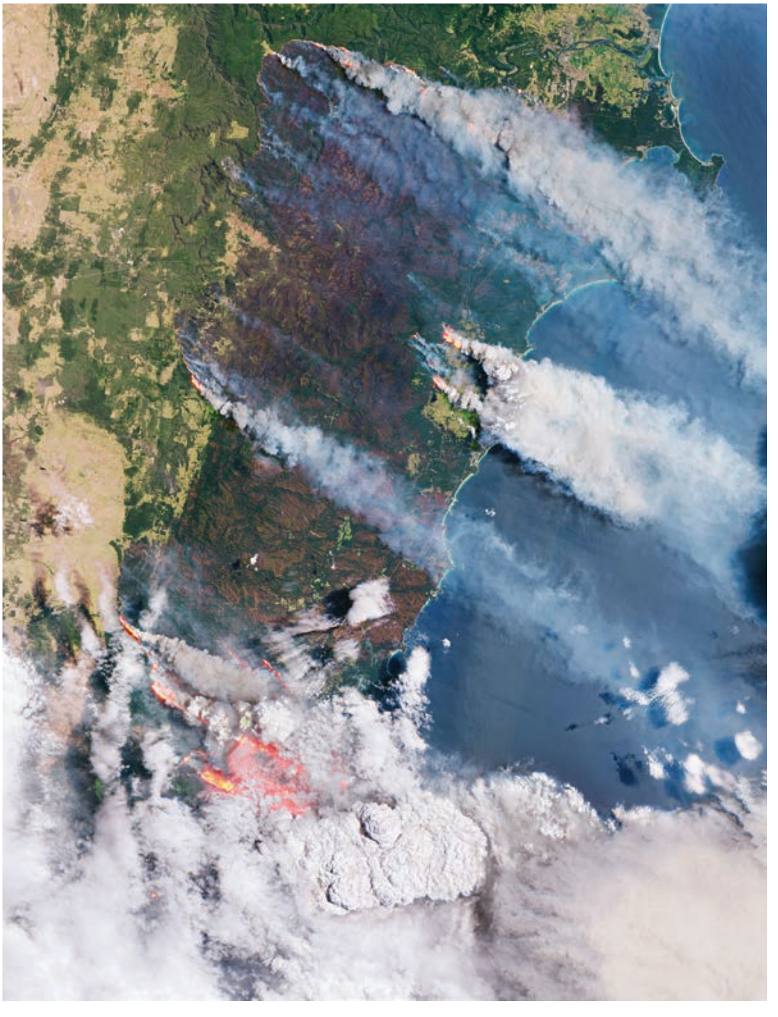


Fig. 7.4. Thick plumes of smoke rise over Batemans Bay on the southern coast of New South Wales, Australia, on 31 December 2019. (Image credit to the European Space Agency. © Contains modified Copernicus Sentinel data (2019), processed by ESA, CC BY-SA 3.0 IGO. Image was cropped from the original: https://www.esa.int/var/esa/storage/images/esa_multimedia/images/2020/01/smoke_and_flames_in_australia/21788537-1-eng-GB/Smoke_and_flames_in_Australia_pillars.jpg)

Conclusions

There are many limitations to the analysis presented in this chapter, mostly due to the very limited information available. As a result, it has sought to synthesise the available knowledge on wildfire impacts on marine species and ecosystems and summarise the post-wildfire issues. Australia's wildfire season is becoming longer, the wildfires are increasing in severity, intensity and frequency, and the impacts on marine species and ecosystems illustrated in this chapter will occur again. Hopefully, the immediate government, scientific and community responses to the wildfires and their impacts will encourage long-term improvement in the way we monitor, manage and conserve marine species and ecosystems. Acting upon the following recommendations will contribute towards mitigating negative impacts to marine ecosystems of future wildfire events.

Recommendations

- Support the establishment and operation of a collaborative, integrated, comprehensive and consistent research and monitoring program for marine environments that include components that build an understanding of wildfire impacts and their mitigation. This should engage government agencies at all levels throughout Australia, citizen scientists and research institutions in a nationally funded program to enable accurate and consistent measurement of environmental change in marine environments.
- Ensure that monitoring programs gathering data on ecosystems and marine species in fire-prone regions support management to include a focus on planning to intervene if wildfire damage to high value marine habitats can be mitigated.
- Establish protected areas that can act as refuges for surviving wildlife in fire-prone locations.
- Ensure that agencies and the natural resource management sector charged with preparing for, assessing and responding to the fire impacts have knowledge of and are sufficiently resourced to include marine ecosystems in their assessments and responses.

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