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Fish Habitat Protection Protocol Against Bushfires

Minister's foreword

Australia is home to a spectacularly diverse range of flora and fauna and our marine environment is no exception, providing habitat for upwards of 33,000 species.

The unprecedented severity of the 2019-20 Black Summer bushfires has had significant impacts not only on our terrestrial landscapes but also these precious aquatic ecosystems, with many downstream coastal environments affected by runoff from ash and land-based pollutants.

The '*Spatial Thinking – Mitigation of Bushfire Impacts on our Marine Environment*' project was established to provide much-needed support for underwater habitat following the fires, as part of the Australian Government's $200 million investment in Bushfire Recovery for Wildlife and Habitat.

Priorities set out under the Australian Government's landmark investment are being informed by scientific and local expertise and many projects, including this initiative, have been carefully co-designed with bushfire-affected communities.

Australians rely on healthy marine environments and the new *Fish Habitat Protection Protocol* combines community and industry knowledge to improve recovery outcomes for underwater habitat, while supporting our coastal regions to plan for a sustainable future.

It is my hope that the protocol will enable further discussions around recovery and empower regional National Resource Management organisations, the seafood industry and coastal communities to implement mitigation strategies that maximise aquatic resilience.

The Hon Sussan Ley MP

Minister for the Environment

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This project was supported by the Australian Government's investment in bushfire recovery for wildlife and their habitats.

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Figure 1. Grey mangroves (*Avicennia marina*) along the Clyde river, NSW, killed by the 2019-20 bushfires. © OceanWatch Australia

Contents

Purpose of this document

This document is the Fish Habitat Protection Protocol (FHPP), which together with the spatial tools is aimed at enabling OceanWatch Australia to work with regional NRM organisations, the seafood industry, and coastal communities to increase the resilience of aquatic ecosystems to the impacts of future bushfire events.

The FHPP is part of the "Spatial Thinking - Mitigation of Bushfire Impacts on our Marine Environment" project, funded by the Australian Government's investment in bushfire recovery for wildlife and their habitats. The Spatial Thinking project focussed on six regions impacted by the 2019-20 bushfires: Kangaroo Island (South Australia), North Tasmania, East Gippsland (Victoria), the North and South Coasts of NSW, and Southeast Queensland (Figure 2). The Fish Habitat Protection Protocol outlines the suggested decision-making process to be followed after a bushfire to mitigate losses of fish habitat assets and complements the spatial mapping tools also produced as part of the "Spatial Thinking" project.

This document also includes the key findings and recommendations from the Spatial Thinking project, collected from workshops and interviews carried out in the six focus regions. These include the research gaps identified throughout this project, and future directions and needs to ensure fish habitat protection.

The 2019-2020 Australian bushfire season

The Australian bushfires that ignited between July 2019 and February 2020 have been exceptionally devastating, burning over ten million hectares[1] and killing an estimated 143 million mammals, 2.46 billion reptiles, 180 million birds, and 51 million frogs[2]. These fires were unique in extent and severity, and they impacted the habitat of already threatened species so intensely that some have seen their habitats shrink by 80%[3]. Over 43 catchments across the country were burnt, and especially since fires were followed by above-average rainfall events, the impacts experienced by these waterways are likely to carry downstream to the coast[4]. Several fish-kills in inland lakes and rivers were recorded by the media, state fisheries and direct field observations[4,5]; however, the full extent of the bushfire impacts on aquatic ecosystems, and particularly on coastal and marine ecosystems, remains understudied.

The processes through which bushfires affect freshwater and marine ecosystems are extremely complex because they are shaped by several variables such as water body characteristics (e.g., flow), soil type and depth surrounding the water body, landscape steepness, wind strength and direction, pre- and post-bushfire rainfall amount, type of surrounding vegetation, the severity of the fire, and the firefighting response[4,6].

Overall, multiple pathways can be activated upon ignition of a large bushfire (Figure 3), and the impacts on coastal and marine ecosystems are dependent on both fires that burnt along the coastline and on inland effects that are carried downstream from headwaters into estuaries. Therefore, not accounting for impacts to all aquatic environments but only to marine and coastal ones would be too reductive.

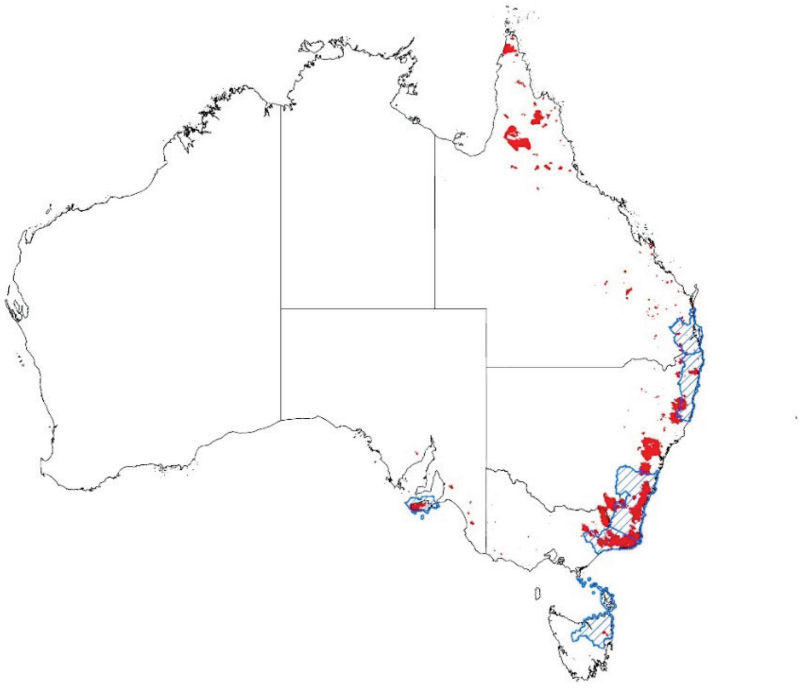

Figure 2. Australian continental boundaries showing States' and Territories' borders, with areas burnt by the 2019-2020 bushfires are shown in red. The focus regions are shown within the dashed blue boundaries. The focus regions are clipped from the Natural Resource Management regions dataset 2020 (Commonwealth of Australia: Department of Agriculture, Water and the Environment, CC BY 4.0), and the black summer bushfire boundaries are taken from the 2020 National Operational Bushfire Boundaries dataset (EMSINA and Geoscience Australia, CC BY 4.0).

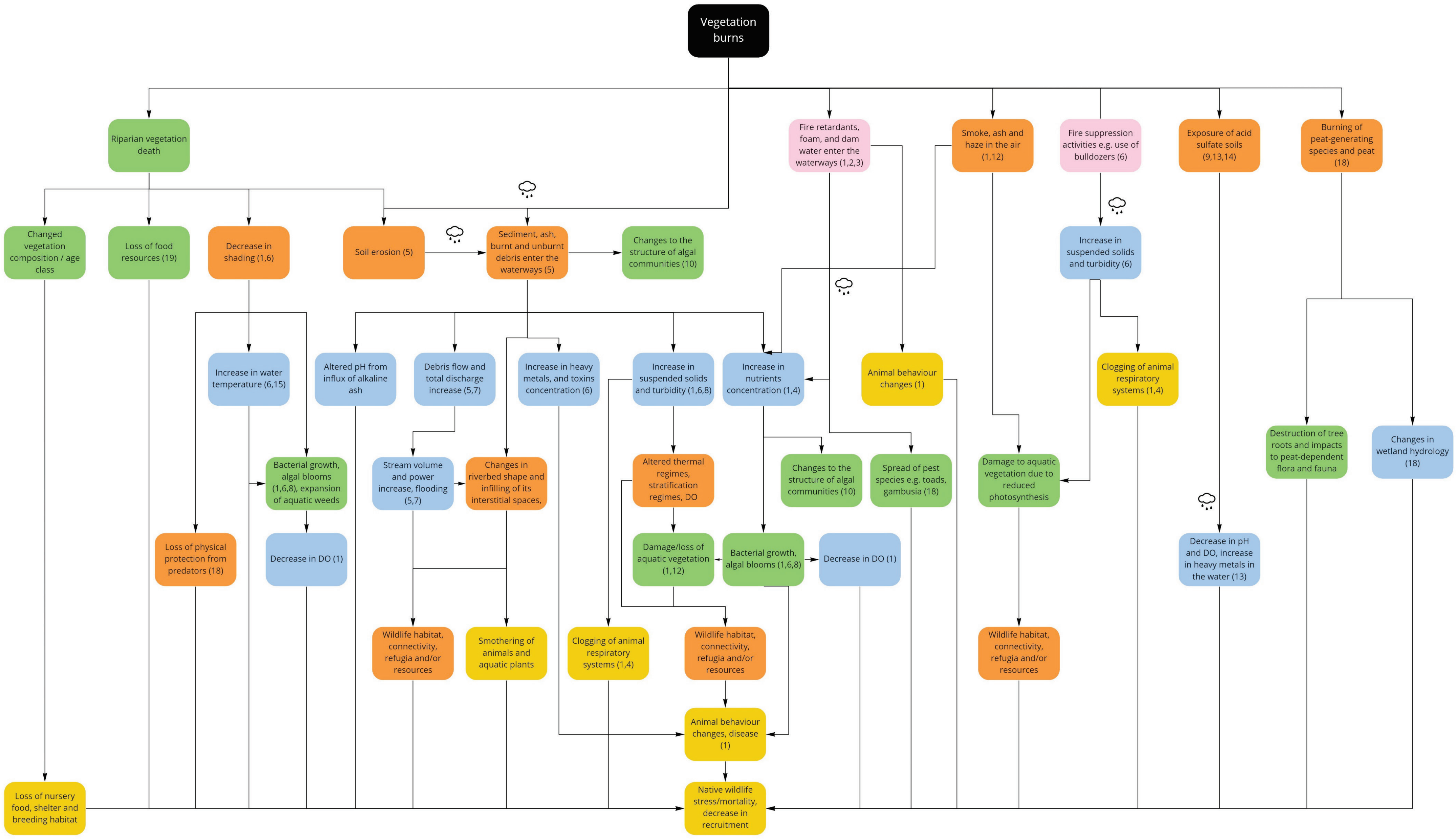

Figure 3. Process map of potential negative effects of bushfires on marine environments.

Figure 3 references

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Figure 4. Esk River, New South Wales © OceanWatch Australia

The Fish Habitat Protection Protocol

The Fish Habitat Protection Protocol (FHPP) is a decision-making process based on the potential negative outcomes for fish (and generally, aquatic flora and fauna) on the process map (Figure 3). Since the FHPP aims at being as broadly applicable as possible in an Australian context, local conditions will ultimately determine whether the measures and techniques suggested are relevant, applicable, and/or effective.

Emergency management can be broken down into four phases (Figure 5), which can be broadly placed into pre-fire management (mitigation and Preparation), and during/post-fire management (response and recovery) – themselves split into short-term and long-term adaptive management.

- The **mitigation** (or **prevention**) phase includes actions taken to prevent or reduce the cause, impact, and consequences of disasters[7].
- **Preparation** instead includes planning, training, and educational activities for events that cannot be mitigated[7].
- The **response** phase occurs in the immediate aftermath of a disaster. Environmental safety during the bushfire, and the duration of the response phase, depending on the level of Preparation[7].
- During the **recovery** period, restoration efforts occur concurrently with regular operations and activities. The recovery period from a disaster can be prolonged[7], and it can include steps that reduce vulnerability to future disasters.

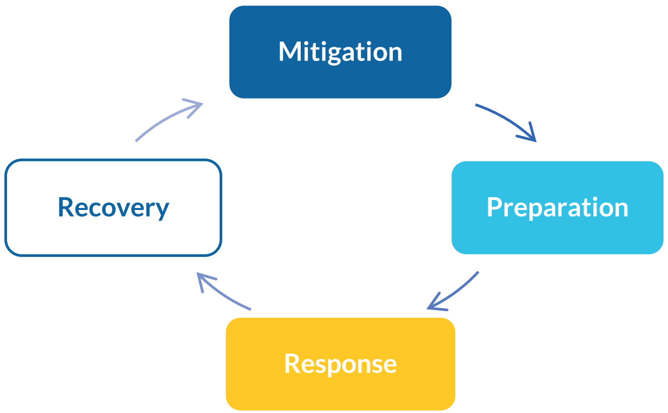

Figure 5. The four phases of emergency management. All vulnerable communities should be in at least one phase of emergency management at any time (modified from FEMA[7]).

Generally, management actions to reduce bushfire risk to aquatic environments fall within five categories:

1. Fuel treatment/removal
2. Fire suppression
3. Post-fire soil stabilization
4. In-water and/or riparian habitat restoration
5. Hillslope restoration[8].

Fuel treatment arguably falls within the mitigation step, fire suppression occurs during the bushfire, post-fire soil stabilisation is part of the short-term response step, while habitat and hillslope restoration can be considered part of the long-term recovery phase (that also acts as mitigation for future bushfire events). The effectiveness of these actions is usually (but not always) evaluated for the specific goal of the action locally (e.g., reduction in the amount of sediment following post-fire sediment control); however, their long-term effectiveness in increasing resilience of ecosystems and protecting wildlife populations is much less clear – due to the influence of so many variables[8]. Because of this, no single approach is likely to be enough to guarantee fish protection and persistence in any fire-affected location. Analysing the reliability and effectiveness of management actions is therefore critical to determine what is most appropriate to do where[8].

In this document, we discuss the application of the phases of emergency management that are relevant to post-bushfire action, focussing on the pathways identified in the bushfires process map (Figure 3). Each pathway is isolated and analysed, and elements of emergency management are explored. The pathway numbering is not indicative of any ranking, or representative of a timeline.

Moreover, several pathways have causative processes or outcomes in common, therefore there is an inherent limitation when looking at each of them separately. Nevertheless, we considered it worthwhile to analyse each process individually, to isolate and discuss their specific attributes. In some cases, not all emergency management steps are discussed, either because there is no scientifically sound advice to inform that step yet as far as we are aware, or because there is no technique currently developed to address it. This field is constantly and rapidly evolving; therefore, it is a hope, and not a shortcoming, that this document will need updating soon.

Bushfire effects on fish

Bushfires and fish have a complex relationship, which has formed over millions of years of co-evolution[8]. Fires can have several consequences to fish, including significant short-term negative consequences to local populations such as local extinctions, as well as long-term positive outcomes such as an increase in habitat complexity, productivity and overall quality (Figure 6)[8,9]. While bushfires can be destructive, interfering with recovery dynamics and even with the role of fire can also have detrimental effects[8], therefore it is important to discuss how do native fish respond to fire and what are the factors that a natural resource manager needs to consider before designing a recovery plan.

Bushfires can be considered a natural disturbance, and they need to be studied in the context of the evolutionary history of the species of interest[9]. Disturbance is a fundamental characteristic of aquatic ecosystems, and therefore many species are adapted to a level of it, and even benefit from it, despite its short-term risks to populations[9]. The immediate outcomes of fire are usually harmful to individuals or local populations, due to increases in water temperatures, decreases in water quality, and habitat destruction that can lead to fish kills, which were recorded in several catchments hit by the 2019-2020 Australian bushfires[4]. Small streams are usually more affected by debris flows compared to larger ones.

Because of this, migratory fish that spend most of their time in large rivers or the oceans are less likely to be impacted by post-fire impacts compared to fish that reside in smaller streams[8]. However, in a well-connected system, fish in affected areas can also migrate to areas that are less affected[8]. Moreover, the more interconnected streams are, and the greater the stream network complexity, the more resilient local populations can be to violent post-bushfire impacts[8,9]. Indeed, large and well-connected systems appear to be more resilient because it is unlikely that all the systems would be affected all at the same time and level, therefore allowing fish from less affected areas to recolonise the affected areas once habitats have recovered[9].

It is important to consider species-specific characteristics, with generalist fish likely being more resilient than range-restricted, resident specialists (Figure 8), and unfortunately, information on species-specific responses of native fish to bushfire consequences is often lacking[9]. Several freshwater Australian fish, such as Galaxia spp., occur in small and isolated populations already threatened by a mix of factors, therefore it is likely that they would not be resilient to the impacts of a severe bushfire and may go extinct following one[11,12].

Indeed, a key factor to consider is that several disturbances can be at play at once in a particular area before/after bushfires, many of which of human origin including certain land management practices, roads, water diversion and management, introduced species, and climate change – many of which contribute to habitat quality decrease and fragmentation[8] (Figure 7). Therefore, any of these other disturbances can exacerbate any negative bushfire impacts and decrease local fish populations' resilience to them.

After the 2019-2020 bushfires, 16 species of freshwater fish, 22 crayfish and several other freshwater invertebrate species (e.g., freshwater mussels, shrimps) were listed as priority species in need of urgent management intervention[10]. This listing was done because their aquatic habitats were severely degraded by debris[10].

Figure 6. Burnt woody debris enriching the complexity of Rocky Creek in Nightcap National Park, NSW. © OceanWatch Australia

Figure 7. Before the 2019-20 fires this shoreline of Conjola Lake, NSW, was characterised by healthy seagrass, now smothered and covered by sand and sediment. © OceanWatch Australia

Because of the complexities of fish responses to bushfires, it is not possible to suggest specific management practices that will always work, everywhere. Moreover, most research has been done in freshwater environments, therefore the understanding of this topic from a marine perspective is very limited. However, as a general consideration, pre-fire management should include addressing all the ecosystem-level threats to bushfire resilience, including habitat loss, degradation, and fragmentation, to maximise the resilience of fish species to bushfires. If a bushfire is burning and it has been decided to suppress it, firefighters need to be aware that firefighting techniques such as retardants, the construction of fire breaks and roads can also have detrimental effects on aquatic habitats. Once a bushfire has (been) extinguished, several post-fire rehabilitation and management actions can be taken, which we will discuss further in this document. However, it is important to remember that the effects of many of these treatments are poorly understood from long-term and large-scale perspectives, due to a lack of comprehensive monitoring information[9]. Finally, it is critical to consider the ecology of local fish species and their additional threats to assess their level of resilience to post-bushfire events to inform any management action aimed at their recovery.

Figure 8. Tianjara Crayfish, focus of bushfire recovery efforts © OceanWatch Australia

Overall recommendations

These recommendations have been developed following workshops or interviews with key members of local organisations in the six focus regions. These members include fire authorities, NRM regional managers, scientists, indigenous organisations, and National Park rangers. Therefore, we thank and acknowledge all of those who have contributed and participated in this project.

Mitigation

- Assess local fish habitat and ensure a good level of **connectivity** amongst patches and refugia. Increase **habitat quality** as much as possible to increase the **resilience** of local wildlife to post-bushfire events and minimise the need to intervene.
- Develop ongoing and **fine-scale mapping** of **cultural, ecological, and economic assets** ensuring that aquatic assets are included to the same standard as land assets and a value framework for active on-ground intervention prioritisation.
- Develop ongoing and **fine-scale mapping** of **threatening processes** kickstarted by bushfires and which may result in impacts to aquatic habitat and wildlife[5].
- Wherever absent, develop readily available **mapping tools** that inform **aerial firefighters** about areas where not to drop retardants or saltwater.
- Set up **uniform and ongoing** indicator species and water quality **monitoring protocols** and/or stations across the country, to build comparable datasets.
- **Fuel load reduction** paired with **ecological assessment** of the impact of the burn, to develop best practices tailored to local aquatic ecosystems following an adaptive management technique that accounts for climate change by state-based fire agencies.
- For higher value assets, implement **finer-scale interventions** to minimise bushfire risk/consequences (e.g., hand removal of highly flammable species).
- **Identify the staff/department/team** who will **deal with bushfire impacts** to aquatic assets (ideally trained in aquatic and fire ecology), to avoid aquatic environments not being protected as much as others.
- Run **public workshops** around the **bushfire emergency management structure**, for key parties to better understand roles, responsibilities, and contacts for assistance.
- Reduce or modify activities that reduce **aquatic resilience** to bushfires, such as coastal development and agriculture[5].
- Build a **community of practice** directory for people in the bushfire management space with aquatic expertise.
- Support **communications and networking** events to increase capacity within the bushfire recovery sector with a focus on aquatic environments.
- Include **indigenous approaches** and practices into the design of fire management plans as much as possible.
- **Increase resources** available to NRM regions and governmental organisations to do **monitoring** work and making the data publicly available.

Preparation

- Bring impacts to aquatic to the **forefront of bushfire research.**
- Develop an official **protocol of prioritisation** for aquatic asset protection.
- Increase **collaboration** between NRM organisations and Fire Services in bushfire risk assessment and response.
- Develop **inter-state relationships** to share learnings and experiences from past bushfires.
- Run/increase **ecological training workshops** for firefighting teams.
- Run practical workshops providing guidance on **best practices** for private and public land managers about **bushfire and mitigation of impacts** to aquatic environments, as well as who to contact for help and advice.
- **Map, assess and rank aquatic assets** linked to threatened species and commercial fishery resources.
- Develop **disaster preparation plans** at a business level for aquaculture and commercial fishing operations for what to do, where to go, or who to call for help in a disaster[5].
- **Quantify species seed stock vulnerability** for various levels of fire intensity.
- Identify **possible fishing and aquaculture business vulnerabilities** to bushfires and look for means to address them. E.g., logistics of product-to-market, stock movement, a continuation of operations, harvest zone water quality testing.
- Increase research funding to develop a better understanding of fire management regimes, with a focus on but not restricted to riparian vegetation.
- Ensure that **enough funding** is provided and/or set aside for **management activities** that include post-bushfire aquatic monitoring and recovery.
- Establish a **network of protected areas** that can act as refuges when waterways and coastal waters are impacted by bushfires[5].
- Plan how to **enforce regulations** in times of disastrous bushfires at a local government level.
- **Update legislation** to allow for local government to be able to work in the fire management space when it has the capacity to.
- Improve the **consideration** that aquatic environments have during bushfire operations.
- Develop/review **rapid assessment protocols** for aquatic environments.
- Use the **process map** (Figure 3) internally to **NRM organisations** to overlay with people responsible for each system
- Expand the **process map** (Figure 3) to include **positive impacts** of bushfires.
- Develop/review **best practices on sedimentation management** (test the efficacy of traditional approaches e.g., coir log and blankets for topography and sediment loads).
- **Quantify** processes represented in the **process map** (Figure 3) , so that it can be more useful for modelling future events.
- Develop methods to **quantify** the number of **marine resources lost** and their economic value.

Response

- Ensure that **staff with aquatic ecology knowledge** are present within **fire control agencies**, particularly with an understanding of impacts and techniques, and the authority to play an active role in advising a firefighting strategy based on aquatic asset location and ranking.
- Conduct **rapid assessment surveys** of impacts, including mapping the fire extent and severity as it progresses to determine and predict losses and necessary interventions in aquatic environments[5].
- Conduct management actions to **protect** aquatic wildlife and habitat **before it is impacted** (e.g., backburning to protect high-value assets).
- Give selected **ecologists** (or fire services staff with ecological training) the **authority to conduct rapid assessments** as soon as possible following response operations.
- Deploy a **survey** to capture observations from the public at short notice and limited cost to inform prioritization of resource implementation.

Figure 9. Consultation at the CFS Station in Parndana, Kangaroo Island.

Recovery

- Assess and identify **habitats and species worse impacted** by the bushfire event.
- Develop **models** that can **predict where the worse runoff issues** will be experienced, to inform recovery action, with the need to possibly plan land vehicle access.
- Implement the **prioritisation ranking scheme** developed in the 'Preparation' phase to guide recovery action.
- Follow the **process map** (Figure 3) to evaluate what processes may be kickstarted by the bushfire in local areas of interest.
- Quickly and readily **support financially and promote monitoring and recovery efforts** that are inclusive of aquatic habitats and wildlife, as well as substitute any monitoring equipment damaged by the bushfires to continue long-term monitoring efforts into the future.

We also acknowledge all recommendations listed in the "impacts of bushfires on coastal and marine environments" report[5].

See **APPENDIX 1** for relevance assessment of these recommendations to key organisations.

Pathway 1 – impacts on riparian vegetation

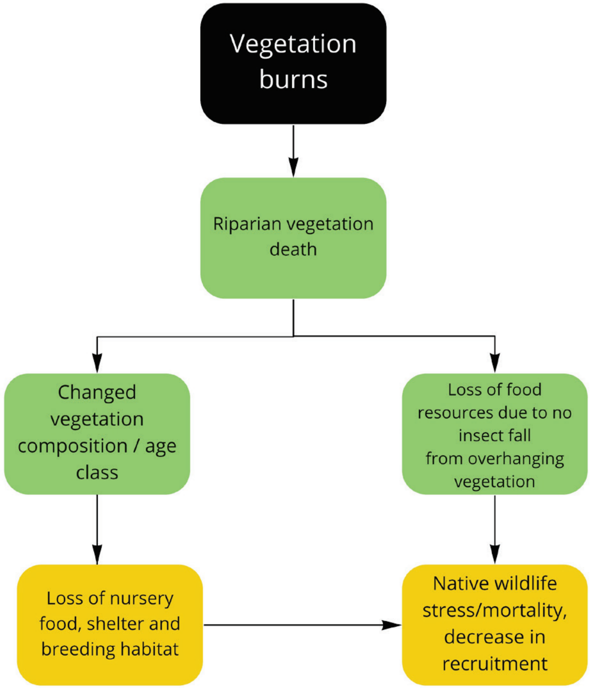

Figure 10. Mangroves burned to death or affected by radiant heat in Batemans Bay, NSW. © OceanWatch Australia

Description

Vegetation growing in the riparian zone (the land along watercourses and water bodies) is extremely important for several reasons, including nutrient cycling, water cycling, and supporting diverse wildlife populations[13,14]. The effects of fire on riparian vegetations can be extremely variable[14], usually dependent on several factors such as fire frequency and intensity, the width of the riparian zone, the degree of fire resistance of local vegetation, and climatic pre-conditions such as droughts[14,15]. While bushfires are generally less frequent in riparian zones compared to nearby upland, however when they occur they have extensive ecological consequences[15]. Despite its inherent ability to withstand a dynamic environment with high levels of disturbance, after a bushfire riparian vegetation can suffer great damages. This impact may eventually cause a drastic change in the composition or destruction of local vegetation communities, and render this zone ineffective at controlling erosion and filtering water before it enters rivers and coastal areas. Bushfires may affect riparian species selectively, with more sensitive species disappearing from affected communities, and the burning of riparian canopy may lead to faster growth of grasses, increasing fuel loads[15]. Moreover, riparian areas can act as fire breaks due to their higher moisture content; however, in very dry conditions they may do the opposite and help a fire spread[15]. It is however important to also consider that bushfires, particularly in headwater streams, can provide nutrients, sediment, plant propagules, and deliver wood debris downstream, which constitute an important ecological asset[15].

As in the case of mangroves affected by fire (Figures 10, 11), the death of riparian vegetation may have short and long-term impacts on fish and other aquatic wildlife that rely on them[16]. Estuarine habitats such as mangroves, sea grass and saltmarsh are extremely important for fish and other aquatic species. For example, mangroves are critical breeding grounds and are a source of shelter and food for wildlife[17], including species important to the fishing industry such as molluscs, prawns, crabs, and barramundi[18], and fish productivity tends to increase with an increase in total area of mangroves[17]. The burning of these estuarine habitats can lead to significant effects on abundance and diversity of local populations[19]. Finally, "*mangroves, saltmarsh and seagrasses capture and store large quantities of carbon both in plants and in the sediment below ('blue carbon'). Australia's coastal wetland ecosystems capture carbon on a per hectare basis at rates of up to 66 times higher and store 5 times more carbon in their soils than those of terrestrial ecosystems such as forests*"[18].

Pathway 1 – impacts on riparian vegetation

Before the fire

MITIGATION

- Avoid high intensity and frequent burning in riparian zones and during sensitive times for in-stream species (e.g., spawning periods)[20].
- Cultural burning/fuel reduction following ecological advice, with monitoring post-burn particularly when the burn occurs in/near-threatened species habitat, in areas near the riparian zone. Manage fire regime according to aspect, location, and climatic conditions[15].
- Long-term weed management
- Limit stock access
- Avoidance of tree removal/harvesting from the riparian zone, to avoid the creation of canopy gaps which in turn allows for faster drying of fuel loads on the ground[15]
- Establishment of access points at strategic locations within the riparian land for fire suppression agencies, particularly to access reliable watering supplies for fire-fighting tankers[21]
- Seed banking where necessary, particularly fire-sensitive threatened species
- Removal of woody debris that has accumulated in the riparian zone from flood events[15]

PREPARATION

- Ensure that firefighting procedures account for sensitive riparian areas and that these areas are flagged as a no-retardant drop, no-foam area

During/after the fire

RESPONSE

- Survey to assess losses
- Exercise of prioritisation of species and areas of higher ecological value
- Establish erosion control measures to trap sediment that would have otherwise been trapped by the burnt vegetation

RECOVERY

Short-term

- Monitor natural recovery
- Replanting if natural seed bank destroyed
- Weeding to allow natives to recover
- Survey for invasive herbivores, and control where necessary
- Limit the impact of heavy rainfalls post-fires where possible by installing sediment control structures, as flooding can increase stream bank erosion and damages recovering vegetation[15]
- Monitor the health of aquatic animals who may suffer from a lack of food and habitat

Long-term

- Limit stock access
- Increase our understanding of the effects of bushfires on riparian vegetation composition, and interactions with stream size, gradient, and climatic variables, to tailor management to local characteristics
- Monitor the recovery of the riparian zone and of aquatic animals relying on its health

Figure 11. Mangroves dead due to heat stress, Batemans Bay NSW. © OceanWatch Australia

Pathway 2 – impacts of peat fires

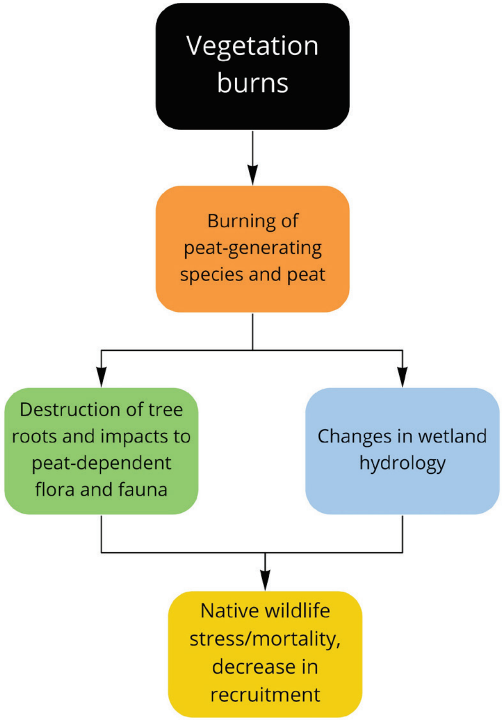

Figure 12. Effects of a peat fire in Ngunya Jargoon IPA, NSW. © OceanWatch Australia

Description

A peatland is a type of wetland with a naturally accumulated peat layer in the soil and dominated by living peat-forming plants. Local water-logged conditions slow the decomposition of organic material (e.g., moss) and turn it into peat[22]. There are many kinds of peatlands creating a variety of landscapes, which are a very important global carbon store[22]. Generally, peatlands are not common in Australia, have unique characteristics compared to peatlands in the rest of the world, and support great numbers of aquatic and semi-aquatic wildlife like crayfish, frogs, and numerous plant species[23,24]. During the 2019-2020 bushfires, peatlands in Australia were affected severely, with records of endangered ecological communities such as the temperate highland peat swamps on sandstone in the NSW Blue Mountains burning at an unprecedented scale and intensity, altering critical structural and functional attributes[25]. These fires had severe consequences on local wildlife relying on these peatlands[25].

Peat is rich in carbon and porous, therefore once dry it is highly flammable[26]. Peat fires are extremely challenging to extinguish, and they can smoulder for several months underground damaging root systems (Figures 12, 13), and then flare up overground[26,27].

Relatively undisturbed peatlands can be resilient to bushfires, retaining most of their peat and plant species as long as they have adequate time for recovering their vegetation cover and diversity in between fires, and if the intensity of the fire is low[28]. High intensity and frequency of fire are likely to damage underground peat layers and overground vegetation cover – which can result in hydrological changes and increase the likelihood of establishment of invasive species[29]. After a severe burn, like the 2019-2020 one in the Blue Mountains, vegetation and peat-forming processes, hydro-physical and carbon storage properties may take years to centuries to recover[25].

Pathway 2 – impacts of peat fires

Before the fire

MITIGATION

- Map and document peatlands around Australia, their properties, and their characteristics
- Survey aquatic wildlife that lives in the peatland and assess their sensitivity to fire

PREPARATION

- Ensure that firefighters are aware of the dangers and challenges of fighting a fire in peatlands which can be very boggy and produce dangerous levels of smoke

During/after the fire

RESPONSE

- Isolate or extinguish the fire so that smouldering fire does not travel underground and flare up into nearby unburnt areas

RECOVERY

Short-term

- Monitor natural recovery
- Accelerate natural plant recovery where necessary, using techniques such as transplanting, shading and fertilising[30]
- Control access of feral animals to fire-affected peatlands, to avoid further damage

Long-term

- Monitor use of groundwater and ensure levels are high enough to keep the peatland hydrated
- Decrease other threats to peatlands, such as domestic stock grazing and trampling, invasive species (e.g., deer, pigs), and human development[29]

Figure 13. Effects of a peat fire in Ngunya Jargoon IPA, NSW.
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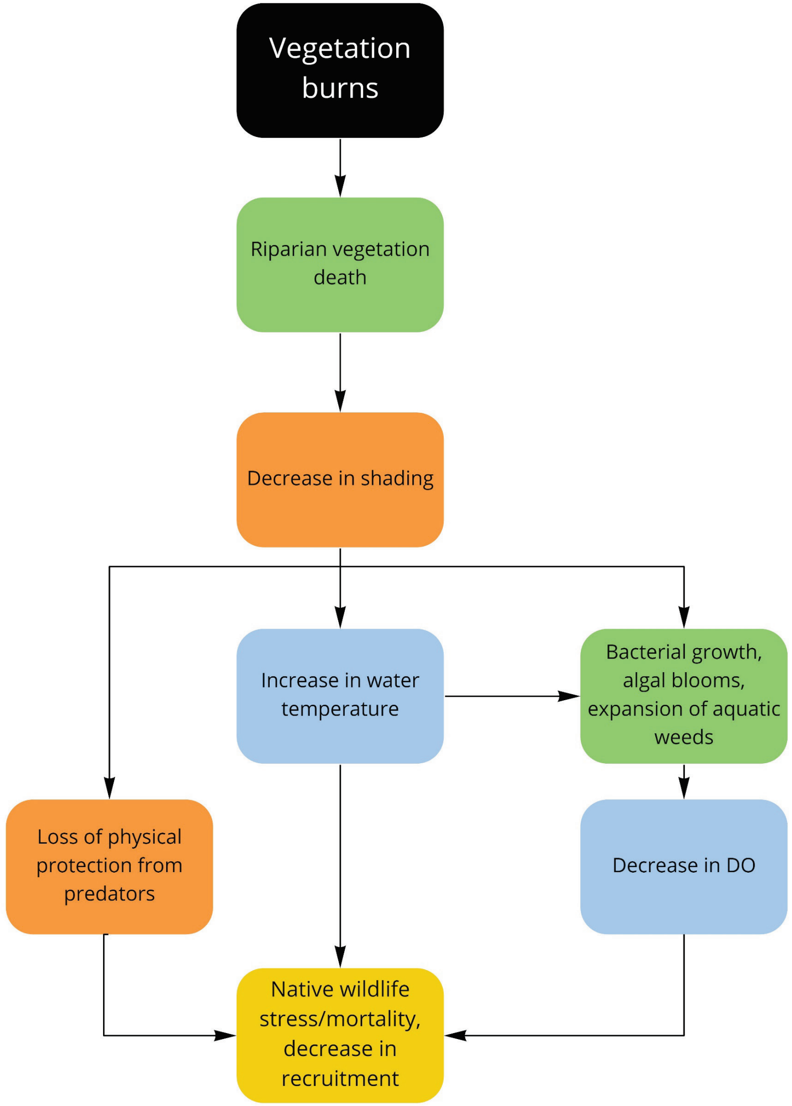
Pathway 3 – impacts of decreases in shading



Pathway 3 – impacts of decreases in shading

Description

Since vegetation provides stream shading, increased light penetration following removal of this cover may cause stream temperatures to rise and the balance of primary producers within the stream to change[31,32]. In-stream temperatures due to bushfires can increase by 2.5–10 °C for maximum temperatures, and these changes depend on the size of the stream and how much canopy was removed by the fire[8]. The lack of canopy cover and increased light penetration have been reported to increase algal growth in streams after fire[33] and reduce the amount of direct leaf and insect fall to streams[34].

Recovery of water temperatures following fires can take years to decades (Figure 14); however, this is crucial for aquatic wildlife[8]. Much aquatic fauna is cold-blooded (e.g., fish, crustaceans), therefore ambient temperature has an important role in influencing their metabolism – which in turn determines how much food they need and how quickly they develop[8]. Moreover, water temperatures can determine spawning and hatching timing, a change that can negatively impact populations[8]. Finally, different species have different thermal ranges they can survive at, which means that temperatures too high can be deadly[8].

Figure 14. Tree canopy slowly recovering from bushfires, Moreton National Park, NSW. © OceanWatch Australia

+ 0.5 – 4 °C
MEAN STREAM TEMPERATURES

+ 2.5 – 10 °C
MAX STREAM TEMPERATURES[8]

Before the fire

MITIGATION

- Establish temperature thresholds of cold-water specialists, threatened and range-restricted species
- Deploy loggers to monitor water temperature long-term
- Translocation of animal populations threatened by bushfire if known to be temperature sensitive
- Help increase in-stream water presence by restricting water extraction
- Ensure adequate amounts of refugia present in the system

PREPARATION

- Design action plans for the eventuality of water temperature rising in sensitive and high-value waterways

During/after the fire

RESPONSE

- Assess as quickly as possible the damage to aquatic habitats. Establish the extent of the damage and whether post-bushfire translocations are needed.

RECOVERY

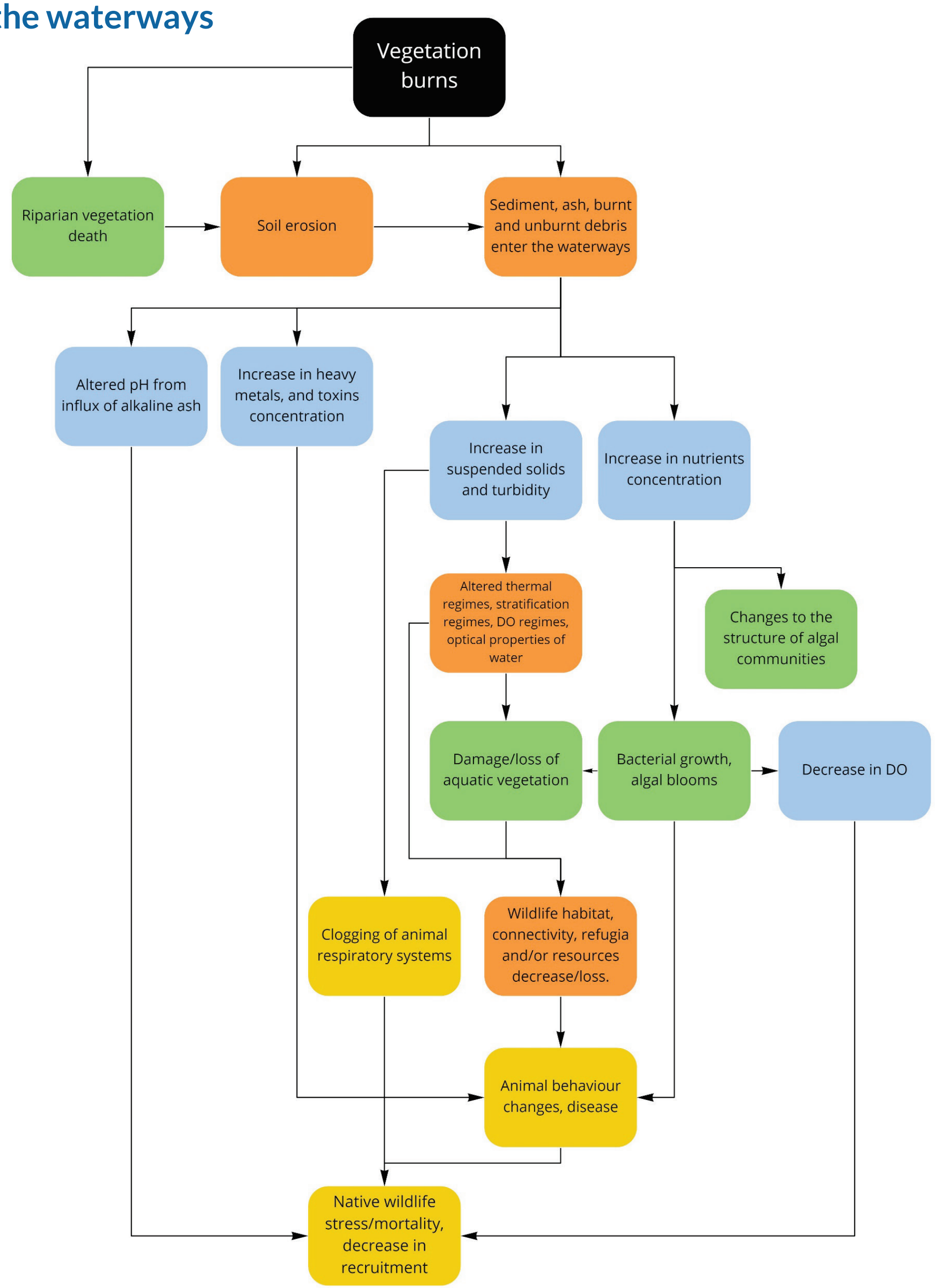
Short-term

- Monitor natural recovery
- Survey wildlife populations in the affected areas and establish their numbers and health
- Habitat restoration activities such as creating refugia and restoring connectivity of streams and estuaries

Long-term

- Habitat restoration action such as re-planting riparian vegetation that will provide shading and temperature mitigation[20]
- Increase protection and improve management of riparian zones in key asset areas

Pathway 4 – impacts of soil erosion and debris entering the waterways



Description

Steep channel processes and hillslope erosion are the bushfire outcomes that perhaps receive the most attention and are mostly studied, particularly in the short-term and small-scale[8]. Bushfires burn vegetation and alter soil properties (e.g., making the soil more hydrophobic), increasing surface erosion[8]. Forested areas within a watershed and streamside vegetation reduce the amount of runoff, sediment and associated contaminants reaching a stream by holding sediment in place[35,36]. By destroying vegetation, bushfires expose forest soils to rain, wind, gravity and the Sun, and increases soil hydro-repellence – and all of this can result in more sediment being delivered to streams[37] (Figure 15). Riparian vegetation is also important for stabilising channel banks and thus its removal promotes scour erosion within the channels. Sediment yields post-fire can be over 1000 times higher than the unburnt annual averages[34]. The magnitude of impacts from suspended sediment in the water is highly variable, depending on the interaction of a wide range of factors, including post-fire rainfall intensity, topography (slope and hillslope length), land use and management (e.g., timber harvest), fire extent and severity, soil erodibility[34,37]. Because of this, it can be challenging to predict the consequences of bushfires on erosion; however, it is possible to identify localities that would be more prone to it or quantify it after the event[38].

Erosion and sedimentation have wide-ranging impacts from water quality to stream and estuary morphology changes. Significant debris flows can severely damage aquatic habitats, up to the point of extirpating impacted wildlife populations (e.g., by smothering animals and plants, clogging gills), simplifying local habitats (e.g., filling in gaps and crevices), and changing water flow rates leading to an increase in flooding[8]. Rises in sediment loads in coastal watersheds lead to increases also in coastal waters, increasing turbidity and limiting light penetration into the water affecting photosynthetic and photosymbiotic organisms (e.g., corals)[6]. In a marine environment, high suspended sediments are linked to an alteration of community composition and an effect on coral growth and recruitment[6]. The increase in sediment loads post-bushfires in waterways and eventually coastal areas can also lead to events of eutrophication, particularly in nutrient-depleted shallow coastal waters with insufficient tidal flushing[6]. However, the same kind of events can turn out to be beneficial by adding habitat complexity through depositing rocks, gravel and woody debris to aquatic habitats, and transporting necessary nutrients[8].

Pathway 4 – impacts of soil erosion and debris entering the waterways

It is therefore important to understand how aquatic wildlife populations respond to and/or recover from these restructuring events to be able to evaluate the need, scope, and timing of management interventions. It is also valuable to mention that debris flows into areas that are important for fishing and aquaculture operations can cause costly damage to gear and vessels.

Options of management interventions can be divided into hillslope treatments, channel treatments and road/trail treatments[39]. Hillslope treatments include erosion barrier treatments (e.g., erosion control mats, log barriers, fibre/straw rolls or coir logs, silt fences), which can be made from natural or man-made materials and are very well-established methods to control erosion. Hillslope treatments also include cover applications, such as dry or wet mulch, slash spreading, seeding, and soil scarification (with seeding)[39]. These treatments are generally designed to slow the flow of runoff and store the soil locally, increasing infiltration and ponding, and reducing sedimentation and turbidity downstream[37]. Channel treatments are in-water interventions designed for different purposes, including trapping silt, debris and sediment, attenuate flows, stabilise streams and their banks to avoid further damage[39]. These include dams, tree felling in-stream, bank armouring, grade stabilisers, debris basins and channel deflectors[39]. Finally, road and trail treatments are interventions aimed at reducing erosion of roads and trails, preventing a concentration of water flow on them (which would ruin the road surface), as well as preventing stream diversion[39]. These interventions include out sloping, overflow structures, debris deflectors and culvert modifications[39]. Usually, in-channel and road/trail treatments work more effectively when paired with hillslope treatments[39].

Figure 15. Tree canopy slowly recovering from bushfires, Moreton National Park, NSW. © OceanWatch Australia

Before the fire

MITIGATION

- Invest in R&D in this space, particularly with the focus of developing techniques that rely solely on the use of natural and biodegradable materials at appropriate scales.
- Assess local fish habitat and ensure a good level of connectivity amongst patches and refugia. Increase habitat quality as much as possible to increase the resilience of local wildlife to post-bushfire events.
- Precise terrain and soil properties mapping to identify areas most prone to erosion. Pair this modelling with fire proneness of areas of interest.
- Evaluate the construction of permanent barriers to control flooding and debris flows areas of interest (e.g., near the habitat of endangered and specialist fish)
- Reinforce fencing
- Create guidelines and best practices for erosion control at the local level, including costing and negative consequences of using each technique

PREPARATION

- Train teams of bush regenerators and natural resource managers in erosion control techniques. Ensure adequate supplies can be obtained in the event of isolation following fire
- Design a post-bushfire plan based on the effectiveness of each technique, considering that some events are difficult or impossible to control and are likely to overwhelm most treatments

During/after the fire

RESPONSE

- Debris flow mapping to evaluate the impact and prioritise locations for recovery action
- Implement a post-bushfire erosion control plan designed during the Preparation phase
- Evaluate the need for restoration efforts and implement a prioritisation scheme to allocate post-disaster funds in the most effective way

RECOVERY

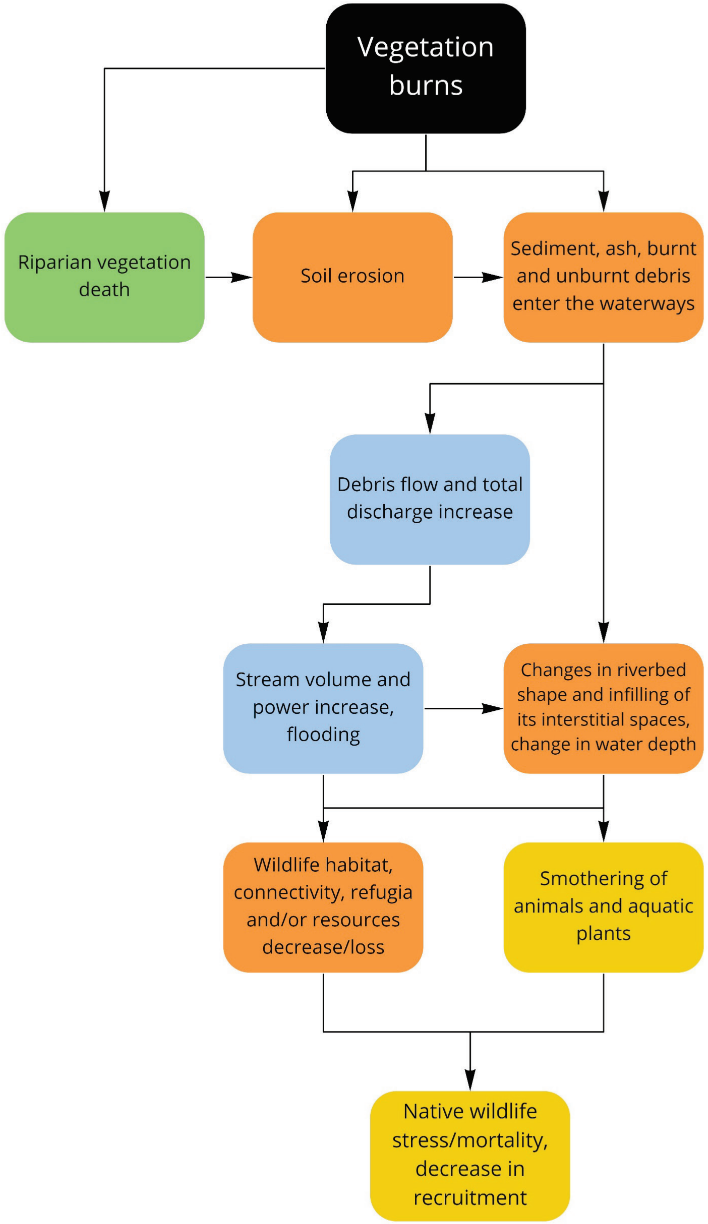
Short-term

- Monitor natural recovery
- If intervention is needed, implement habitat restoration techniques and potential wildlife translocation to better habitats

Long-term

- Restore/increase and protect fish habitat size, complexity, and connectivity

Pathway 5 – impacts of erosion and debris on stream beds and banks



Description

Bushfires can significantly alter soil properties, such as increasing water repellence. For example, this can happen if a bushfire erodes the soil exposing a deeper, water repellent layer[40]. This alteration can result in the same amount of rain pre-fire leading to greater in-stream flows after the bushfire, causing an increase in stream volume, changes in riverbed shape, and increases in water discharge. These changes come with consequences to water quality parameters such as increased turbidity and decreases in salinity of downstream estuaries. Some of the management techniques have already been mentioned in this document as they are also relevant to erosion control, specifically the in-channel treatments. These include building dams with rocks, straw, or logs, aimed at preventing/reducing downcutting (i.e., deepening the channel of a stream by removing material from the stream's bed) and attenuating water flow. Introducing grade stabilisers (i.e., structures made of plant materials, rocks, or timber) can also be an effective way of preventing channel incising and downcutting. Grade stabilisers are "*a permanent structure used to drop water from a higher elevation to a lower elevation, (...) used to reduce or prevent excessive erosion by reducing velocities in a watercourse or by providing channel linings or structures that can withstand high velocities*"[41]. Materials used to build grade stabilisers include concrete, metal, rocks, timber, or other suitable plant material[39]. Stream bank armouring with rocks, plants or other materials can be used to reduce bank erosion and therefore changes in stream shape and direction[39].

Figure 16. Aerial view of Snowy River National Park after bushfires. Photo by Greg Brave, Shutterstock.

Pathway 5 – impacts of erosion and debris on stream beds and banks

Before the fire

MITIGATION

• Assess the bank integrity of streams and rivers, particularly those of high ecological or cultural value, and carry out any reinforcements needed to increase their structural resilience
• Design a stream flow model that pairs with soil erodibility estimates to determine the likelihood of banks and stream beds being affected by post-bushfire rainfalls

PREPARATION

• Train teams of bush regenerators and natural resource managers in stream bank reinforcement and erosion control techniques

During/after the fire

RESPONSE

• Debris flow mapping and field work to evaluate the impact and prioritise locations for recovery action

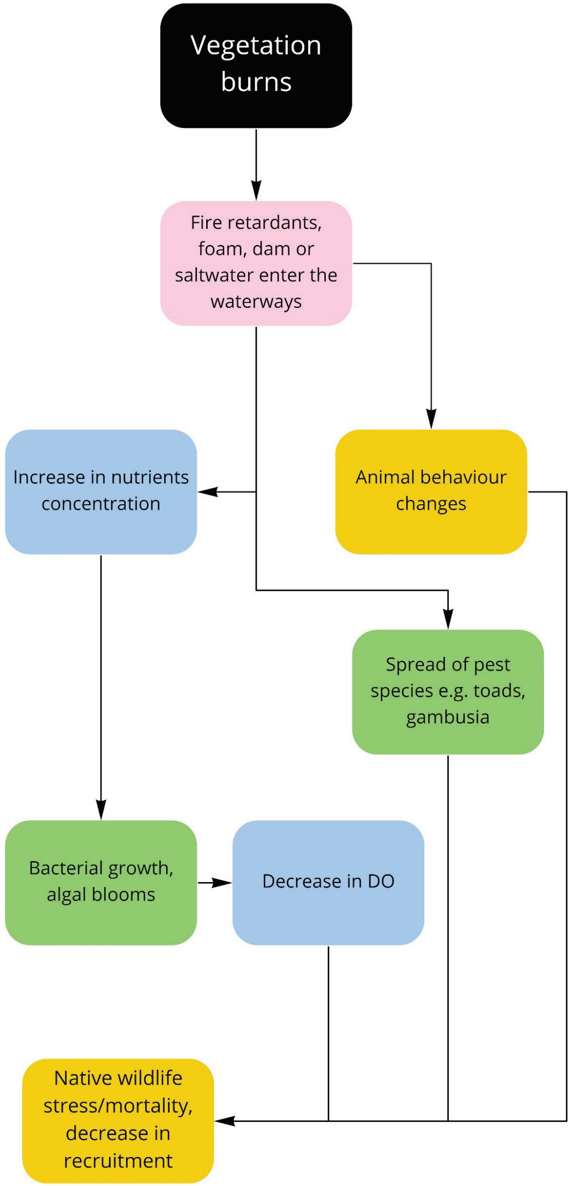
• Evaluate the necessity and the cost-effectiveness of deploying techniques such as building dams and grade stabilisers. They tend to be very costly measures, so early assessment is recommended

RECOVERY

Short-term
• Monitor natural recovery
• Build structures such as dams and grade stabilisers to minimise structural damage to stream beds and banks
• Assist the natural revegetation of stream banks

Long-term
• Ensure that streams, rivers, and estuaries are protected from man-made threats to their integrity, to increase their resilience to future bushfires

Pathway 6 – impacts of water bombing and retardants



Pathway 6 – impacts of water bombing and retardants

Description

Firefighting chemicals can be extremely dangerous to aquatic wildlife[42]. Fire retardants, mixed for delivery to the fire, can contain about 10% fertiliser[43]. If they enter aquatic systems, the fertilisers in these retardants can add nutrients (e.g., ammonium phosphate, ammonium sulphate salts), and can lead to cases of eutrophication[43] and aquatic wildlife mortality[44,45]. Moreover, firefighting foam can be made with substances called per- and poly-fluoroalkyl substances (PFAS), which are a group of compounds including perfluorooctane sulfonic acid (PFOS), and perfluorooctanoic acid (PFOA). These compounds have been found to have several negative impacts on human and wildlife health, such as that of fish, crustaceans and cetaceans[42]. PFAS-containing foam can still be used in Tasmania[46]; however, Tasmania Fire Service has been moving away from the use of PFAS for the past 15 years. PFAS are not in any firefighting product used in NSW[47], following the Protection of the Environment Operations (General) Amendment (PFAS Firefighting Foam) Regulation 2021[48]. In 2018, the SA Environmental Protection Authority announced a ban on firefighting foams containing PFAS with a mandatory removal by February 2020[49]. In Queensland, a phase-out of firefighting foams containing PFOA or PFOS was announced in July 2016, with a full ban in place since July 2019[50]. Nevertheless, between 2017 and 2020 Taylor *et al.* (2021) detected concentrations of PFAS in Australian sea lion (*Neophoca cinerea*) and Australian fur seal (*Arctocephalus pusillus doriferus*) pups found dead in South Australia and Victoria[42]. These findings indicate that these contaminants are currently present and persistent in the Australian marine environment despite the recent phase-outs and bans in firefighting practices.

Moreover, the use of saltwater to fight fires on land or near freshwater bodies can be detrimental for habitats and wildlife adapted to freshwater and/or sensitive to salinity. Finally, the use of dam water to fight fire near freshwater systems can run the risk of spreading alien species (e.g., mosquito fish)[51]. Therefore, firefighting must be done following an ecologically sound plan based on a risk analysis that takes these potential environmental consequences into account.

Before the fire

MITIGATION

- Extend the phasing out and banning of PFAS-containing firefighting chemicals all over Australia
- Test existing chemicals against sensitivity of Australian aquatic flora and fauna
- If unavailable, design maps that indicate clearly which drops are most suitable, and where

PREPARATION

- Ensure that firefighting crews are aware of the dangers of using firefighting chemicals in the proximity of aquatic environments
- Ensure that firefighting crews are aware of the dangers of using dam or salt water in the proximity of freshwater environments
- Ensure that the distribution of invasive species is well known to firefighting crews so that they can avoid transporting/using waters that might spread them
- Design a recovery plan for any waterbody contaminated while firefighting

During/after the fire

RESPONSE

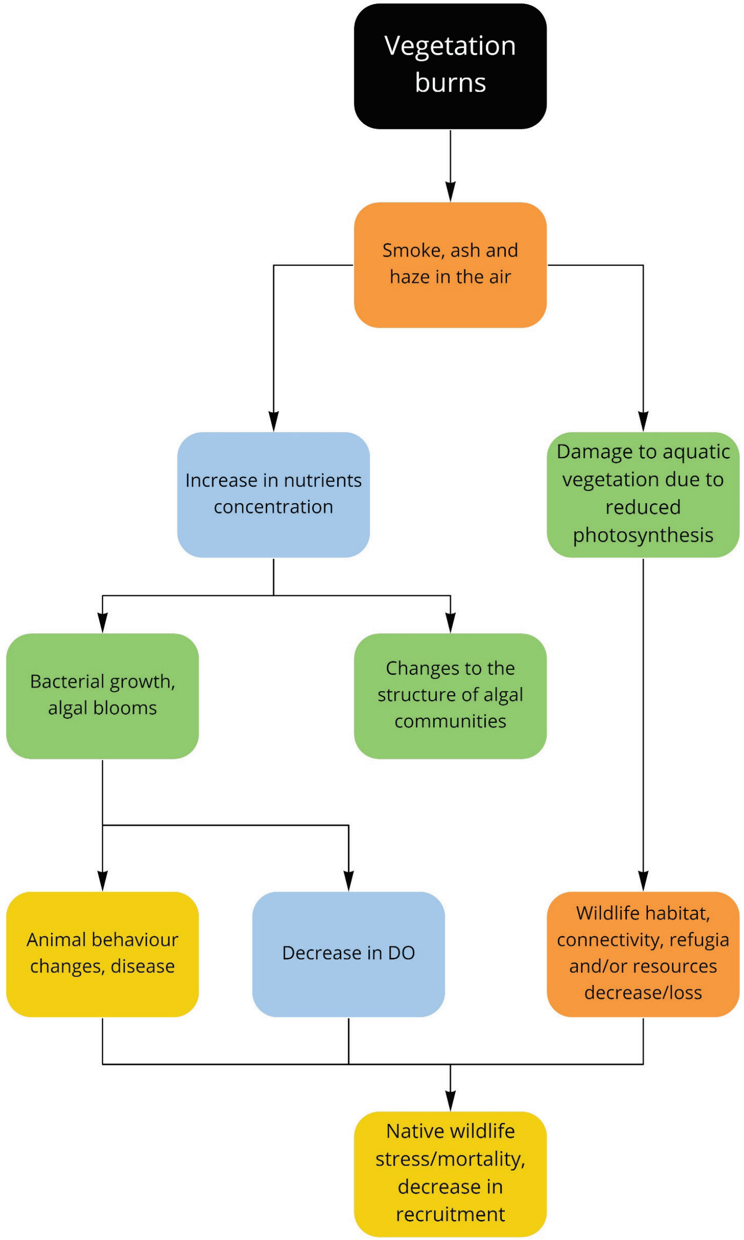
- Identify any waterbody that might have been contaminated while firefighting

RECOVERY

- Implement rehabilitation techniques depending on the type of contamination (i.e., biological or chemical). Translocate wildlife if necessary.

Figure 17. Bundoora, Australia - December 30, 2019: Erickson Air Crane firebombing helicopter (Sikorsky S-64) sucking up water to fill its tank in a lake while a smaller Bell 412 helicopter fills behind. Photo by Ryan Fletcher, Shutterstock.

Pathway 7 – impacts of smoke and haze



Description

Bushfires can produce exceptional amounts of smoke and haze, significantly reducing the visibility of several km, which poses a dangerous issue to vessels navigating at sea by increasing risks of collisions, with the subsequent possibility of losing human lives and environmental impact[6]. Moreover, haze episodes eventually lead to the deposition of aerosols that can reach seas and lands thousands of km away from the bushfires. The aerosols from the 2019-2020 bushfires reached the South Pacific Ocean and even Chile and Argentina[52]. These aerosols can remain in the stratosphere for several months after bushfires extinguish, with effects of unclear consequences on the atmosphere and global climate[53]. Through this mechanism, severe bushfires can be a source of nutrients like nitrogen, phosphorus and iron for waterways and the open ocean[54]. These nutrients, and particularly iron, can be important ocean fertilisers and drive primary productivity (i.e., facilitate phytoplankton growth), therefore these events can have a significant effect on marine ecosystems[54]. Li *et al.* (2021)[54] found that due to the 2019-2020 Australian bushfires:

"*The Chlorophyll-a concentrations in both surface and water columns from coastal Australia to the South Pacific Ocean increased due to particle deposition, and gradually decreased with the increase of distance from the location of bushfires for more than 3 months. ΔChla* in the Southeast Pacific Ocean reached a maximum value of 23.3 half of a month after the occurrence of atmospheric particle pollution. The high correlation between aerosol particle deposition and the increase in ΔChla suggested rapid uptake of extraneous nutrients and growth of marine phytoplankton within 8 days; ΔChla peaked at 6.4 in the Tasman Sea. In the water column, increases in the content of total particles and phytoplankton were observed with a maximum depth of 64.7 m*".

* standardized anomalies in Chlorophyll-a concentration.

While the ocean fertilisation role can be particularly important, there is the risk that these events could lead to eutrophication events, particularly in oligotrophic systems (e.g., coral reefs) and nutrient-depleted shallow coastal waters with insufficient tidal flushing[6,55]. Eutrophication events are one of the major causes of sea grass beds losses, increase the risk of coral bleaching, and increase mortality rates for other aquatic organisms[6].

Pathway 7 – impacts of smoke and haze

Before the fire

MITIGATION

• Ensure adequate flushing in managed estuaries, in line with current management plans and needs for the area

PREPARATION

• Increase research on this topic, particularly "long-term continuous spatiotemporal remote sensing observations with extensive space coverage, in coordination with in-situ atmospheric and marine monitoring procedures"[54] as well as on the responses of Australian species of conservation and commercial interest to these events

• Ensure that vessel captains and crews have the necessary preparation for navigation during hazy days, or increase their capacity to stay onshore (e.g., with financial incentives or aid)

• Plan maintenance of impellers to cope with increased levels of ash, perhaps modifying the design through innovation with leading outboard/inboard marine engineering companies as a future sales feature.

During/after the fire

RESPONSE

• Conduct planned field research as soon as it is safe

• Ensure the safety of all vessels out at sea, conduct search and rescue missions where necessary

RECOVERY

Short-term

• Open managed estuaries and ICOLLs where necessary to flush excess nutrients and sediments

• Ensure regular water quality measurements are conducted due to possible impacts to water potability and human/wildlife health

• Plan for the rehabilitation of affected habitats

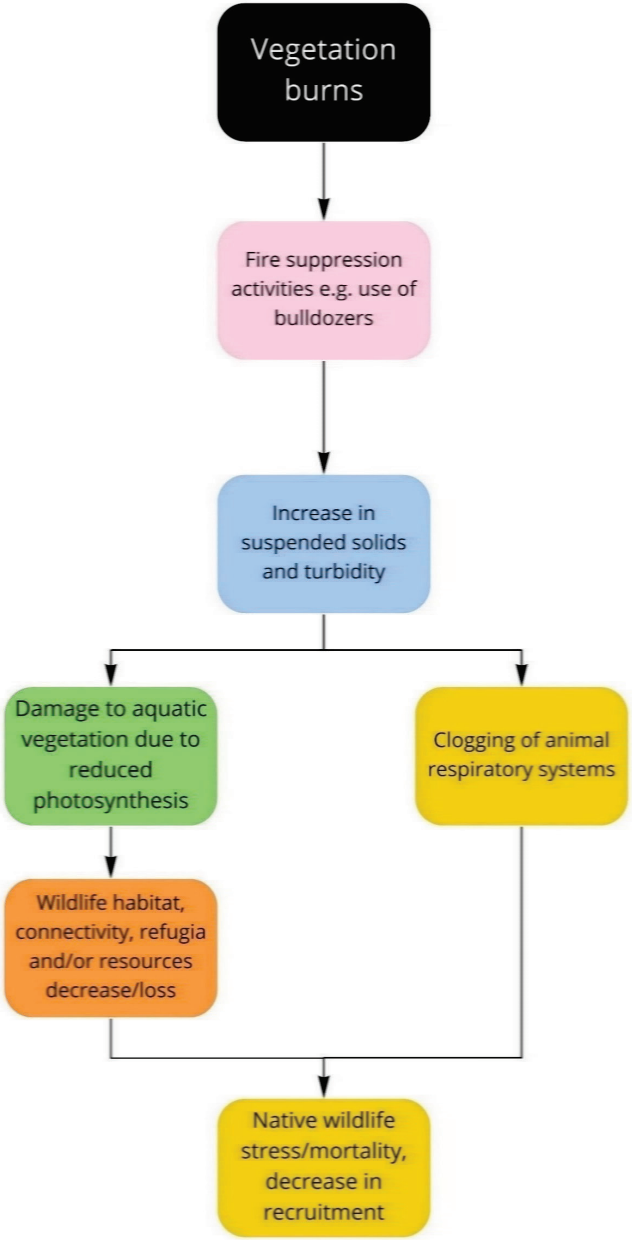
Long-term

• Rehabilitate affected habitats

Figure 18. Wagga Wagga, NSW Australia - 5th January 2020: Already reduced by a long-running drought, the Murrumbidgee River is enveloped by smoke from a nearby bushfire. Photo by Greg Stonham, Shutterstock.

Figure 19. Iluka, NSW - 27 November 2019: Bushfires in Australia. Photo by Anna LoFi, Shutterstock.

Pathway 8 – impacts of heavy firefighting machinery



Description

Firefighting techniques can include the building of firebreaks (i.e., control lines), which are gaps in vegetation to slow or stop the progress of a bushfire. These firebreaks are usually built with bulldozers and other heavy machinery[34]. For example, in the 2009 bushfires in Victoria ~9000 km of control lines were built, sometimes over 60 m wide[34]. While this can be critical to controlling bushfires, it may have the unintended consequences of increasing soil erodibility and consequently having the cascade of effects that were discussed in Pathway 4.

Before the fire

MITIGATION

- Research the effectiveness of fire breaks in function of their size, and prepare to implement the minimum size possible while fighting a fire

PREPARATION

- Design firefighting plans that rely on natural fire breaks as much as possible

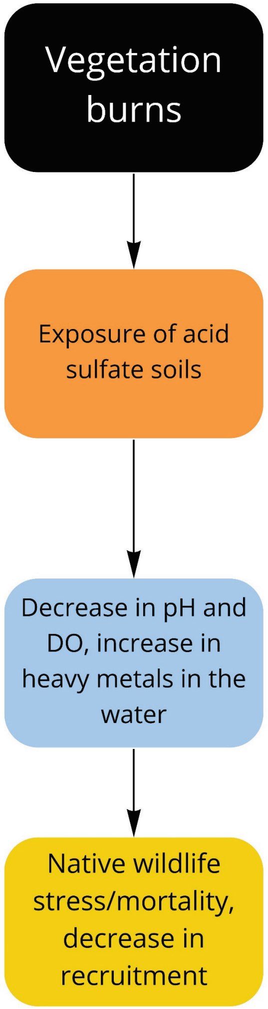
During/after the fire

RESPONSE & RECOVERY

- See Pathway 4

Figure 20. Swamp edge break by USFWS/Southeast.

Pathway 9 – impacts of Acid Sulfate Soils (ASS)



Description

The term Acid Sulfate Soil (ASS) refers to a type of soil that contains metal sulfide minerals, is saturated with water, is almost free of oxygen[56], and it is quite commonly found in Australia. For example, ASS is found in every estuary in NSW[57]. When ASS is burned and exposed to the oxygen in the air a reaction is triggered. This oxidation produces acid (usually sulfuric acid), which can reduce soil pH to less than 4[58]. The acid then can attack soil minerals, releasing metals like aluminium and iron[56]. Then, rainfall can wash the acid produced and the metals released into nearby waterbodies, lowering the pH and dissolved oxygen (DO), and increasing heavy metals concentrations. Some ecosystems can absorb and neutralise the acid, however sensitive aquatic plants and animals may be killed due to the changes in water quality (Figure 21). Surviving wildlife development may be impaired, while more tolerant organisms (e.g., mosquitoes) may instead thrive[59].

This acid release not only has ecological consequences but also has economic impacts on commercial fishing and aquaculture activities such as oyster growing[57].

These effects can be difficult and expensive to manage and treat, therefore avoiding them is the best approach[59]. If, however, it is impossible to divert bushfires and avoid ASS exposure to oxygen, different techniques can be implemented depending on the risk level and local conditions, including:

- *"Applying alkaline products such as lime;*
- *Planting vegetation or increasing organic matter inputs to encourage micro-organisms to metabolise acidity and metals;*
- *Diverting saline groundwater to disposal basins;*
- *Maintaining water levels with temporary regulators;*
- *Reinstating wetting and drying patterns to wet soils and prevent the build-up of sulfidic sediments through dilution with freshwater flows."*[59]

ASS may be found in:

- COASTAL WETLANDS
- FORMER SEASHORES
- SANDY SOILS
- NEAR ESTUARIES

Pathway 9 – impacts of Acid Sulfate Soils (ASS)

Before the fire

MITIGATION

• Prevent activities (other from bushfires; e.g., the building of drainage systems for agriculture) that can trigger ASS oxidation, or modify them in such a way as to prevent risk[57]

• Conduct regular water quality monitoring in acid sulfate soil areas

• Conduct research on wildlife resilience thresholds to the effects of acid leakages into local waterbodies, prioritising threatened and range-restricted species

• Design a safety plan to treat and/or remove sensitive threatened wildlife from aquatic areas if they become affected (e.g., the extraction of galaxiid fish, crayfish and mussels from the wild and temporarily housing them at aquarium facilities, as a response to the 2019-2020 bushfires by the Arthur Rylah Institute, Victoria)[60]

PREPARATION

• Consult ASS risk maps (e.g., Figure 22) and plan for bushfire fighting accordingly

• Educate wider public but particularly natural resource managers on the dangers of ASS oxidation and recovery measures

• Ensure that firefighting teams are aware of the presence of ASS in local areas, and they are provided with a detailed map to inform their firefighting plans – particularly near aquatic and in coastal areas

During/after the fire

RESPONSE

• Conduct water quality monitoring to assess the level of change and damage

• Conduct wildlife surveys to assess any impacts

RECOVERY

Short-term

• Monitor natural recovery

• Implement appropriate management strategies among those listed in the description section

Long-term

• Implement long-term water and soil quality monitoring and manage known ASS areas to increase their resilience to bushfires

Figure 21. Dead fish caused by ASS. Photo by Kari Saari, cropped (CC BY-SA 4.0).

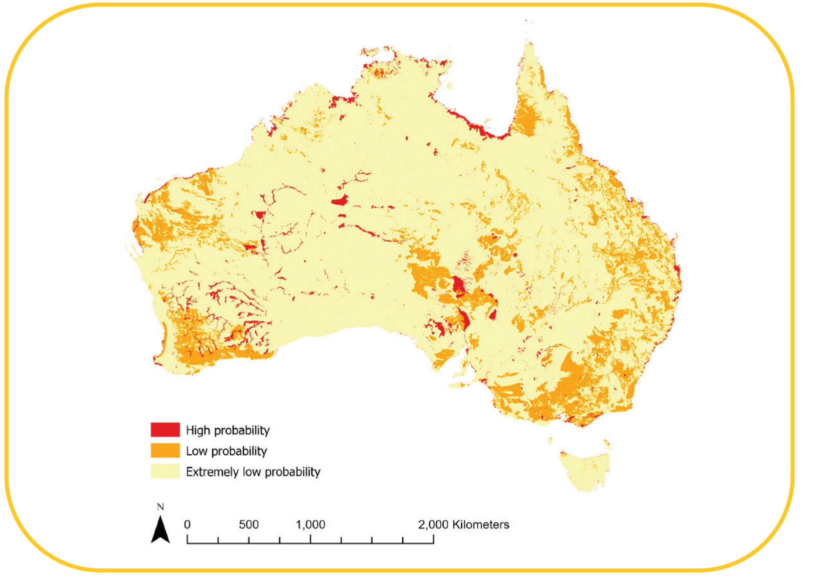


Figure 22. Overview of the Atlas of Australian Acid Sulfate occurrence probability. Data by: Fitzpatrick, Rob; Powell, Bernie; Marvanek, Steve (2011), Atlas of Australian Acid Sulphate Soils. v2. CSIRO Data Collection.

Australian bushfire impacts to aquatic environments: a public survey

Details on the survey

The survey was designed to answer the question “What bushfire impacts to aquatic environments were observed in each of the six focus fire grounds?”, and to provide a means for the public to communicate and report observed impacts to OceanWatch. The six fire grounds focus of this project (Figure 23) have significant environmental and climatic differences between each other and within each one, therefore the expectations we had before launching this survey were explicitly general. The Southeast Queensland bushfires affected coastal areas in the Moreton Bay islands and Noosa Heads, therefore we expected negative impacts reported by the seafood and diving industries, as well as from rangers on the islands and Noosa National Park. In Coastal NSW, several areas were burnt severely and followed by heavy rainfall, particularly in the South Coast. Because of this, we expected most impacts to come from this region, spanning from aquatic habitat destruction to water quality decreases to impacts to businesses relying on healthy waterways.

For East Gippsland in Victoria, several coastal areas were severely impacted, such as the Cape Conran Coastal Park, Croajingolong National Park, and towns like Mallacoota. However, this region was less affected by above-average rainfall right after the bushfire events compared to coastal NSW, therefore we expected relatively fewer reports of aquatic impacts. The bushfires in Northern Tasmania were much higher in the catchment compared to the fires in all other focus regions, therefore we expected fewer and different types of impacts reported, with fewer coastal impacts. Finally, Kangaroo Island was ravaged by the 2019-2020 bushfires, from the middle of the island down to the sea, followed by above-average rains in February 2020. Therefore, we expected several impacts reported by rangers and the public of wildlife, habitat, and water quality impacts.

The survey was built on the ESRI Survey123 platform, and it was officially launched in December 2020, about 12 months following the fires. The survey was available online to the public and used to collect data in the field by OceanWatch staff until June 2021. This survey was particularly aimed at and publicised in the six regions focus on the “Spatial Thinking” project.

The survey was divided into five sections, led by the questions (1) “Have you observed any animals impacted by the 2019-2020 bushfires?”, (2) “Have you observed any water quality impact caused by the 2019-2020 bushfires?”, (3) “Have you observed any aquatic habitat (including aquatic plants) impact caused by the 2019-2020 bushfires?”, (4) “Have you observed any socio-economic impact caused by the 2019-2020 bushfires?”, and (5) “Have you observed any other or any additional impact caused by the 2019-2020 bushfires?” – to which more questions followed if the answer “yes” was chosen by the respondent. The following questions included the location of the impact, the factors that contributed to causing the impact, and whether the impact was still ongoing or had (been) resolved.

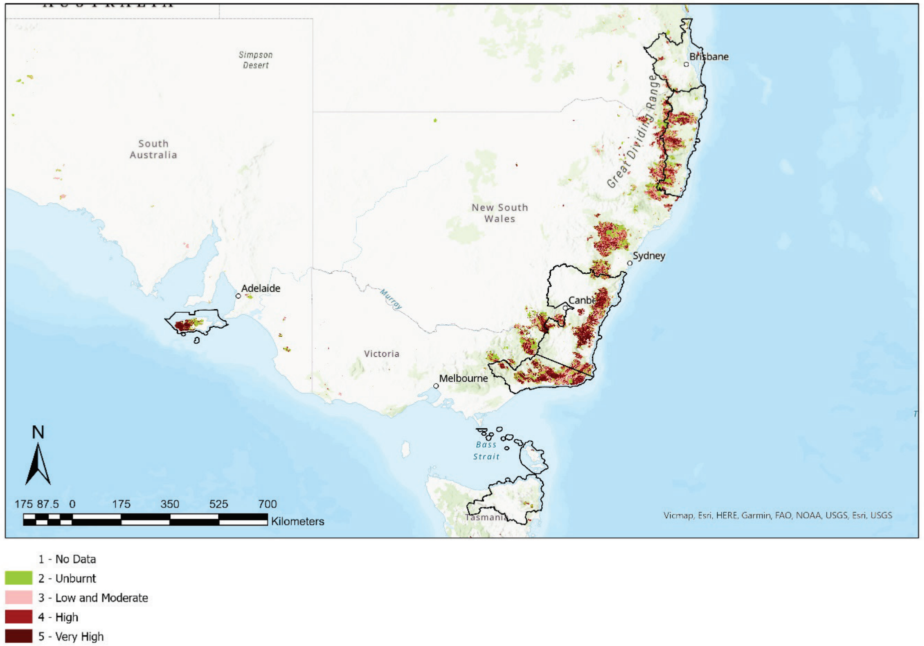


Figure 23. Target regions clipped from NRM regions data (CC BY 4.0), with Fire Severity data (CC BY 3.0 AU). Data credits to the Commonwealth of Australia: Department of Agriculture, Water and the Environment.

One of the major limitations of this survey is the time that passed between the bushfires and this project, which in many cases was over one year. Moreover, online surveys can be a difficult means to reach remote communities, or communities with limited digital literacy. Nevertheless, before the launch of this survey, there were no geographically explicit means to collect information about impacts to aquatic environments noticed by communities and practitioners. Given the paucity of Australian-based scientific information on the effects of bushfires on aquatic environments, we thought that collecting observations from people who live and work in/around Australian waterways was the best way to gain an understanding of the types of impacts that occurred post-bushfires. Of course, bushfire impacts can be subtle, difficult to attribute to a specific cause, or could be reported with mistakes due to the time passed between the fires and the survey. For example, the impact of the bushfires was worsened by the drought that preceded them, as well as extraordinary summer heat and low water in rivers such as the Macleay River. The 2019-2020 bushfires were then followed by significant flooding in many affected areas. Therefore, the impacts measured or reported by individuals may have been attributed to the combined impacts of these events. Therefore, these observations need to be treated as leads, as hypotheses to be tested, and as a first attempt to understand bushfire changes to aquatic environments at a regional and national scale.

Summary of the observations submitted and collected

A total of 68 surveys were completed either by the public or by OceanWatch interviewing stakeholders throughout the project. The demographics that were most responsive to the survey were coastal residents, professional fishermen, aquaculture farmers and environmental workers (e.g., LGA, NRM, Council, Parks). 44% of the survey respondents who provided feedback stated that completing the survey was completely worth their time, and 53% stated that it was partly worth their time. 4% of impacts were observed in late 2019, 58% in 2020 and in 2021. Three respondents reported impacts from previous bushfires (dated to 2017), which we decided to keep in our database as they represented relevant information.

Most observations were of impacts to water quality (N = 36), followed by socio-economic impacts (N = 31; Figure 24). Most impacts were reported as ‘not recovered’ (N = 36), followed by ‘partially back to pre-fire conditions’ (N = 34). Only 14% of impacts reported (N = 16) were of impacts ‘fully back to pre-fire conditions’ at the time of submission (Figure 25).

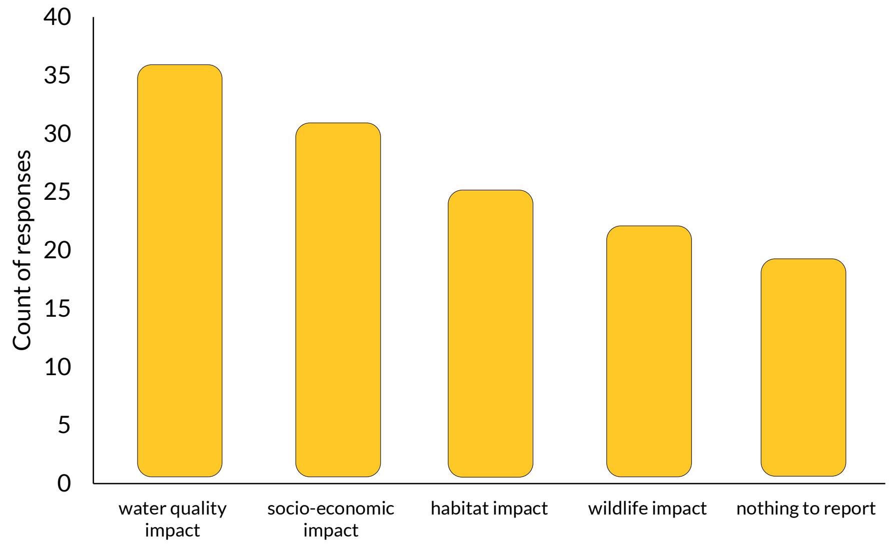


Figure 24. Count of how many responses were submitted per category. A single survey may have contained observations in more than one category.

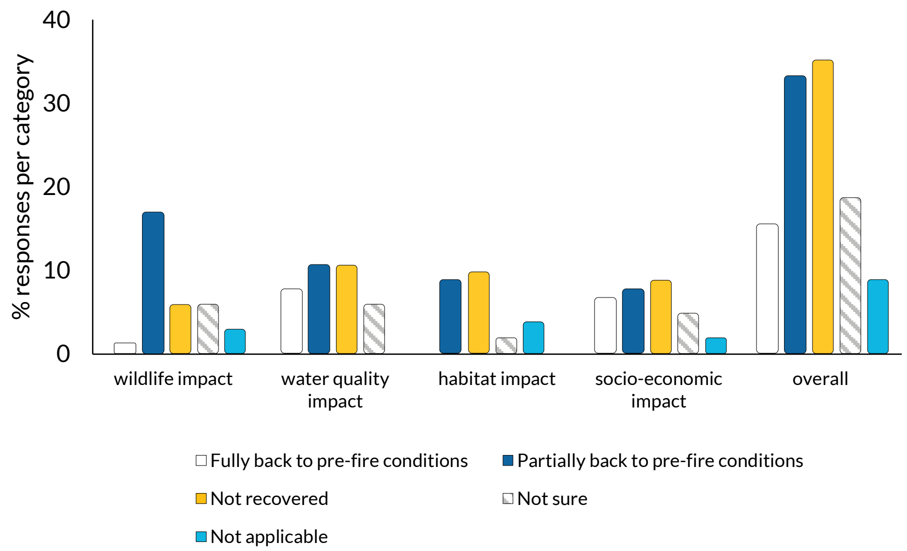


Figure 25. Per cent of respondents who reported to what level the impact observed had recovered since the launch of the questionnaire (i.e., around 12 months post-bushfires in most cases), in each category.

Wildlife impacts

Most respondents reported observing a negative bushfire impact on wildlife (N = 17), while a few reported only change (N = 3) or even positive impacts (N = 2). Of the categories that could be chosen to classify the impact, 'wildlife death' was the one selected the most (Figure 26). Most reports were about aquatic wildlife (N = 15); however, 5 respondents submitted observations related to non-aquatic fauna (e.g., kangaroos).

54% of respondents (N = 12) reported no measures have been implemented to treat this animal impact to their knowledge. Amongst the measures implemented, soil erosion control and the help of rescue teams were mentioned. 64% of respondents (N = 14) stated that they were completely confident that the impact was linked to bushfires.

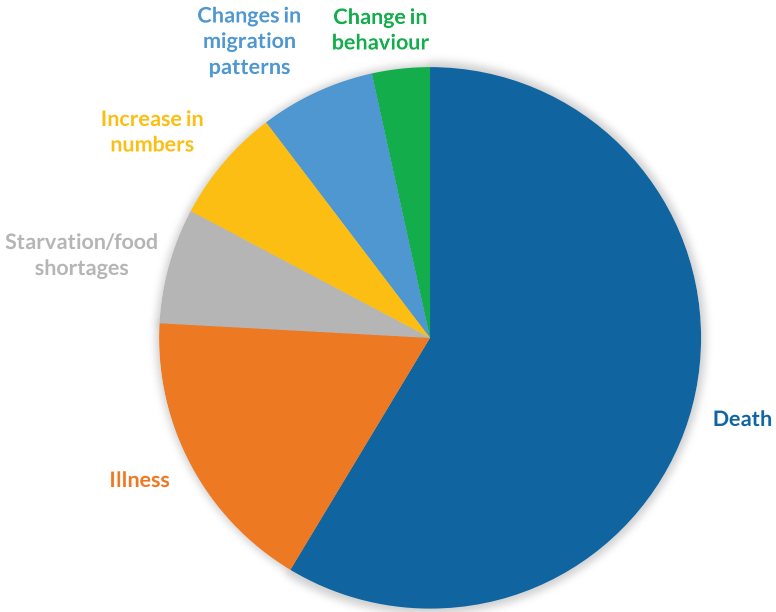


Figure 26. Categories that were chosen to classify the wildlife impacts submitted. More than one category could be chosen per impact.

Water impacts

Water quality impacts were the most numerous reported, with most respondents reporting ash the in water as the cause of the impacts noted. 78% of respondents (N = 28) stated that they were completely confident that the water quality impact was linked to bushfires. Most reports were of debris in the water (N = 12), followed by a general water quality decrease (N = 9; Figure 27).

47% of respondents (N = 17) reported that no remediation measures have been implemented to treat the water quality impact, to their knowledge. Nevertheless, 22% of respondents (N = 8) reported that the water quality was treated by opening the affected estuary, sediment control techniques, or volunteers cleaning up the affected area. Between the measures reported were the deployment of sediment management devices such as coir logs and blankets, removal of ash and debris from popular shorelines, or clean-ups by volunteers. However, only one respondent reported that the technique employed was effective (the removal of ash and debris), while the others were only partially effective or ineffective.

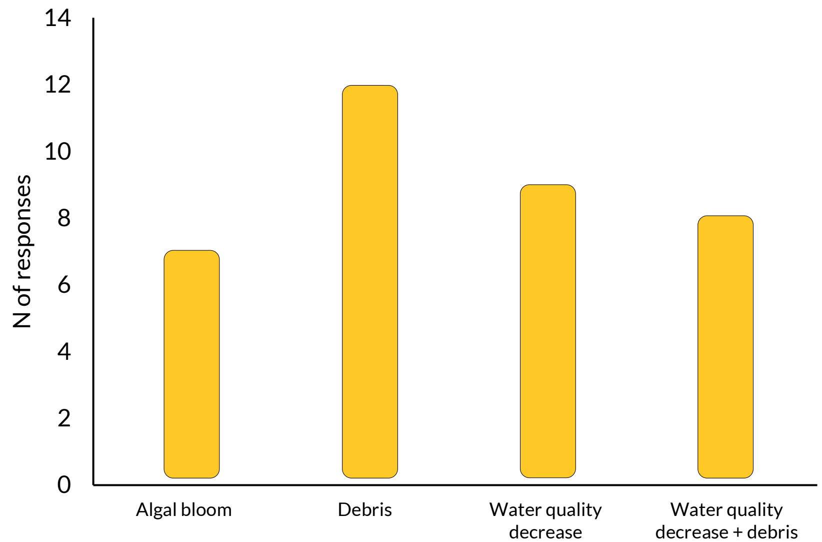


Figure 27. Classification of water quality impacts divided into categories. Only one option could be selected for each impact submitted.

Habitat impacts

Most observation of habitat impacts included habitat destruction (N = 13) and habitat degradation (N = 8). The top two causes identified for the reported impacts were ash and fire itself, and the habitat most reported as affected was mangroves (Figure 28). 40% (N = 10) of respondents stated that the impact they observe did not recover. Moreover, 48% (N = 12) of respondents reported no measures have been implemented to treat the habitat impact to their knowledge, while only 16% (N = 4) reported that measures were implemented, including weeding and revegetation. 72% of respondents (N = 18) stated that they were completely confident that the habitat impact was linked to bushfires.

Socio-economic impacts

Socio-economic impacts include impacts to businesses reliant on aquatic environments, impacts on tourism, local use of aquatic environments, or wellbeing of coastal communities. The most-reported impact was damage or loss of infrastructure (N = 11), followed by loss of stock (N = 10) and impeded access to water resources (N = 10; Figure 29). 80% (N = 25) of respondents were completely confident that the impact was linked to bushfires, with the top cause of the impact reported being fire itself. 29% (N = 9) of the socio-economic impacts reported were classified as not recovered. 45% (N = 14) respondents reported no remediation measures were implemented to treat the impact to their knowledge, while 42% (N = 13) were not sure.

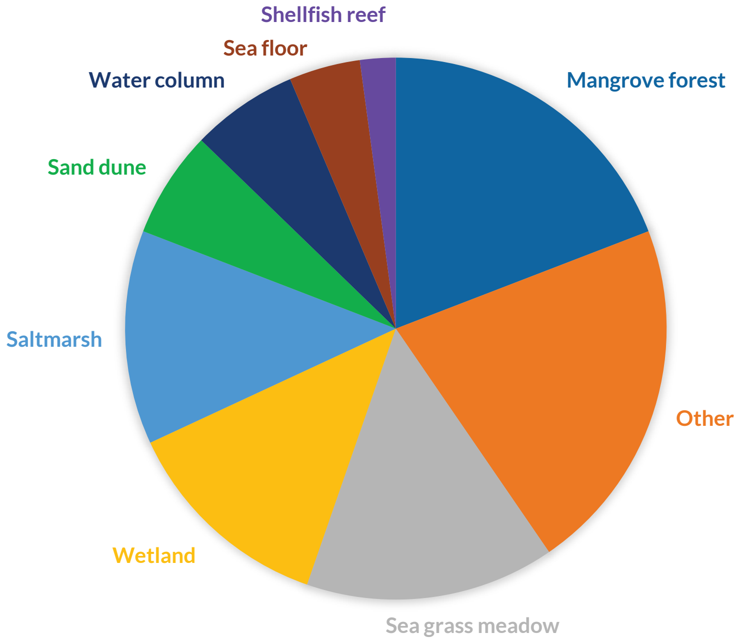


Figure 28. Habitats reported as affected by bushfires. Mangroves were the most reported, followed by sea grass. More than one could be selected for each impact. Kelp impact was an option, but it was never reported.

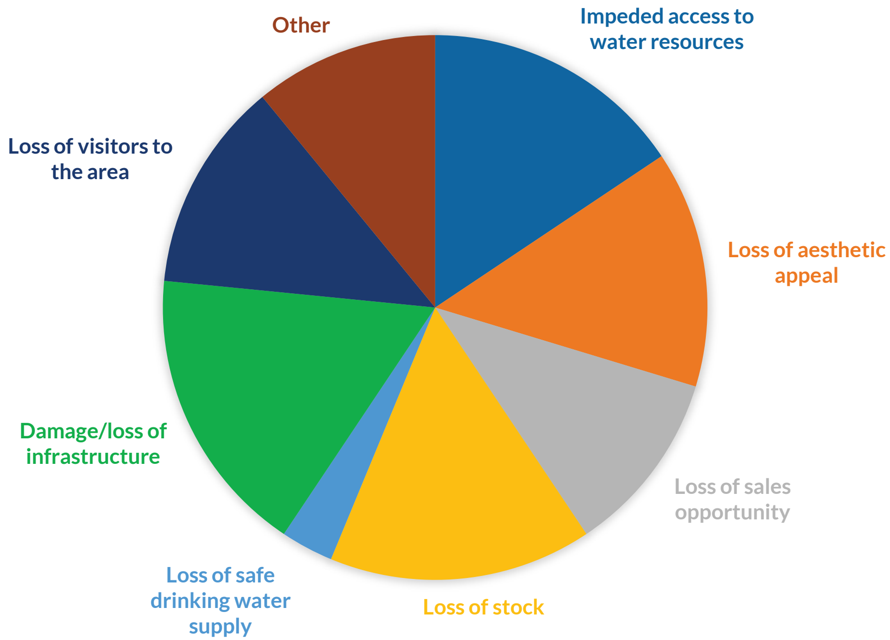


Figure 29. Categories of socio-economic impact available to be chosen. More than one could be selected for each impact.

Locations of the impacts

Survey responses were not equally distributed among focus fire grounds, with most observations of impacts (or lack thereof) coming from NSW (Figure 30). 14 observations were not able to be mapped because of wrong or absent coordinates (water quality N = 2, habitat N = 1, socio-economic N = 2, nothing to report N = 9). 22 observations came from the NSW North Coast (Figure 31), 64 came from the NSW South Coast (Figure 32), while 7 were reported from NSW but not in either NRM region. Ten observations instead came from Southeast Queensland, 3 of which were ‘no observations to be reported’ (Figure 33). 4 observations were submitted from North Tasmania (Figure 34A), while only one observation was collected from East Gippsland (Figure 34B). 11 impact observations came from Kangaroo Island, predominantly from the western side of the island (Figure 35). OceanWatch staff were unable to travel to Victoria due to Covid-19 restrictions, which may have limited observations during investigation in person.

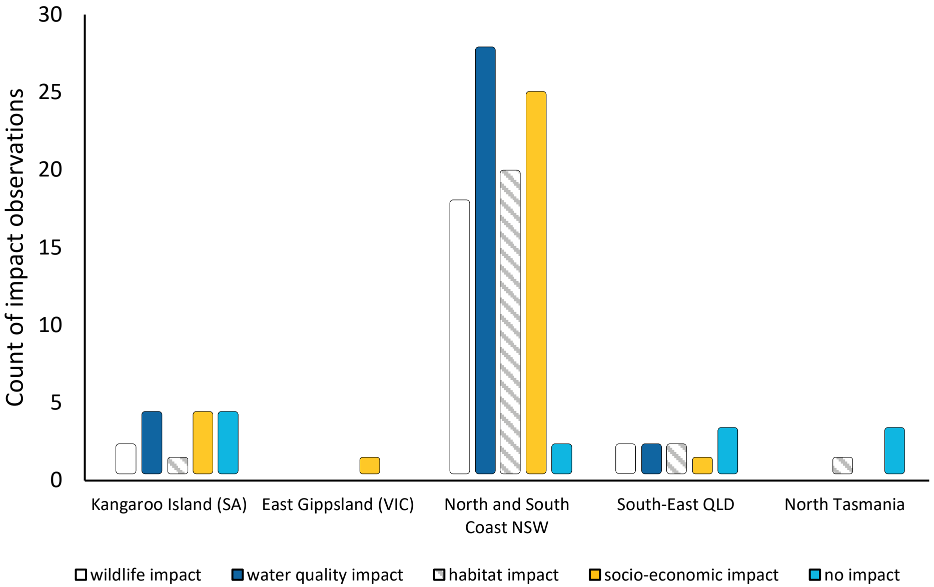


Figure 30. Count of impact observation by categories, with most coming from North and South Coast NSW.

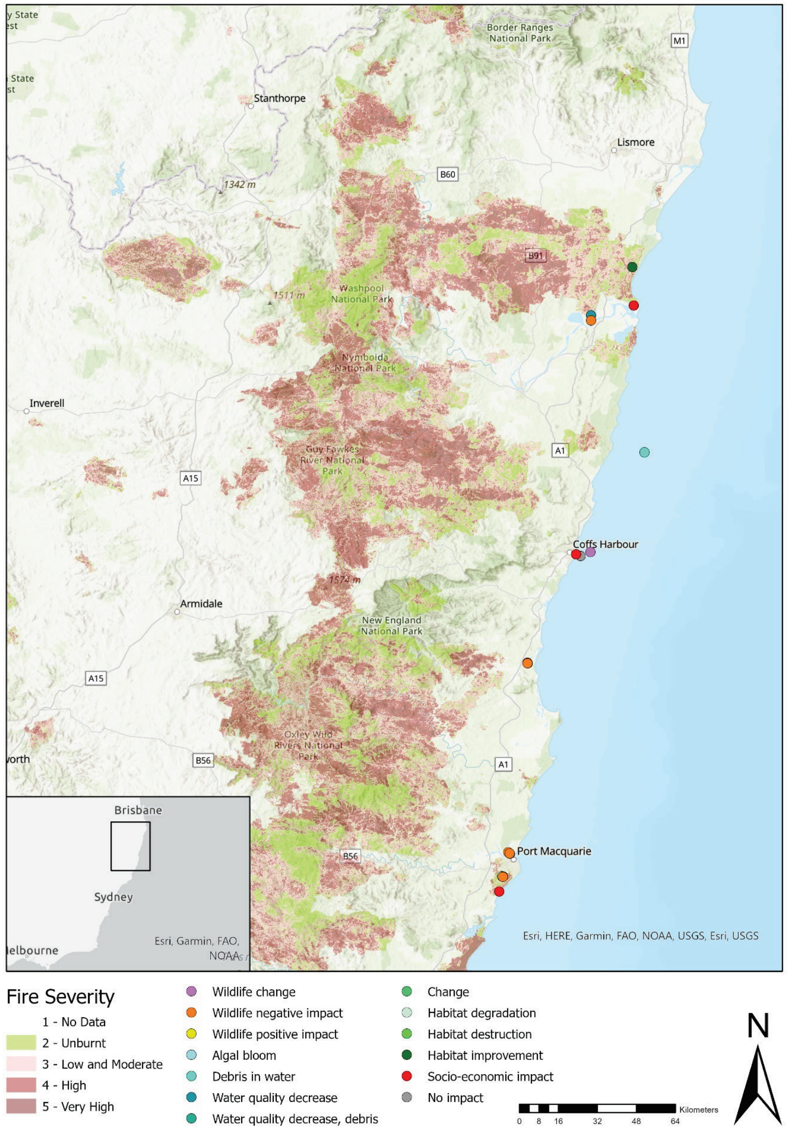


Figure 31. Bushfire impact observations from the North Coast of NSW. Fire Severity data (CC BY 3.0 AU) credit: Commonwealth of Australia: Department of Agriculture, Water and the Environment.

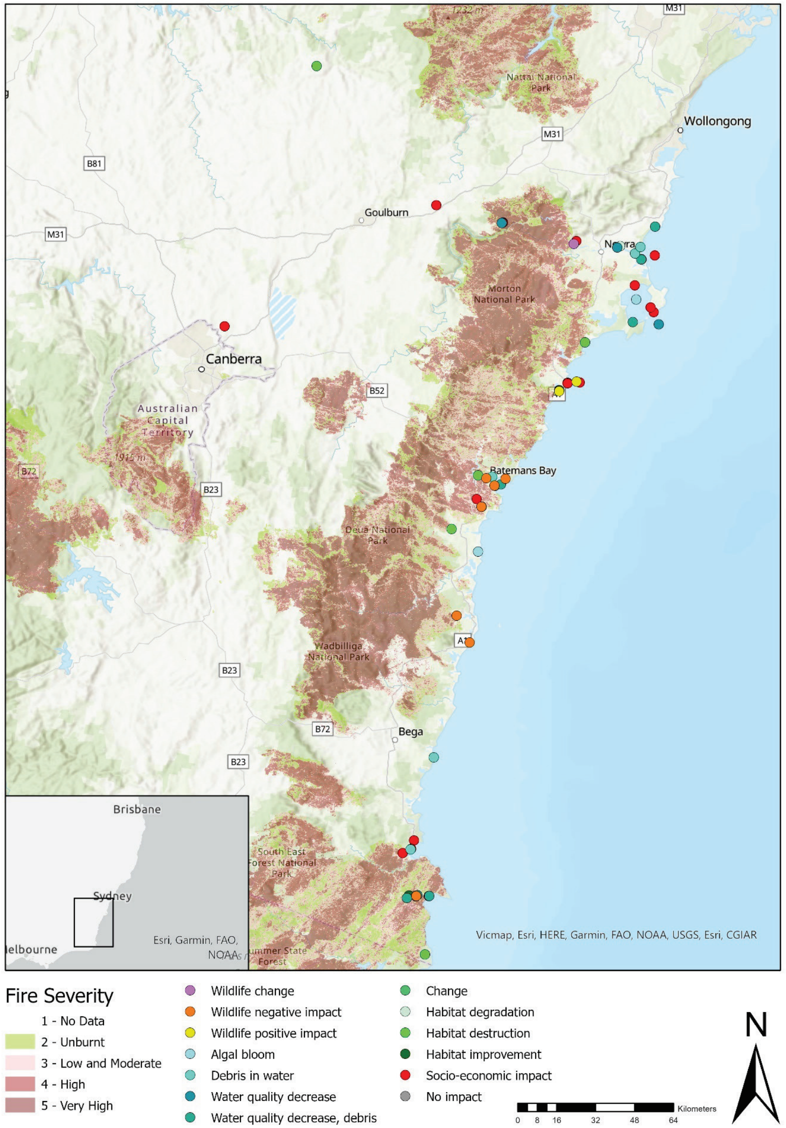


Figure 32. Bushfire impact observations from the South Coast of NSW. Fire Severity data (CC BY 3.0 AU) credit: Commonwealth of Australia: Department of Agriculture, Water and the Environment.

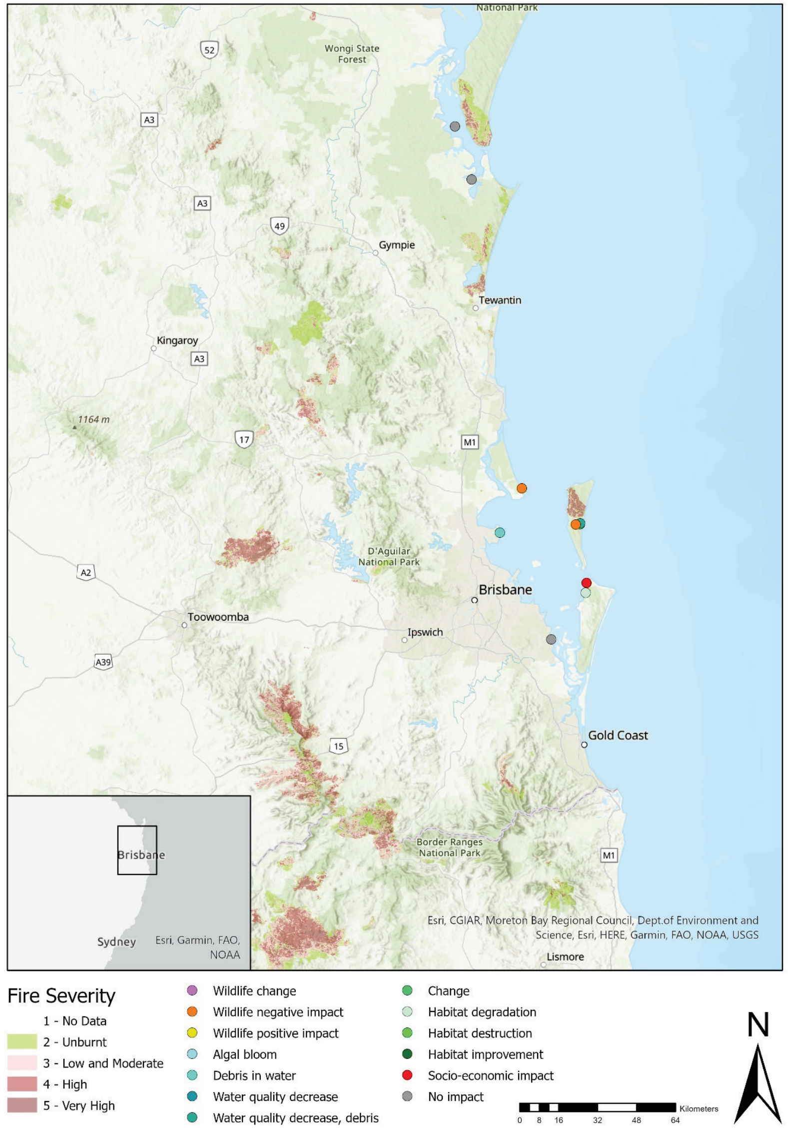


Figure 33. Bushfire impact observations from Southeast Queensland. Fire Severity data (CC BY 3.0 5AU) credit: Commonwealth of Australia: Department of Agriculture, Water and the Environment.

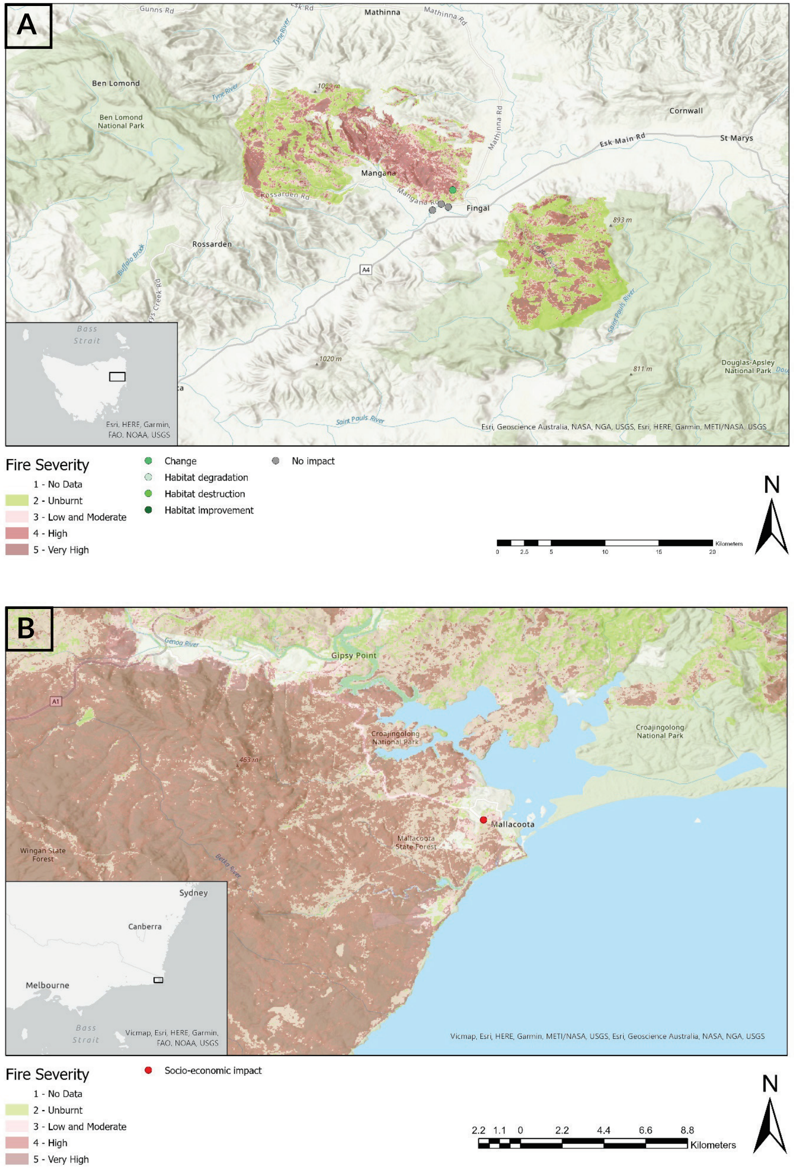


Figure 34. Bushfire impact observations from the North Tasmania (A) and East Gippsland in Victoria (B). Fire Severity data (CC BY 3.0 AU) credit: Commonwealth of Australia: Department of Agriculture, Water and the Environment.

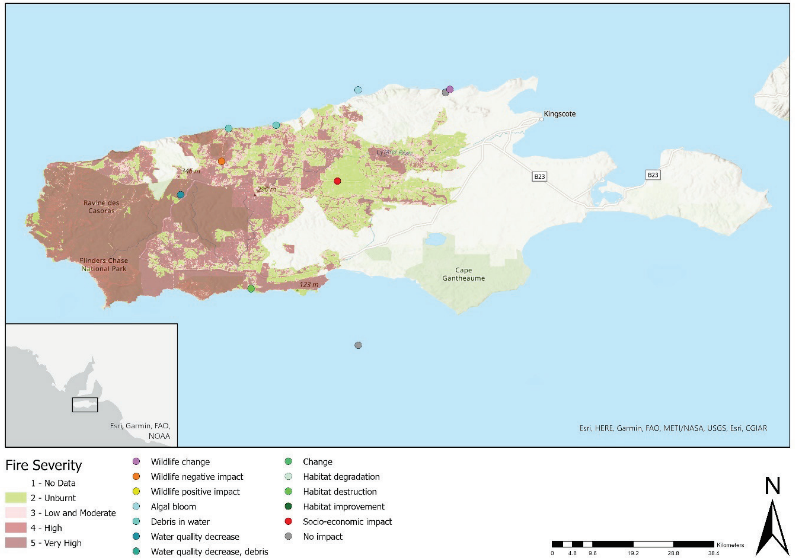


Figure 35. Bushfire impact observations from Kangaroo Island, South Australia. Fire Severity data (CC BY 3.0 5AU) credit: Commonwealth of Australia: Department of Agriculture, Water and the Environment.

Conclusions

This survey was the first done in Australia to investigate the types of bushfire impacts felt by affected communities. It was an exercise that provided a wealth of information, and its blueprint will remain in the toolbox of OceanWatch for future disaster response. The results from this survey met expectations in several instances. Expectations were met in NSW, where most observations were submitted from. Coastal NSW was one of the regions worst impacted by the 2019-2020 bushfires, and indeed the survey was able to capture this by collecting several impacts in all categories.

Expectations were also met in Northern Tasmania, where most survey submissions or interviews supported the absence of observable impacts to coastal or even freshwater streams nearby the fire grounds. We were able to collect only one observation of impact to a stream that ran through the fire ground near Fingal. We noticed that some areas were better monitored and studied by scientists and land managers compared to others, therefore change would have likely been easier to notice compared to other areas.

Consequently, it is likely that the lack of or lower monitoring efforts in remote areas such as the open seas (but also understudied freshwater environments) may have experienced less of an impact from bushfires, or their impacts largely went/are going unnoticed.

Southeast Queensland somewhat defied expectations, with a few reports of no impacts reported by professional fishermen. This lack of impact was generally blamed on the dispersing energy of the high seas where these fishermen work, which likely diluted ash and other debris that did not make it far from shore. Despite this, a few coastal habitat impacts were reported, and ash and debris were reported on beaches and coastal water, which suggests that bushfire impacts are either less significant or less obvious the furthest the observer was from shore. Reports of impacts from Southeast Queensland included the destruction of mangroves and seagrass, which are key coastal habitats for a vast suite of wildlife. Looking at changes in catch due to bushfire effects was outside the scope of this study, as they may not be detectable or could take years to eventuate.

Expectations were not met in East Gippsland, which was another region badly impacted by the 2019-2020 bushfires, because it only had one impact reported, in the socio-economic category. However, a fish kill was reported to the Victorian EPA in the Tambo River.

The lack of impacts reported was explained by East Gippsland CMA by the fact that the region was not hit by above-average rainfall like coastal NSW, and therefore apart from general damages to riparian vegetation, no obvious water quality or habitat impact was experienced. It is also possible that, like in other regions, the timing of the survey and its online nature played a role in the low response rate.

Finally, Kangaroo Island was badly damaged by the 2019-2020 bushfires; however, we obtained conflicting reports. While we had a few reports of no impacts, specifically from fishermen who operate far from shore, or aquaculture farmers who operate completely onshore, we also obtained reports of interesting environmental changes. These changes include estuary morphology changes in the Stun'Sail-Boom River in the southern part of the island, fish mortality in various waterways, as well as water quality changes. This information, which is similar to Southeast Queensland, supports that any effects to the high seas may either be minimal or much harder to notice than changes of waterways closer to or on land.

The knowledge gaps, and future directions

During the 'Spatial Thinking' project we collated a series of research questions to be addressed soon. Work that is not research-based is also needed to address gaps that became evident throughout our project.

Knowledge gaps

ECOLOGY

- What is the relative impact of bushfires on aquatic ecosystems compared to drought?
- What aquatic species are put most at risk by bushfires?
- May bushfires be beneficial or even necessary to some aquatic species, and if so, which species and in what way?
- For how long do bushfire impacts affect aquatic ecosystems?
- How much fish/marine invertebrate stock was impacted by the bushfires, and how much is that worth economically?
- What are the impacts of peat fires on marine ecosystems?

MANAGEMENT STRATEGY

- What are the most effective data to collect post-bushfire to inform aquatic environments' recovery, and when should they be collected?
- What management options are available for these species (e.g., translocations, the establishment of insurance populations), in view of future bushfires?
- Should we have an aquatic ecologist in fire service departments across Australia?

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Figure 36. Impacts of bushfires and post-bushfire floods, NSW. © OceanWatch Australia

Figure 37. High turbidity in the Wonboyn River, NSW, over one year after the 2019-2020 bushfires. © OceanWatch Australia

APPENDIX 1 - Mitigation: ✔ relevant to the organisation

Mitigation	NRM REGIONS / MARINE NRM	STATE DEPARTMENT FOR ENVIRONMENT	STATE FISHERIES	DEPARTMENT OF AGRICULTURE, WATER & ENVIRONMENT	FIRE SERVICES	LALC	LANDCARE	LOCAL GOVERN-MENTS	ACADEMIA	FUNDING BODIES	PRIVATE LAND MANAGERS
1. Assess local fish habitat and ensure a good level of **connectivity** amongst patches and refugia. Increase **habitat quality** as much as possible to increase the **resilience** of local wildlife to post-bushfire events and minimise the need to intervene.	✔		✔				✔				
2. Develop ongoing and **fine-scale mapping** of **cultural, ecological, and economic assets** ensuring that aquatic assets are included to the same standard as land assets and a value framework for active on-ground intervention prioritisation.	✔	✔	✔			✔		✔			
3. Develop ongoing and **fine-scale mapping** of **threatening processes** kickstarted by bushfires and which may result in impacts to aquatic habitat and wildlife[5].	✔	✔	✔						✔		
4. Wherever absent, develop readily available **mapping tools** that inform **aerial firefighters** about areas where not to drop retardants or saltwater.		✔			✔						
5. Set up **uniform and ongoing** indicator species and water quality **monitoring protocols** and/or stations across the country, to build comparable datasets.		✔		✔					✔		
6. **Fuel load reduction** paired with **ecological assessment** of the impact of the burn, to develop best practices tailored to local aquatic ecosystems following an adaptive management technique that accounts for climate change by state-based fire agencies.					✔	✔		✔			✔

Mitigation: ✔ relevant to the organisation

Mitigation	NRM REGIONS / MARINE NRM	STATE DEPARTMENT FOR ENVIRONMENT	STATE FISHERIES	DEPARTMENT OF AGRICULTURE, WATER & ENVIRONMENT	FIRE SERVICES	LALC	LANDCARE	LOCAL GOVERN-MENTS	ACADEMIA	FUNDING BODIES	PRIVATE LAND MANAGERS
7. For higher value assets, implement **finer-scale interventions** to minimise bushfire risk/consequences (e.g., hand removal of highly flammable species).					✔	✔	✔	✔			✔
8. **Identify the staff/department/team** who will deal with bushfire impacts to aquatic assets (ideally trained in aquatic and fire ecology), to avoid aquatic environments not being protected as much as others.	✔	✔	✔	✔	✔	✔	✔	✔			✔
9. Run **public workshops** around the bushfire **emergency management structure**, for key parties to better understand roles, responsibilities, and contacts for assistance.		✔			✔						
10. **Reduce or modify activities** that reduce aquatic resilience to bushfires, such as coastal development and agriculture[5].	✔	✔		✔				✔			✔
11. Build a **community of practice** directory for people in the bushfire management space with aquatic expertise.	✔					✔					
12. Support **communications and networking** events to increase capacity within the bushfire recovery sector with a focus on aquatic environments.	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
13. Include **indigenous approaches** and practices into the design of fire management plans as much as possible.					✔	✔					
14. **Increase resources** available to NRM regions and governmental organisations to do monitoring work and make the data publicly available.				✔						✔	

Preparation: ✔ relevant to the organisation

Preparation	NRM REGIONS / MARINE NRM	STATE DEPARTMENT FOR ENVIRONMEN T	STATE FISHERIES	DEPARTMENT OF AGRICULTURE, WATER & ENVIRONMENT	FIRE SERVICES	LALC	LANDCARE	LOCAL GOVERN-MENTS	ACADEMI A	FUNDIN G BODIES	PRIVATE LAND MANAGER S
1. Bring impacts to aquatic environments to the **forefront of bushfire research**.	✔			✔		✔	✔	✔	✔	✔	
2. Develop an official **protocol of prioritisation** for aquatic asset protection.		✔	✔	✔	✔				✔		
3. Increase **collaboration** between NRM organisations and Fire Services in bushfire risk assessment and response.	✔				✔						
4. Develop **inter-state relationships** to share learnings and experiences from past bushfires.	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔
5. Run/increase aquatic **ecological training workshops** for firefighting teams.	✔	✔			✔	✔			✔		✔
6. Run practical workshops providing guidance on **best practices** for private and public land managers about **bushfire and mitigation of impacts** to aquatic environments, as well as who to contact for help and advice.	✔					✔	✔	✔	✔		
7. **Map, assess and rank aquatic assets** linked to threatened species and commercial fishery resources.			✔			✔					
8. Develop **disaster preparation plans** at a business level for aquaculture and commercial fishing operations for what to do, where to go, or who to call for help in a disaster[5].	✔		✔								
9. Quantify species **seed stock vulnerability** for various levels of fire intensity.		✔							✔		

Preparation: ✓ relevant to the organisation

Preparation	NRM REGIONS / MARINE NRM	STATE DEPARTMENT FOR ENVIRONMENT	STATE FISHERIES	DEPARTMENT OF AGRICULTURE, WATER & ENVIRONMENT	FIRE SERVICES	LALC	LANDCARE	LOCAL GOVERN-MENTS	ACADEMIA	FUNDING BODIES	PRIVATE LAND MANAGERS
10. Identify **possible fishing and aquaculture business vulnerabilities** to bushfires and look for means to address them. E.g., logistics of product-to-market, stock movement, a continuation of operations, harvest zone water quality testing, staff Preparation, debris/fuel/chemical containment needs, digital data losses.	✓									✓	
11. Increase **research funding** to develop a better understanding of fire ecology, dependence, and resilience of local plant species, to improve fire management regimes, with a focus on but not restricted to riparian vegetation.										✓	
12. Ensure that **enough funding** is provided and/or set aside for **management activities** that include post-bushfire aquatic monitoring and recovery.										✓	
13. Establish a **network of protected areas** that can act as refuges when waterways and coastal waters are impacted by bushfires[5].		✓	✓					✓			✓
14. Plan how to **enforce regulations** in times of disastrous bushfires at a local government level.		✓		✓				✓			
15. **Update legislation** to allow for local government to be able to work in the fire management space when it has the capacity to.					✓			✓			
16. Improve the **consideration** that aquatic environments have during bushfire operations.	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
17. Develop/review **rapid assessment protocols** for aquatic environments.	✓	✓	✓			✓			✓		

Preparation/Response: ✔ relevant to the organisation

Preparation	NRM REGIONS / MARINE NRM	STATE DEPARTMENT FOR ENVIRONMENT	STATE FISHERIES	DEPARTMENT OF AGRICULTURE, WATER & ENVIRONMENT	FIRE SERVICES	LALC	LANDCARE	LOCAL GOVERN-MENTS	ACADEMIA	FUNDING BODIES	PRIVATE LAND MANAGERS
18. **Quantify processes** represented in the process map (Figure 3), so that it can be more useful for modelling future events.		✔							✔		
19. Develop methods to quantify the number of marine resources lost and their **economic value**.		✔	✔						✔		
20. Use the **process map** (Figure 3) internally to **NRM organisations** to overlay with people responsible for each system.	✔										
21. Expand the **process map** (Figure 3) to include **positive impacts** of bushfires.	✔								✔		
22. Develop/review **best practices on sedimentation management** (test the efficacy of traditional approaches e.g., coir log and blankets for topography and sediment loads).	✔							✔	✔		
Response											
1. Ensure that **staff with aquatic ecology knowledge** are present within **fire control agencies**, particularly with an understanding of impacts and techniques, and the authority to play an active role in advising a firefighting strategy based on aquatic asset location and ranking.					✔						
2. Conduct **rapid assessment surveys** of impacts, including mapping the fire extent and severity as it progresses to determine and predict losses and necessary interventions in aquatic environments[5].	✔	✔	✔	✔	✔	✔		✔	✔		✔

Response/Recovery: ✔ relevant to the organisation

Response	NRM REGIONS / MARINE NRM	STATE DEPARTMENT FOR ENVIRONMENT	STATE FISHERIES	DEPARTMENT OF AGRICULTURE, WATER & ENVIRONMENT	FIRE SERVICES	LALC	LANDCARE	LOCAL GOVERN-MENTS	ACADEMIA	FUNDING BODIES	PRIVATE LAND MANAGERS
3. Conduct management actions to **protect** aquatic wildlife and habitat **before it is impacted** (e.g., backburning to protect high-value assets).	✔	✔			✔			✔			✔
4. Give selected **ecologists** (or fire services staff with ecological training) the **authority to conduct rapid assessments** as soon as possible following response operations.					✔						
5. Deploy a **survey** to capture observations from the public at short notice and limited cost to inform prioritization of resource implementation.	✔								✔		
Recovery											
1. Assess and identify **habitats and species worse impacted** by the bushfire event.	✔	✔	✔	✔		✔		✔	✔		
2. Develop **models** that can **predict where the worse runoff issues will be experienced**, to inform recovery action, with the need to possibly plan land vehicle access.								✔	✔		
3. Implement the **prioritisation ranking scheme** developed in the 'Preparation' phase to guide recovery action.	✔	✔	✔	✔		✔	✔	✔			✔
4. Follow the **process map** (Figure 3) to evaluate what processes may be kickstarted by the bushfire in local areas of interest.	✔	✔	✔	✔	✔	✔	✔	✔			✔
5. Quickly and readily **support financially and promote monitoring and recovery efforts** that are inclusive of aquatic habitats and wildlife, as well as substitute any monitoring equipment damaged by the bushfires to continue long-term monitoring efforts into the future.								✔		✔	