FROM PRISTINE TO POLLUTED

HOW CHEMICALS AND POLLUTANTS DRIVE

FISHERY DECLINES AND ECOSYSTEM COLLAPSE

Case Study:

Richmond River

New South Wales, Australia

March 2024

FROM PRISTINE TO POLLUTED: HOW CHEMICALS AND POLLUTANTS DRIVE FISHERY DECLINES AND ECOSYSTEM COLLAPSE. CASE STUDY: RICHMOND RIVER, NEW SOUTH WALES, AUSTRALIA

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IPEN is a network of over 600 non-governmental organizations working in more than 120 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals.

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National Toxics Network (NTN) was a not-for-profit civil society network striving for pollution reduction, protection of environmental health and environmental justice for all. NTN worked towards a toxics-free future.

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Cover photo by J Larsson, OzFish Unlimited, Richmond River Chapter

Author’s Preface

My family have given me tremendous support and opportunity in my life. School holidays were always a chance to escape suburbia and be immersed in nature. Often times we’d go somewhere by the water, be it a river, a lake or the ocean beaches. At every opportunity I had a fishing rod in hand, with high hopes for capturing a big fish, but even small fish were enthralling to me.

My Mum was a radiography nurse with an interest in science and biology that I came to share with her. My Dad was a public servant working in quarantine inspection service with an economics background. Interactions with veterinary scientists at my Dad’s work, were formative in influencing my thinking through high school and direction to University.

My interest in aquatic animals continued to grow, but rather than embark on a marine biology degree I chose to explore my interests through a veterinary degree at University of Sydney. Through the undergraduate degree the science of animal health and food production captured my mind and upon graduation I launched into a rural job that spanned dairy cattle, birds, cats and dogs. It was another five years later with an injured back from pulling out calves and repairing injured hooves that my original visions of becoming a fish veterinarian returned.

I was very lucky to again have good fortune shine on me and I commenced work for the State Government as a fish veterinarian at a regional laboratory. The lab was stacked with immensely skilled veterinary pathologists to whom I owe a great debt for their patience in imparting their knowledge to me. The job involved investigating the causes of fish kills and fish disease all around the State, embracing both field work and laboratory diagnostics. The role also had a biosecurity policy component. It was a slow dawning through this time, that all was not well with the health of the rivers. Expanding knowledge helped me recognize there were multiple threats. It became clear to me that disease in aquatic animals was tightly associated with the health of the environment in which they lived.

In wild capture fisheries the media and conservation group narratives were focused on over-fishing. Fisheries management also focused on catch as the dominant influence on fishery productivity - declines were regularly attributed to too much fish being caught. Correspondingly, management responses sought to reduce catches through implementing a range of measures like size limits, bag limits, closed seasons, marine protected areas, license buy-backs, restocking and quota. The effects of the degrading water quality and habitat were not given the same consideration. This struck me as being inconsistent with the evidence of disease expression and mortality incidents which had nothing to do with fishing activities.

Dr Mariann Lloyd Smith, founder of the National Toxics Network (NTN) and member of International Pollutants Elimination Network (IPEN) and Joanna Immig connected with me to co-author the report, Aquatic Pollutants in Oceans and Fisheries**.** Following this endeavor, IPEN supported me, through NTN, with a team of co-authors and editors to produce three case studies: Richmond River, NSW, Australia; Mekong River, Vietnam; and Fraser River, British Columbia, Canada. These case studies explore a history water pollution brought by changes to land-use and changes of pollution governance over time. Each case study gives insight to the current day circumstances and offers up pathways for restoration. A synthesis report brings together common themes from the three cases studies.

I hope that humanity can quickly learn from the global body of science and haphazard pollution governance through time, to achieve restoration of aquatic ecosystems. To do this, relies in no small part, on our ability to control the water pollution we generate.

Matt Landos

Table of Contents

Introduction

The Richmond River and its tributaries trace their way from sources 1000m above sea level to the Pacific Ocean in the north coast of NSW, Australia. The 6,900km^2 catchment receives around 1,300mm rainfall per year in its sub-tropical location predominantly over the warmer summer months.

The 1,000km^2 floodplain forms a large part of the system with the tidal limit extending up to 110km upriver in dry times[1]. Around 11% of the catchment is protected within State based National Parks and reserves. More than 80% of the catchment has been cleared or modified for agriculture and urban settlements including Lismore, Casino, Kyogle, Coraki, Ballina, and Evans Head.

The region has a population of around 130,000 permanent residents, more than tripling since 1950, and more than 2.41 million tourist visitors per year generating significant potable water demand and consequent increases in treated wastewater flow into the river.

The catchment receives run-off from significant scale beef (more than 2,800km^2) and dairy cattle grazing, sugar cane (150km^2), irrigated cropping and intensive horticulture, for macadamia nuts (75km^2), and tropical fruits. Run-off includes sediment, a spectrum of agricultural chemicals (pesticides, veterinary products), surfactants, and fertilisers used in farming, stormwater from regional towns, and wastewater from municipal treatment plants.

The Richmond River supported a First Nations/Indigenous subsistence fishery for food from thousands of years prior to colonial invasion to the present. After European colonization a commercial, recreational, and much reduced First Nations/Indigenous fishery has operated and currently harvests seafood resources from the river.

1 https://rous.nsw.gov.au/floodplains-and-floods

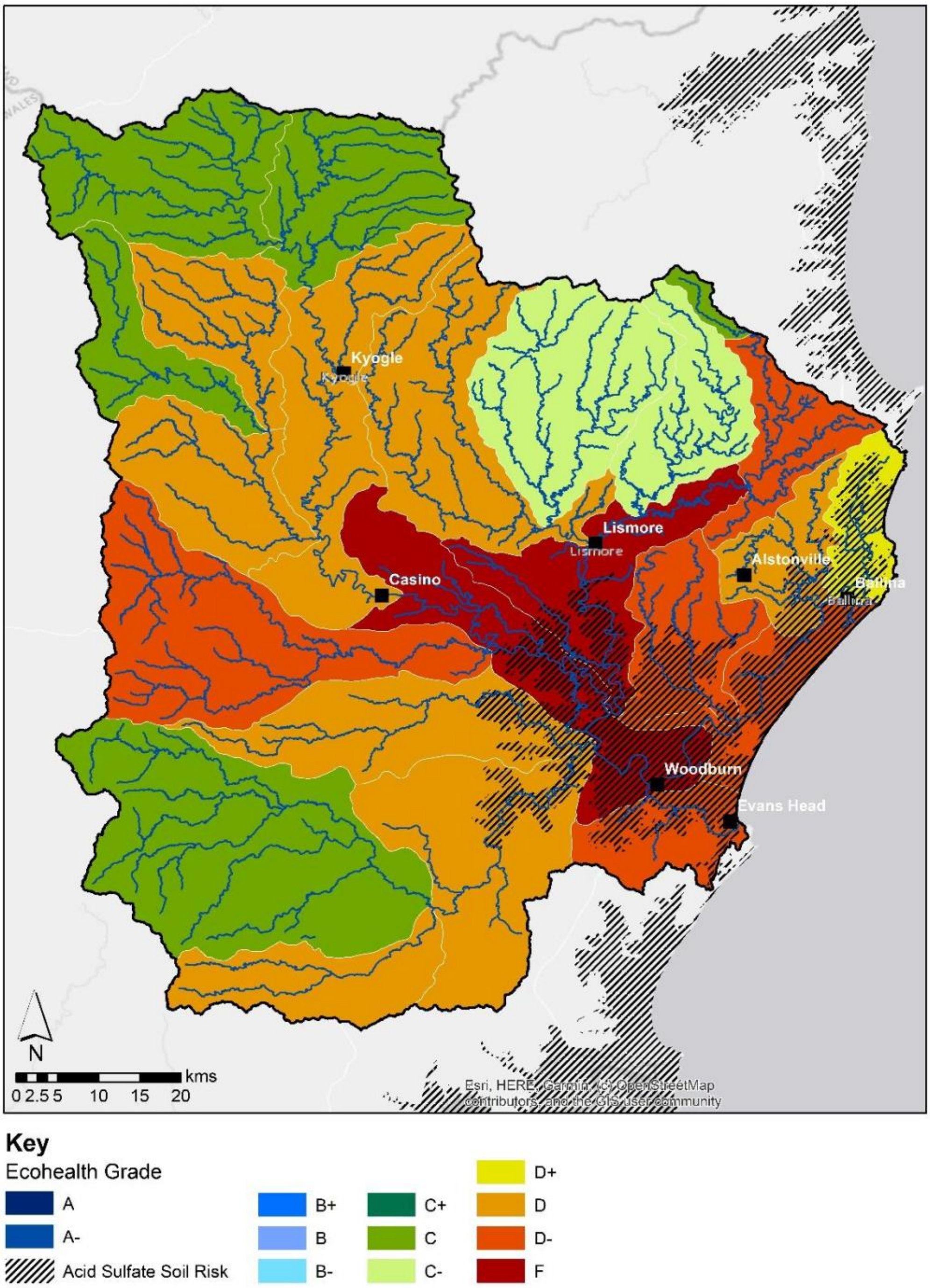

Figure 1: Map of Richmond River catchment with University of New England Ecohealth grades and Acid Sulfate soil risk areas shaded (Source: S. Mika)

Richmond River First Nations people seafood history

First Nations/Indigenous people of the Githabul/Ngarakbul Nations lived around the Richmond River catchment and utilised its aquatic resources for more than 20,000 years prior to the invasion by

European settlers in the 1840's[2]. Thousands of First Nations/Indigenous people were observed by first settlers at various points along the river catchment (89).

> "Bundjalung (Githabul/Ngarakbul) people shared a distinctive pattern of life – seasonal food gathering from the rainforest to the sea, the use of regional bush medicines, cycles of ceremonial events and belief in an ancient and strict customary Law… the spiritual power of the *budheram (budjeram),* the sacred dimension of all life, was universally respected and its secrets protected." (90)

In an early description of Ballina around 1847, a group of 400-500 First Nations/Indigenous people were reported to be camped together during the oyster season adjacent the North Creek midden (piles of oyster shells) (91). The midden sites may also have been culturally important burial sites (92). These substantial oyster middens, up to 400m long and 4m high, contained the remains of shellfish, fish, and marsupials dating back 1650-2000 years. They represent archaeological evidence of sustained annual oyster harvest of an estimated 17 tonnes (93) of the river's shellfish for food and ceremonial significance (92). The shells were also used for spear tips and carved to make fishhooks (94). The middens contained so much shell material they were exploited by early settlers to build roadways in Ballina in 1890 (95).

Prior to colonial arrival and through to at least 1870, First Nations/Indigenous people harvested the natural oyster catch on the mangrove roots.

Figure 2: First Nations people spearing fish in seagrass and collecting oysters off mangroves in Richmond River 1870. Source: Richmond River Historical Society

There is evidence that First Nations/Indigenous groups assisted cultivation of oysters through placement of material back into the river to assist catching juvenile spat (96) and understood the cycle of production timing visitation to when oysters were at their best to eat (97). The abundance of oysters in the river at the time of European settlement was evidence that First Nations/Indigenous people did not over-exploit the resource (98).

2 https://lismore.nsw.gov.au/the-arrival-of-europeans

First Nations people wove nets, known locally as *tow-row*, from Lawyer Cane Vine and twine from the inner bark of the Kurrajong tree that grew around the creeks. The nets were used to trap and catch fish (98).

The productivity of fish and pipis on local beachfronts was reported by local indigenous communities to be part of their food gathering in the 1950's and 60's, indicating the river still had significant fishery productivity up until that time.

> "For the generation who grew up in the 1930s and 40s on the Aboriginal Reserve at Cabbage Tree Island (an island in middle of Richmond River near the Tuckean Broadwater), the Tuckean Swamp continued to be accessed along the waterways and through the land of friendly farmers. Turtles, mud crabs, prawns, mullet, waterfowl, flying foxes and animals from the higher ground such as koalas, possums and bandicoots were among those harvested."[3]

Six seasons of the year, with the accompanying changes in plants and animal activity, provided the signals for what was available (99).

"Sacred lands and hunting grounds were involuntarily turned into someone else's property and families were torn apart to an extent that still impacts on the new generations."[4] Some fishing rights have been reinstated allowing First Nations/Indigenous harvest of seafood resources to the present day for consumption by their community.

The First Nations/Indigenous cultural norm of sharing as opposed to saving for one's personal gratification and advancement (100), likely played a part in protecting natural resources from overexploitation. This contrasts starkly with colonial capitalist values which promoted personal accumulation. The shift in values appears foundational to driving over-exploitation and degradation of the aquatic environment.

***BREAKOUT BOX**

Fishery habitat of the Richmond River

In NSW fish habitat is defined in the *Fisheries Management Act 1994* to include: riparian (riverbank) vegetation; shellfish and mangroves seagrass; saltmarsh; coastal wetlands; rocky reef; inter-tidal sand/mudflats with large populations of infauna; freshwater in-stream gravel beds, large rocks and snags and native aquatic plants[5].

These habitats collectively provide ecosystem services to support the aquatic food web including: direct generation of food (insects, leaf matter for grazing aquatic invertebrates); filtration and sediment sequestration and stabilisation; and physical structures to protect vulnerable early life stages from predation and protect from coastal erosion; habitats for spawning and nursery rearing.

Freshwater wetlands contribute blooms of plankton and zooplankton that are essential food resources for early larval development of fish and prawns. The wetlands also support spawning and nursery areas for many species that contribute to aquatic food webs and move between fresh and saline waters in annual migrations.

3 http://jalilands.com.au/assets/nj-cultural-calendar-2017-a3-version.pdf

4 https://planetcorroboree.com.au/blogs/culture-country/bundjalung-nation

5 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/468927/Policy-and-guidelines-for-fish-habitat.pdf

Figure 3: First Nations people on Richmond River 1865. Note the dense riparian vegetation and significant timber snags in the river creating rich fish habitat. Source: Richmond River Historical Society

CLOSE BREAKOUT BOX****

Colonial invasion and catchment landscape in 1839

At the time first European settlers arrived in 1839 around 750km^2 of the 6862km^2 catchment was covered by the *Big Scrub* lowland rainforest. This was significant because of the role it played in stabilising sediments, controlling nutrients, and supporting persistent stream flows by helping to recharge groundwater. Less than 1% of the Big Scrub rainforest remains today[6]. There was also a vast vegetated 1,000km^2 floodplain and wetland network.

The estuarine and freshwater fisheries were bountiful at the time of early colonisation. The estuary adjacent to Ballina in the main arm of the Richmond River and North Creek had significant sub-tidal oyster reefs, seagrass meadows, and mangroves extending up into saltmarsh and freshwater wetlands.

Colonial changes to land use and fishery habitat

Destruction of sub-tidal oyster reef

A report from 1860 during early colonisation in the Camden Haven River, which has a floodplain around two thirds the size of the Richmond River, illustrates the number of oysters which were rapidly exploited by the colonial capitalists and depleted (101). Bags of oysters, each containing around 1,200 oysters, were shipped down to the rapidly expanding Sydney colony as food and for lime production for use in mortar for construction of the growing colony in Sydney.

6 https://www.industry.nsw.gov.au/water/basins-catchments/snapshots/richmond

Figure 4: Oyster shells in the mortar in the Laundry Vaucluse House built around 1820s © Sydney Living Museums / Historic Houses Trust

> "In the 1860's a man could work his warp stake (rake) into the bed and not leave that spot for sixteen or twenty days, getting fifteen to twenty bags a day all that time. For a long time ten to twelve or even fifteen boats were so employed until only three or four bags could be got… some came back in about three years only to get at most six or seven bags per day." (102)

The uncontrolled exploitation of natural oyster beds by European settlers had removed most of the native oyster beds in NSW by the late 1860's (101), including within the Richmond River, within 25 years of settlement. The Government's initial response was to introduce the *Act to regulate Oyster Fisheries and to encourage the formation of Oyster beds 1868.* Subsequently it held a Royal Commission in 1876 to identify the best way to cultivate oysters, utilise, improve, and maintain natural oyster beds resulting in the *Fisheries and Oyster Farms Act 1884* (103) which capped the number of oyster leases in North Creek and the main arm of the Richmond River.

The oyster industry shifted from harvesting wild oysters, as the sub-tidal reefs were over-harvested and damaged due to siltation, to the cultivation of dredge beds, until the rates of disease from polychaete mudworms increased, forcing more changes to cultivation from around 1887.

The polychaete mudworms may have been inadvertently introduced from New Zealand on oyster spat imported a few years prior to replenish depleted New South Wales stocks (104), or on imported New Zealand oysters that were competing for market share in Sydney (96), although some other scientists question this hypothesis (105).

Prior to this, annual production from the Richmond River had been 576 bags (1759 bushels[7]) totalling nearly 700,000 oysters per year (93). It is likely that clearing the vegetation from the catchment led to increased sediment pollution in the river. This enhanced the conditions for settlement of the mudworms on the oyster shells, as has been reported in other Australian estuaries (105).

7 A bushel of oysters weighs 40-60 pounds (18-27kg) contains 100-150 oysters.

The sub-tidal shellfish reefs have never recovered and the significant keystone ecosystem functions such as: filtration; assimilation of nutrient; substantial production of high value food into the bottom of aquatic food webs in the form of spawning and whole oyster meat; lowering of turbidity; and formation of complex reef structures that offer habitat and protection for other species have been lost (101).

Figure 5: Oysters were a popular food in the new Richmond River colony in the growing town of Lismore in 1911-Comino's Oyster Saloon served them up. Source: Richmond River Historical Society

Oyster farmers transitioned to farming on bundles of cut mangrove sticks referred to as ‘cultch’ (or ‘fascines’ in Europe) around 1902. This triggered the cutting of significant areas of river mangrove trees to replace the cultch sticks every few years during the period between 1900-1950 including cutting and shipping millions of them to other estuaries (106). This activity was responsible for the destruction of more than 3,000,000 river mangrove trees in the Richmond River[8], leading to the loss of fish habitat and ecosystem services.

Mangroves efficiently capture and store nutrient, carbon, fine sediment, and buffer against erosion. When mangrove tree resources were depleted, the industry shifted technology again to tarred hardwood rack and tray systems in the early 1950’s.

There has been some limited recovery of the river mangroves in some areas.

Stress on mangroves has also been studied elsewhere in Australia, where herbicide run-off from sugarcane agriculture (48) was implicated with mangrove die back. However, data is lacking in the Richmond River to understand whether levels of exposure have been harmful to mangroves.

The productivity of the industry in the Richmond River between 1944 and 1970 averaged 364 bags per year (93), each containing approximately 1200 oysters, which suggests the productivity approached half a million oysters a year.

In the late 1960’s and early 1970’s the oyster industry collapsed because of parasitic disease outbreaks attributed to Qx disease (*Marteilia sydneyi*) (105). The disease outbreak occurred concurrently with further degradation of water quality from expanding agriculture with accompanying fertiliser and

8 https://sei.sydney.edu.au/publications/patrick-dwyer-historical-harvesting-of-river-mangrove-for-use-as-oyster-sticks-in-nsw/

agricultural chemical use and massive acid discharges from increased floodplain drainage and floodgate installation below areas of acid sulphate soil.

Year-round commercial oyster farming has now all but ceased on the Richmond River with many leases relinquished. The native Sydney Rock Oyster (*Saccostrea glomerata*) has been depleted with intertidal populations reported to be >90% dead based on local surveys in 2018 (J Larsson pers comm (OzFish Unlimited 2021)).

While data is not available for Australia, data from the USA has shown that a restored oyster reef could provide an additional yield of 2.6kg/10m^2/year of commercial fish and crustaceans, demonstrating the importance of this habitat to fishery productivity (107).

Selective timber extraction, river snag removal and riparian vegetation clearing

In 1842, early settlers exploited stands of red cedar (*Toona ciliata var. australis*) and hoop pine (*Araucaria cunninghamii*) growing near the riverbanks. The trees were hundreds of years old and once cut down were floated to timber mills located further down the Richmond River, before being loaded onto ships for export to Sydney and beyond. Thousands of large trees close to riverbanks were taken first. By the 1850's bullock teams were dragging logs from higher in the catchment to the river (108).

The cedar cutters also removed snags (fallen trees) from the river to allow both free movement of logs in floods and the development of shipping freight routes from the river mouth up to Lismore. The consequence was a rapid increase in sediment pollution as riverbanks were readily eroded without their riparian vegetation cover's filtration capacity and interlinked root systems to hold the soil in place.

Figure 6: Drogher Aggie towing a raft of logs along the Richmond River

Figure 7: Upper Richmond River de-snagging barge circa late 1800's. Note the complete loss of riparian vegetation and in-stream timber habitat. Source: Richmond River Historical Society

Figure 8: Early 1900's timber train and bullock teams transporting logs from Rappville, west of Lismore Source: Richmond River Historical Society

By the early 20th century riparian vegetation had been removed from most of the catchment for cattle access to waterways and cropping to utilize cleared land.

The importance of riparian vegetation was acknowledged as long ago as the 1940's with enactment of the *Irrigation and Water (Amendment) Act 1946* which introduced a prohibition on the destruction of trees in or alongside any prescribed river or lake without a permit on both public and private land.

Despite this, a catchment wide study in 2014 identified the status of riparian zones throughout the catchment was poor with loss of native vegetation, abundant weeds and trampling due to cattle access, with marked active bank erosion driving up sediment concentrations and turbidity moving down the catchment (109).

Another study in 2015 showed that less than 9% of the riparian zone had seen some level of improvement in vegetation in the past 30 years based on aerial image analysis, indicating a substantial amount of restoration is yet to be commenced (110).

Where riparian vegetation remains, it reduces some of the negative effects of land-use on aquatic algae (diatoms) and macroinvertebrate assemblages (111).

In the past 5 years 35 grants have been provided to restore riparian areas on private land, in the Richmond River Catchment, through using NSW Recreational Fishing Licence money, administered through NSW Department of Primary Industries-Fisheries[9]. In addition, $4.25 million AUD has been spent to restore water quality in Emigrant Creek under the new Marine Estate Management Strategy 2018-2028 led by NSW Government Local Land Services working with 34 landholders, through sealing dirt roads, restoring riparian vegetation, and preventing riverbank erosion through installing wave/wash mitigation structures[10].

The shading effect of riparian vegetation has been lost which has promoted the growth of filamentous blue-green algae which in turn, reduces the productivity of invertebrates at the base of the food web and the creatures that rely upon them. The tree roots and snags that had provided physical protection and homes for fish and invertebrates are also lost. Also lost were the insects, leaves and sticks which once fell from the riparian trees and contributed to the base of the food web.

Agricultural impacts

Land clearing

The first farmer settlers arrived in 1862 encouraged by the *Crown Lands Occupation Act 1861* which opened selection of Crown (public) land for sale. From forty to 320 acres could be acquired on the condition of paying a deposit of one-quarter of the purchase price after survey at the rate of 1 pound per acre. Purchasers were required to live on the land for three years, with an intent to increase farming and agricultural development and establish an agrarian population[11, 12]. As part of the "conditional purchase" the selector, as they were known, had to clear several acres of land each year. This was very hard work and if not done, the land would be forfeited[13].

Rapid and vast loss of native vegetation from the catchment followed to make way for cropping and livestock (112). This was in keeping with the colonial attitude exemplified by English philosopher John Locke 1690 in the Second Treatise of Civil Government, that native vegetation was without value and

9 https://www.dpi.nsw.gov.au/fishing/habitat/rehabilitating/ahr-grants-program

10 https://www.lls.nsw.gov.au/regions/north-coast/key-projects/natural-resource-management/marine-estate-management-strategy

11https://www.abs.gov.au/ausstats/abs@.nsf/featurearticlesbyCatalogue/88FD067140FC3F4DCA2569E300102388?OpenDocument

12 https://www.foundingdocs.gov.au/item-sdid-80.html

13 https://www.richhistory.org.au/lismore-history/district-history/dairying/

land values would be increased 10 to 100-fold if man were to labor on the land[14]. This destructive fiction continues to thwart environmental protection efforts to this day.

This further escalated the sediment movement into the river and changed the hydrology as a greater proportion of rainfall rapidly ran off the cleared catchment, rather than penetrated to recharge groundwater.

Regular dredging of the river soon became necessary to counter the rapid sediment influx to maintain river shipping. The Lismore port closed in 1954 as other land transport routes opened[15].

Seagrass meadows once lined the shallow banks of the estuarine reaches of the Richmond River. Seagrass loss is linked primarily to increases in sediment, leading to decreasing light penetration and smothering of meadows (113) (114) (115). The elevated nutrient (nitrate, phosphate) levels from wastewater and livestock discharges also stress the seagrass through promoting overgrowth of epiphytic algae on them (21).

Significant seagrass meadows in the junction of Emigrant Creek and the Richmond River and in North Creek have been degrading over decades with only scarce remnants remaining today. Commercial fishers observed some significant seagrass losses coincided with major flood events which are recognised as major sources of pollutant and sediment mobilisation (116). Seagrass meadows in other areas have been observed to recover in 1-2 years after flood events from persistent rhizome beds and reproduction from adjacent beds (117) (118). The failure of recovery of Richmond River seagrass meadows aligns with the sustained nature of poor water quality.

Dairy and beef livestock expansion and cattle dip sites

The plateau area of the catchment had some early attempts at corn (maize) cultivation that gave way to dairy production in the 1870's. Dairy surged in the 1880's with refrigeration, ice factory, and cream separator technology driving the expansion and eventual formation of the North Coast Fresh Food & Cold Storage Co-operative Company Ltd (NORCO) in 1895 in Byron Bay.

Many farms established alongside rivers for access to water and freight routes for product to be transported to domestic and international markets. By 1905 one fifth of the State's butter was being produced in the Richmond Valley. Butter from the Richmond River dairies was exported to Britain from 1897.

The arrival of agricultural fertilisers around 1900 boosted agricultural production. However, downside costs were externalised to the environment as it drove the eutrophication of the river and generated increased climate-impacting emissions of nitrous oxide. The manure from the milking sheds was hosed into the river daily until regulatory changes in the 1970's reformed this practice. Cattle manure also entered the river directly as cattle had access to the river for drinking water throughout much of the

14 https://www.marxists.org/reference/subject/politics/locke/ch05.htm

15 https://www.richhistory.org.au/lismore-history/lismore-chronology/timeline/

catchment. This, combined with the growing settlement's wastewater, began to burden the river with excessive nutrient pollution.

Cattle suffered from parasitic tick infestations and from the early 1900's were treated with arsenic-based compounds across 1648 cattle dip sites in the catchment. Cattle dip sites were commonly located near waterways to source water diluent for the dipping area. Arsenic based chemicals were used until resistance emerged in the 1950's[16]. From 1955-1962 the organochlorine DDT was used before resistance developed to it and dips switched to organophosphate chemicals. All these pesticides were contamination risks to the river.

Settlers quickly realised that native grasses did not support good dairy production and introduced clover and paspalum. In low lying flood plain areas this inadvertently created new pollution risks to the river, as the introduced grasses did not tolerate inundation and would rapidly die and decompose, consuming oxygen from the overlying water (11). With drainage through constructed channels the toxic water rapidly re-entered the river and contributed to fish kills.

Dairying remained a significant land-use and production was supported through use of fertilisers to improve pasture growth, until it declined in the 1970's when beef cattle farming became dominant and a steady transition to tropical fruit and nut horticultural crops took place that is ongoing to the present day.

Sugar cane and Wetland drainage

Sugar cane cultivation began in the late 1860's (124) on much of the newly cleared land as it proved to be hardy in local conditions. Initially small mills were built on many properties on the plateau and up North Creek, as roads were non-existent (125).

Dredging was also performed in Richmond River and North Creek to aid navigation and movement of cane to mills. The dredged materials were used to in-fill tidally impacted land from 1883-1890, resulting in lost fish habitat such as saltmarsh to further the urban development of Ballina.

There have been dramatic reductions in saltmarsh areas because of in filling for urban development on the floodplain that continues to the present day. Impacts on saltmarsh have accumulated also from grazing stock and installation of floodplain drainage structures such as floodgates for reclamation. All of these changes have altered tidal inundation of saltmarsh since the 1930's (126). High sediment loads from clearing vegetation from the catchment have also caused reduction of salt marsh areas with ingress of mangroves. Unfortunately, in some areas drains and roads are preventing the saltmarsh spreading to new areas as mangroves move in with increasing sea levels.

Nitrogen and phosphate fertilisers boosted sugar cane and other crop production from the 1900's to the present day but have enriched the waters draining the catchment with these nutrients to levels that are harmful to aquatic ecosystems (109).

Those farmer settlers who attempted farming on some flood plain areas suffered sustained and repeated flooding destroying their crops and livestock. The settlers did not realise that many of the

16 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/532458/Arsenic-and-ddt-residues-at-cattle-dip-yards.pdf

lowest areas underlying soils were of acid-sulphate composition. The drainage of these wetland areas began to set off the production and release of sulphuric acid and mobilised toxic metals to drain back into the river.

Wetlands normally function to help slow the flush of flood waters in the main river, filtering and processing the organic matter and driving recharge of aquifers that feed the river water in dry times. Floods on the Richmond used to take an estimated 100 days to re-enter the main flow of the river, but with modern drainage, flood waters now re-enter in less than a week sometimes resulting in deoxygenation of up 35km of river to the mouth and causing massive fish kills (36).

Figure 9: Deoxygenation fish kill Ballina Quays 2008. 35 tonnes of fish taken to dump from the Quays estate alone.

Drainage works began in the 1880's by private landholders. In 1906 the Newrybar Drainage Trust established itself under the NSW *Water and Drainage Act* to 'drain off the flood waters, and so rendering the land fit for grazing and agriculture'.

Public Works completed drainage schemes in 1915 with a desire to drain the Tuckean wetland in the hope of making 16,000 acres of area available for cropping and grazing through hastening the removal of flood water that was known to remain in the area for months.

Initially these early works did not prevent movement of tidal saltwater up drains and into the Tuckean swamp, so some fishery connectivity and production continued through this period.

The large Broadwater sugar mill began operation in 1881 on the floodplain adjacent to the Richmond River, receiving cane barges from growers along the river where cane was planted to the edge of the riverbank. It remains in operation today with cane trucked in. Sugar mills were initially fuelled by burning coal to crush and produce the sugar. Energy from around a tonne of coal was required to crush 12.7 tonnes of cane[17]. In 2005 the Broadwater sugar mill opened co-generation plant which burns biomass from the cane and forestry industries to generate power.

17 https://www.lrrsa.org.au/LRR_SGRa.htm#Northern%20New%20South%20Wales

The extent of habitat loss and increased pollution discharge was dramatically increased in late 1960's and early 1970's when further major flood mitigation works established floodgates on three major wetland areas on the Richmond River floodplain (Tuckean Swamp, Bungawalbyn/Sandy Creek, Rocky Mouth Creek). This precipitated creation of vast acid and toxic metal flows into the river with disastrous consequences for fishery productivity (99).

Many minor meandering watercourses across the floodplain emanating from the former wetlands were straightened and re-purposed as drains which lost all function as an aquatic habitat due to critically low pH values and the creation of anoxic conditions due to the periodic dying of excessive plant growth driven by nutrient enrichment.

Tuckean swamp had been associated with the reliable annual arrival of thousands of ducks to feast in the wetland which First Nations people had hunted prior to colonial invasion (99). They no longer come as the aquatic vegetation and animal life has been replaced with much less abundance of acid and iron tolerant species- the former vast productivity is gone (99). With many Australian estuarine and freshwater fish highly migratory, the loss of connectivity between their desired habitats creates substantial bottlenecks for fishery productivity.

Application of pesticides to control the sugar cane grubs began in 1947 with organochlorines. Mercury-based fungicides were permitted for use on sugar cane for more than 60 years prior to their removal from use in June 2020. This was long after they had been removed in other international countries who had earlier ratified the Minamata Convention on Mercury, making them legally obligated to eliminate uses (127). While Australia signed the treaty in 2013 it was not legally bound by its obligations until it ratified it in December 2021. More detail is provided on theMinamata Convention in the Governance chapter, below. Across Australia in the last 25 years an estimated 50,000 kilograms of mercury has been released into the environment through use on sugar cane.

Today, numerous herbicides, insecticides, and fungicides are used for routine crop applications to the approximately 15,000ha currently under cultivation[18].

Horticulture

In the 1870's colonial settlers attempted to farm macadamia nut trees without success due to lack of knowledge, [19]pests, and fire. However, from the 1970's an industry developed in the middle and upper catchment of the Richmond utilizing pesticides to control pests and disease. Recently macadamias have begun to replace areas of sugar cane cultivation on the floodplain with the macadamia orchards now covering more than 10,000ha in the catchment. Other horticultural enterprises have developed from the 1970's including avocadoes, custard apples, blueberries and bananas. With the emergence of new horticultural crops, there has been a considerable expansion of area now subject to routine spraying with numerous agricultural chemicals.

The macadamia industry's early plantings had problems with orchard floor management due to trees being too densely planted, shading out all the light from the floor of the orchards which were commonly planted on slopes. The bare earth under trees is readily eroded with heavy subtropical rainfall on sloping orchard sites. Large amounts of sediment runoff into rivers and can carry pesticide

18 https://www.aph.gov.au/DocumentStore.ashx?id=8926bf25-a5a8-4d53-a78b-a2779a7f703e&subId=300808#:~:text=Richmond%20River%20cane%20growers%20hold,workers%20and%20600%20cane%20farmers.

19 https://www.wildmacadamias.org.au/rare-macadamias/history/

residues which have dripped off the trees and deposited from sprays during application and bound to the soil particles. This generates toxic risks for the receiving aquatic ecosystem (128).

Private landholders continue to profit from all these horticultural crops but externalize, and thus socialize, the significant adverse costs from some farms failing to adopt best practice land management. These costs impact municipal water storage and filtration, trigger biodiversity loss and drive declines of fishery productivity.

In addition to sugar cane, tea tree plantations have been developed on the floodplains often within drained former wetland areas. They are also sprayed with pesticides and fertilised at times with wastewater biosolids and other fertilisers generating toxic run-off risks for receiving waterways.

Urban development and wastewater treatment

As nutrient pollution loads discharging into the river from the wastewater of growing towns were recognized to be an issue wastewater treatment plants (WWTP) were built. Casino had the first WWTP built in 1932, Lismore followed in 1939[20], Ballina in 1970 and Alstonville in 1976. While these plants improved the quality of wastewater discharge through reducing nutrients, they were still sources of significant nutrient enrichment of the river (129).

Today, WWTP are managed under NSW Environment Protection Authority licenses that stipulate targets for discharge quality. Only nitrate, phosphate, faecal coliform, total suspended sediments, oil and grease, pH and biological oxygen demand are subject to monitoring to meet EPA license conditions.

Current license conditions do not have requirements to monitor, or limit discharge quality, for wastes that are now present in modern sewage influent flows such as pesticides, pharmaceuticals, microplastics, plasticizers and industrial consumer chemicals (130).

Research has identified that Australian WWTP effluent contains the ‘forever’ polyfluorinated alkyl substances (PFAS) from a variety of consumer and industrial applications. Only partial capture of these compounds into the biosolids occurs (131). A study in 2020 identified 69 emerging contaminants at low concentrations in WWTP effluent[21].

WTTPs accumulate sludge that periodically needs to be removed and disposed of. The wastewater sludge, or biosolids, tends to capture most of the contaminants from the influent wastewater. While there are standards for defining its suitability for re-use as an agricultural fertilizer, this can nevertheless represent a pathway for contaminant re-distribution to the catchment. Most of the biosolids material from WWTP in the Richmond River catchment is deemed to be suitable for application to agriculture.

20 https://watersource.awa.asn.au/business/assets-and-operations/nsw-council-slashes-sewage-treatment-costs-with-plant-upgrade/

21 https://watersource.awa.asn.au/technology/research/emerging-contaminants-and-antibiotics-in-wastewater-effluent/

In 2018, the US EPA reported it was unable to assess the impact of 352 pollutants identified in biosolids due to a lack of data or risk assessment tools[22] which raises equally significant concerns about the scope and rigor of Australian assessment.

Some areas of rural housing are not connected to sewer and some on-site sewerage management systems can also contribute to nutrient, pharmaceutical, and personal care product enrichment of the river.

Water extraction in the Richmond River catchment

Dams and weirs

The construction of Rocky Creek Dam (~14,000ML) was completed in 1953 for municipal water supply to the region. It was planned to achieve a safe yield of 9,600ML annually. Emigrant Creek Dam was built in 1968 to support the expanding population in Ballina and Lennox Head with 1,100ML safe yield annually. Toonumbar Dam (~11,000ML) was completed in 1971 and supplies water and irrigation demand in the upper Richmond Valley.

Collectively, the dams significantly alter the volume and persistence of flows down the Richmond River. In turn, this reduced flow, leads to increased concentrations of pollutants like nitrate and phosphate.

The average annual discharge from the Richmond River is 1,920,000ML with wide variation from 15-233% around this figure. Annually around 12,000ML of water demand is taken out of the river catchments for bulk water supply to 41,868 residential properties and 5,114 non-residential properties by Rous Water (132). With climate change predicted to make water supplies more unreliable (133), greater impacts on the fishery are anticipated in the future, as regional populations are continuing to grow rapidly and drinking water demand is anticipated to be 37% higher by 2060 (132).

Around 2345 licences exist for extraction of surface water (Figure 11) for irrigation, stock watering, town water supply, industrial water demand totalling 99,881ML/year.

22 https://www.epa.gov/office-inspector-general/report-epa-unable-assess-impact-hundreds-unregulated-pollutants-land

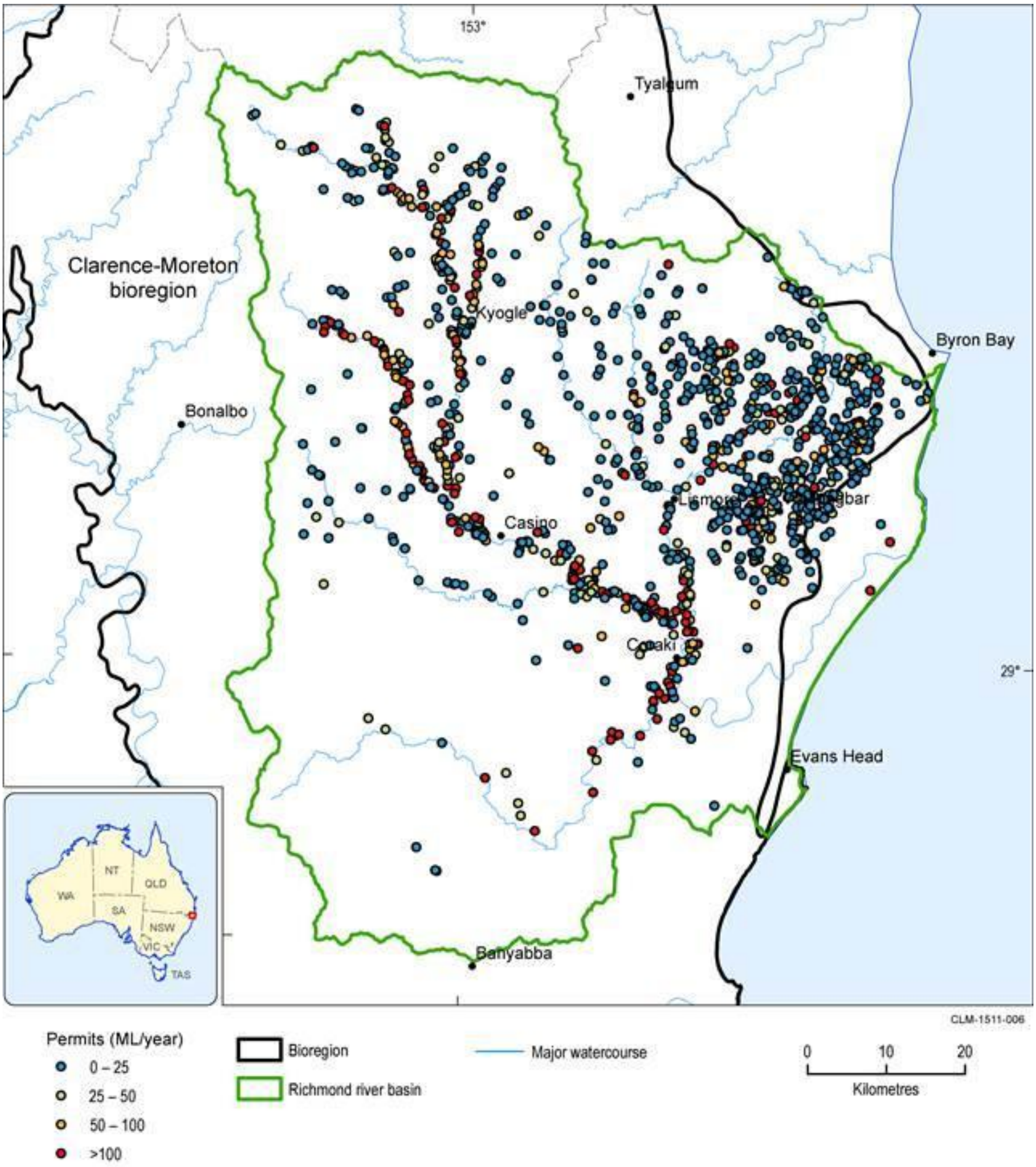

Figure 10: Location of surface water licences in the Richmond river basin (the colour indicates the amount of allocated water) Source: https://www.bioregionalassessments.gov.au/assessments/15-current-water-accounts-and-water-quality-clarence-moreton-bioregion/1511-surface-water

There has, however, been some rethinking of the impacts of engineered structures on the environment with some major weirs built on significant branches of the river which impeded fish passage being removed or redesigned. For example, the Norco Weir built in the mid-1950's near Casino was removed in 2007. The Manyweather Weir near Casino was constructed in 1966 to augment town water supply. It was never used for that purpose and in 2009 it was removed, restoring fish passage to 288km of freshwater habitat. In 2017 a fishway was constructed to replace the Kyogle weir and effectively re-opened fish passage to more than 300km of upper freshwater catchment.

Through State Government funding numerous other fish passage obstructions, such as pipe and box culverts and causeways have been removed in the past 15 years[23], to lower the amount of head loss to <100mm, reduce water velocity and provide deeper water passage.

Bore extraction of groundwater

Around 2400 bores extract groundwater in the Richmond River catchment (Figure 12). A water sharing plan operates for some of these which are regulated (134). Not all bores are licenced with allocations for water extraction. For example, stock bores to supply water to cattle are considered under a basic water right. Around a maximum total volume of extraction is estimated to be ~11,000ML.

Thus, the capacity to restrict extraction is somewhat limited during periods of low flow.

The extraction of significant volumes of groundwater has the potential to compound the effects of dams and weirs on the persistence of stream flow. The Tuckean Wetland is also characterised as a groundwater dependent ecosystem (134), hence it is vulnerable to over-extraction of groundwater during drought periods.

23 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/634612/A-short-summary.pdf

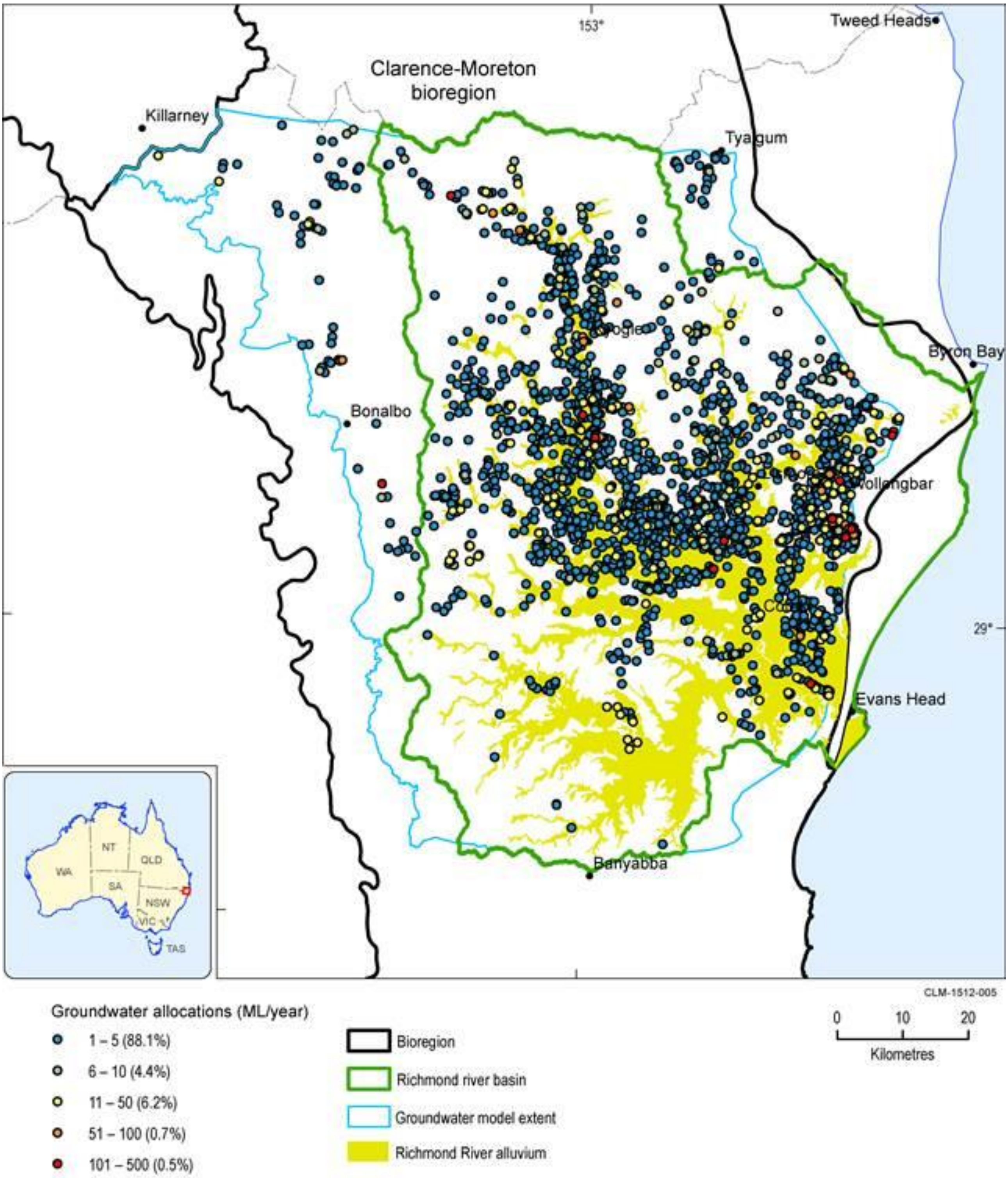

Figure 11: Estimate of groundwater usage per bore within the model domain of the groundwater model for the Clarence-Moreton bioregion, based on assumption 100% of allocation was used. Source: https://www.bioregionalassessments.gov.au/assessments/15-current-water-accounts-and-water-quality-clarence-moreton-bioregion/1512-groundwater

Roads

The catchment is crisscrossed by thousands of kilometers of bitumen, concrete and unsealed dirt roads. The major Australian coastal highway transects the catchment. Stormwater quality is not required to be monitored, prior to its entry into the river.

Unsealed roads contribute significant amounts of sediment pollution to the river. A recent State Government project under the Marine Estate Management Strategy sealed a 5.65km section in the lower Emigrant Creek catchment to reduce the sediment runoff into the river by an estimated 1000 tonnes[24].

Pollution status of Richmond River

The degraded water quality of the Richmond River has been under the spotlight for over 30 years. In that time there have been at least 26 reports[25] from different Government and research agencies that have identified the condition of the Richmond River as poor and developed plans to improve it. Unfortunately, to a large extent, these plans are yet to translate into sustained improvements in water quality, although some small-scale useful catchment restoration activities have commenced in the last 10 years.

Differing land uses are recognized to have negative impacts on organisms that form the basis of the aquatic food web. Diatom algae and macroinvertebrate communities (Figure 11) have been identified to be the worst impacted by cattle grazing and sugar cane (111).

24 https://www.marine.nsw.gov.au/__data/assets/pdf_file/0007/1226797/MEMS-Stage-1-Status-update-report-for-local-government-Initiatives-1-to-3.pdf

25 https://www.dailytelegraph.com.au/news/nsw/lismore/the-dramatic-demise-of-the-richmond-river-a-timeline/news-story/94cce2b5fd5566d8a52c4e38b1c7f468

Figure 12: Macroinvertebrates from freshwater reaches of Richmond River Source: Brendan Cox

Increased Sediment

Clearing native forest for agricultural cultivation and livestock production results in increased sediment flux into waterways, decreased groundwater flow, reduced streamflow persistence, increased run-off leading to increased flood peaks (135). Local observations as early as 1885 had already noted flood severity had worsened because of the significantly deforested catchment (136). Recent all-time flood peaks in 2022, suggest climate change effects are exacerbating these problems now with consequential fish kills and sediment laden flood plumes pushing many kilometers into the ocean.

The loss of riparian vegetation and snags has led to increased bank scouring during floods and bank destabilization and slumping because the filtration effect offered by riparian vegetation has been lost. As a result, there has been massive increases in sediment entering the local waterways.

Forestry activity continues in the remaining remnant native forests within the catchment to this day with around 7000 hectares of vegetation altered or removed per year over the past decade (137). Reductions in the protection of riparian zones from forestry activities, from 10m down to 5m buffer zones, have caused greater sediment pollution risks from this industry.

Studies in 1994-1996 found 75-90% of annual sediment movements occurring during high flow flood events, with the catchment losing more than 200,000T of sediment in an average year (138) with the turbidity elevated after even minor rainfall events.

The huge increase in sedimentation into the river has filled in many deep pools removing fish refuge areas during droughts and smothering aquatic vegetation. Critical spawning habitat such as rocky caves for some species like Eastern Freshwater Cod have been in-filled with sediment due to increased rates of landscape erosion (139). The once prolific large predatory fish is now listed as ‘threatened’ under State and ‘endangered’ under Commonwealth law. There is a recovery plan for the species, however any actual recovery of their numbers in the Richmond is yet to be witnessed.

Historically productive estuary commercial fishery locations for setting nets have become unfishable due to silt shallowing the river in locations like Dungarubba Creek and German Creek.

A more recent significant increase has occurred in the past 30 years with the establishment of around 10,000ha of macadamia nut orchards. Older plantings with poor orchard floor management are estimated up to mobilize 3.8 tonne per hectare of soil due to water flow down the trunk of trees (140) and up to 2 tonne per hectare per year of topsoil can be lost from orchards planted on a 5^{o} slope (141) and 25 tonne per hectare per year from 15^{o} slopes (J Bright pers comm 2023) into waterways.

This sedimentation has altered the river substrates, reducing the most productive gravel and vegetated areas, as finer sediments now dominate the riverbed. (109).

The mostly diffuse nature of sources of sediment pollution are functionally unregulated by Government. Voluntary sediment control measures are encouraged within educational guidance documents. However, the recommendations within these guides are not enforceable.

Nutrient enrichment

The state of the river was described as poor in 1987 by the then State Pollution Control Commission because of excess nutrients from treated industrial and sewage effluent (129). Urban and agricultural run-off contributed to increased turbidity in medium and high flow events. Nutrient levels were elevated downstream of major towns: Lismore, Coraki, Kyogle and Casino and contributed to nuisance algal growth during low flows (129).

Dairy farms were also considered significant contributors of nitrate and phosphate due to the use of fertilizers and intensive nature of farms and river-side locations (129). The loading of nitrate and phosphate entering the river after rainfall run-off events has increased by 2.5 and 3.0 times respectively in the 50-year period up to 1996 (142).

Significant upgrades to wastewater treatment in Kyogle have occurred since 1987. Lismore WWTP was upgraded in 2017 and Casino in 2018 improving effluent in relation to the monitored parameters (nitrate, phosphate, faecal coliforms, total suspended sediment, biological oxygen demand) as required to meet EPA license conditions.

Catchment wide measurement of nutrients in 2014 in the EcoHealth study (109) and subsequent Rous County Council monitoring in some drinking water sub-catchments identified concentrations remained well above the guidelines outlined in (Table 1). NSW Government department of Environment Energy and Science derive their water quality trigger values from the Australian and New Zealand Water Quality Guidelines (ANZECC) 2000[26].

The 2014 EcoHealth study showed the upper estuary had areas of high algal biomass (three times over the guideline value for chlorophyll a) accompanying two-to-six-fold elevations in total nitrogen (TN) and seven-to-fifteen-fold elevations in total phosphorus (TP). The nutrient concentrations generally increased moving down the catchment (109).

This suggests diffuse source agricultural (fertilizer and animal manure) and urban nutrient pollution are a problem in addition to WWTP effluent.

Table 1: Table of derived water quality guidelines from ANZECC 2000 for Richmond River (109)

Category	**Turbidity (NTU)**	**Chlorophyll a (µg/L)**	**NOx (µg/L)**	**SRP (µg/L)**	**TN (µg/L)**	**TP (µg/L)**
Freshwater site above 150m elevation	25	4	25	15	250	20
Freshwater site below 150m elevation	50	4	40	20	500	50
Estuary	10	3.3	15	5	300	30

(NTU- Nephelometric Turbidity Unit, NOx-Oxides of nitrogen; SRP-soluble reactive phosphorus, TN0Total Nitrogen, TP- Total Phosphorus)

There is significant ongoing monitoring data of nutrient loadings in the water supply sub-catchments collected by Rous County Council which illustrate sustained elevations of nutrient loadings.

The macroinvertebrate scores throughout the catchment were low, indicating a loss of critical components of the aquatic food web, likely driven by sustained aquatic pollution and compounded by

26 https://www.environment.nsw.gov.au/ieo/Richmond/report-03.htm#P307_25850

reduced flows due to capture in dams to service growing population demands and greater irrigation use.

Acid discharge, metals and dissolved oxygen

Drained wetlands on the floodplain are contributing to the degradation of the river due to the fact they comprise acid sulphate soils. Rous County Council maintains a series of water quality stations that provide ongoing monitoring data[27] (Figure 12) from these drained former wetland areas. These demonstrate significant acid discharges and large volumes of critically low dissolved oxygen water entering the estuary leading to fish kills (143) and adverse impacts on aquatic productivity.

The acid discharges mobilizes metals into aquatic food webs (34) and contribute to stress, diversity loss and increased mortality in exposed microbenthic communities (144)**,** oysters (145) (29) and fish (32) and other aquatic organisms.

Acid exposure of resident estuarine fish triggers regular outbreaks of red-spot disease (12) contributing to discarding of up to 30% of commercial bream catch at times (B Heynatz pers comm).

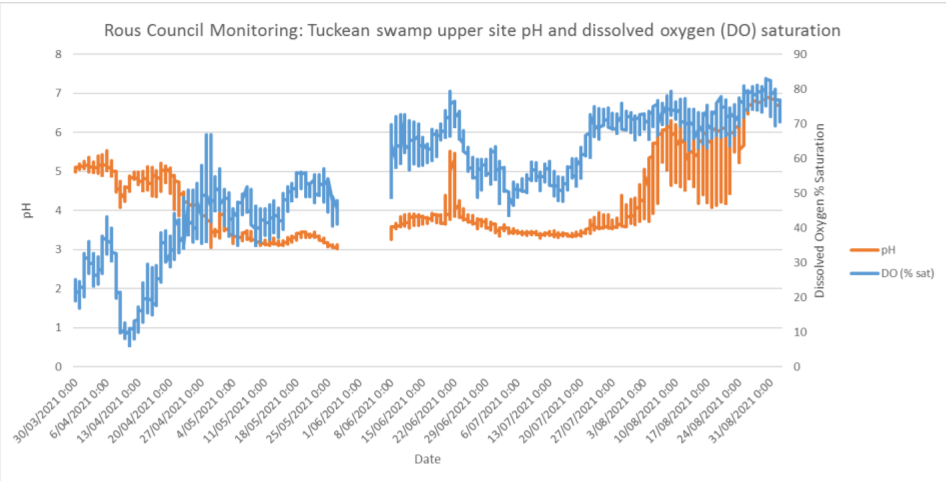

Figure 13: Water quality exiting the drained and flood-gated Tuckean Swamp April to August 2021

Agricultural chemicals

This category includes pesticides (insecticide, herbicide, fungicide, rodenticide) and the wetting agents used to apply them and veterinary products like antibiotics and disinfectants.

Heavy sub-tropical rainfall enhances the risk of agricultural chemical products and metabolites moving from the place of application on land into the river.

Like other parts of the world, after introduction of pesticides from 1947 into agriculture, the persistent organochlorine chemicals made their way into waterways and aquatic food webs. Very high concentrations of residues, up to 110,000ppm of DDT, persist in some soils and adjacent groundwater at historic cattle dip sites (146). Detectable levels of dieldrin and DDT were still present in surveys of

27 https://rous.nsw.gov.au/water-quality-in-the-richmond

fish and birds in 1983-84 (147) and lindane was detected in reticulated water in 1986-87 (121). Aldrin and lindane were detected in drains in 1987. Dieldrin was used on sugarcane until a voluntary ban in 1985 (129). Government reports from 1987 and 1993 identified residues of DDT, PCBs, chlordane and dieldrin in some fish including blackfish (*Girella tricuspidate*), flathead (*Platycephalus fuscus*), sea mullet (*Mugil cephalus*), yellowfin bream (*Acanthopagrus australis*) and whiting (*Silago ciliata*) (148). No more recent data was identified.

An array of pesticides superseded the organochlorines and remain in wide use including glyphosate, triazine herbicides (atrazine, simazine) and diuron, organophosphates (eg chlorpyrifos), mercuric fungicides and neonicotinoids. Currently there are 1606 registered pesticide products and 9 products with active minor use permits just for use on sugar cane in Australia[28].

The NSW Department of Environment, Energy and Science diffuse source pollution strategy does not consider pesticides as a priority group of pollutants.

A 2020 review of pesticide monitoring prepared for Rous County Council identified 89 active constituents as potential water contaminant risks from current and historic use across (149). An aggregated list including pesticides that were identified as being in use from NSW DPI publications of industry pest control guidelines can be found in Appendix 1.

Of the pesticides likely to be used in the catchment, only 5% are tested for each month at offtakes for drinking water supply. Laboratory capacity to test for the full screen identified only 5-30% of analytes could be tested, depending on which laboratory was used.

There is no Government archive of records that keeps track of volumes or types of pesticides used, so critical appraisal of risk is fraught with error, due to significant data gaps There is no immediate laboratory capacity to determine the extent of aquatic contamination for ~70% of the pesticides that are permitted to be applied to the catchment (150).

A range of pesticides are used extensively by local Government for roadside weed control, weed control in drains and on sports fields. Pesticides include the phenoxy herbicides, triclopyr, fipronil and glyphosate-based herbicides. These pesticides are recorded on paper but are not digitally aggregated, nor publicly reported.

The NSW Department of Primary Industries in 2021 still recommends use of chemicals including methomyl, diazinon, beta cyfluthrin carbendazim and neonicotinoid insecticides on macadamias. These are applied by air-blast spray rigs which tend to generate more spray drift compared to boom spray rigs as they have higher release heights, project the spray upwards into the tall tree canopy requiring high fan speeds that create very small droplet sizes which are more prone to drift.

A mercury-based fungicide, Shirtan, registered for application to sugar cane was only removed from use in 2020. There is no contemporary data available on mercury loads in Richmond River fish. A 1976 study identified elevated mercury content in bream from the nearest major river (Clarence River) at 0.54mg/kg which is above the 0.5mg/kg guideline for human consumption (151). Oysters from the Richmond River were tested by Southern Cross University in 2018 from a lease near the river mouth.

28 www.apvma.gov.au search Pubcris “sugarcane” accessed 6 October 2021.

Levels of mercury were below human consumption guidelines at <0.12mg/kg wet weight (A Reichelt-Brushett pers comm 2018).

Rous County Council water quality monitoring detected widespread glyphosate residues in 2003 in the drinking water sub catchments of the Richmond River. Repeat sampling performed for Rous Water in 2009-10 at two locations where water is sourced for drinking water, failed to identify any of the 31 pesticides in their limited screen of the 68 pesticides known to be in use in the catchment at the time. Detections of diazinon from macadamia farm use were found in 2017 in Emigrant Creek dam. More recent data generated by Southern Cross University using more sensitive passive sampler techniques has continued to find residues of a range pesticides at multiple catchment locations confirming offsite movements (A Reichelt Brushett 2021 pers comm).

For the past two decades there has been no comprehensive monitoring data for the Richmond River below the drinking water offtake points. Based on similarity of land-use types and rainfall, the identification of chlorpyrifos, 2,4-D, atrazine, diuron, hexazinone, metalochlor, and tebuthiuron in a single sample from the adjacent Clarence River Catchment (43) suggests pesticide residues are likely to also be more widespread in the Richmond River.

There have only been four samplings since 1986: Rous County Council (119) (120); Southern Cross University (A Reichelt-Brushett pers comm 2021) and others (121) have detected several herbicides. Given the routine application to crops, roadside verges and drains in a high rainfall catchment, frequent ingress to the river is expected. These have likely contributed stress (122) to the seagrass as has been described in other areas of Australia also adjacent sugar cane, soya, macadamia, banana cultivation (123).

A further comparison with the more detailed sampling undertaken in Great Barrier Reef catchments illustrates aquatic pollution is occurring with numerous herbicides, fungicides, and insecticides including neonicotinoids (152). These have been clearly associated with damage to the aquatic food web and fisheries habitat (48) (47). Similar land use patterns and pesticide use in the Richmond River catchment signal that similar river pesticide pollution is likely occurring, but it goes undetected due to inadequate monitoring.

PFAS (Polyfluorinated alkyl substances) and PBDE (Polybrominated Diphenyl Ethers)

Firefighting foams and fire retardants are highly likely to be entering the Richmond River via wastewater and storm water as detected elsewhere (79) and as noted in the PFAS National Environmental Management Plan version 2.0[29]. They may also be re-entering via mobilisation from wastewater sludge which is applied to agricultural land on the floodplain and concentrates in soil (153).

A single timepoint sample in Emigrant Creek taken by Rous Water, after a recorded incident, failed to identify any PFAS or PBDEs at any of the six sites tested, which receive some stormwater run-off from roads. The Emigrant Creek sub-catchment does not receive any wastewater treatment plant effluent, or sludge biosolids, so is unlikely to be representative of the entire catchment. PFAS and PBDEs are

29 https://www.awe.gov.au/sites/default/files/documents/pfas-nemp-2.pdf

known to accumulate in Wastewater Treatment Plant (WWTP) sludge ponds and are released with effluent (131).

Ballina and Lismore Councils do not measure the concentration of PFAS or PBDEs in wastewater released as NSW Environment Protection Authority (EPA) does not require them to under their licence conditions. The biosolids intermittently removed from Ballina plant are distributed onto agricultural fields on the floodplain. No monitoring of the potential run-off is undertaken.

It is expected that levels of PBDEs in Richmond River sediments will be relatively low compared to Europe, North America and Asia, based on scattered sampling elsewhere in Australia in 2002-2003 (154).

Surfactants

Surfactants such as alkylphenol ethoxylates are considered ubiquitous contaminants due to their widespread industrial, consumer and agricultural use, high mobility, high volume of use and persistence in water. No data for the Richmond River was found. Ballina and Lismore Council's wastewater operators do not actively monitor for the presence of these compounds, and the NSW EPA discharge licences do not require them to.

Pharmaceuticals and personal care products

It is likely contaminants are present in the Richmond River as studies in other Australian WWTP demonstrate incomplete removal of a range of pharmaceuticals and personal care products (155). As the rate of pharmaceutical consumption in the population continues to increase, the load of pharmaceutical contamination continues to expand due to the failure of regulation to require complete removal from effluent prior to discharge[30]. Personal care products are also a source of microplastic pollution.

Ballina and Lismore Council do not undertake any surveillance for pharmaceuticals in wastewater released into the river as they are not required to under the operation of their EPA licences. Some monitoring is performed on the ocean outfall from nearby Lennox Head WWTP.

Microplastics and associated toxic contaminants

No data could be identified to determine the level of microplastics and associated contaminants in the Richmond River, however it is highly likely they are present, since home washing machines and WWTPs (156) do not completely remove them and stormwater is expected to transport fragments of tyre abrasion and plastic litter from roads.

Ballina and Lismore have greywater recycling systems operating which may lead to spreading microplastics via irrigation back onto the catchment as has been described elsewhere (157).

Wastewater sludge, or biosolids, is often diverted for re-use in agriculture and is applied to floodplain farms such as tea tree plantations, where it can run-off into waterways in heavy rain. Ballina and

30 https://ntn.org.au/wp-content/uploads/2015/05/NTN-Pharmaceutical-Pollution-in-the-Environment-2015-05-1.pdf

Lismore Council do not undertake any monitoring for the presence or quantity of microplastics which are being discharged in wastewater. Plastic films are also utilized in some local agriculture such as blueberry farms, that can degrade and become another source of contamination.

Rubber tire derived chemicals and poly aromatic hydrocarbons (PAHs)

No monitoring data is available to quantify levels in the Richmond River for these contaminants to enable an assessment of the potential toxicity on aquatic food webs.

Diffuse source storm water pollution is not functionally controlled as the agency responsible for it, NSW Environment, Energy and Science, lacks the head of powers, and the multiple agencies who have some interface with the issue have yet to resolve how to monitor or mitigate the potential pollution impacts.

Ballina Shire council requires all new development applications to demonstrate how the proposed stormwater systems achieve the following minimum reductions in pollutants: 80% reduction in total suspended solids (TSS); 60% reduction in total phosphorus (TP); 45% reduction in total nitrogen (TN); 90% reduction in gross pollutants (GP). Litter traps are used on stormwater, however fine entrained or dissolved contaminants are not treated, or monitored by councils before they enter waterways.

With thousands of kilometers of roads and a major motorway passing through the catchment some stormwater pollution is inevitable from these classes of chemicals.

Greenhouse gases (carbon dioxide, methane, nitrous oxide) and climate change

The rapidly growing population and agricultural industry in the region is continuing to contribute to increasing local emissions of greenhouse gases. While total grid power consumption is relatively flat (offset by uptake of rooftop solar) (158), other sources of emissions such as vehicles and agriculture and methane from poorly managed landfills are increasing. Specific local data on greenhouse gas levels is not available, defaulting to the national monitoring levels.

Long term water temperature data was not found for the Richmond River. Modelling suggests annual mean air temperatures may rise by up to 2.3°C with a significant reduction in stream flows of up to 24.3% also predicted by 2099 (159). Local oyster farmers have lost some oysters in the past 3 years due to high air temperatures in summer exceeding the tolerance of the native farmed oysters when they are exposed to air at low tide. The increased intensity of rainfall is exacerbating the erosion of the destabilized catchment compounding the issues in the river and putting more stress on the fishery and its habitat. 2022 marked the most severe flooding in the catchment in recorded history.

Local volunteer group OzFish Unlimited have identified through saltmarsh field mapping the stead ingress of mangroves into areas of former saltmarsh that may be a further sign of sea level rises (S Posselt pers comm 2022).

BREAKOUT BOX

Byron Bay local council are the most progressive of the local Government bodies in creating a Net Zero Emissions Action Plan for Council Operations. They are planning a rapid transition by 2025 to 100% renewable energy use through:

-solar installations, changing streetlights to LED

-development of a bioenergy facility

-undertaking performance audits on all council buildings

-transition to electric council vehicles and tools

-investigate fuel efficiency of heavy vehicle fleet and transition to renewable fuel sources

-explore car sharing services and options for decentralized workforce

-planning to embed emissions reduction into procurement policies

-conduct education for staff on carbon monitoring and offsets

-implement a carbon offset policy for Council

-incorporate carbon neutral criteria into leasing and licencing of council assets

-implementing the integrated transport plan and bike plan

-finalizing the sustainable visitation strategy

-investigating alternative construction materials for infrastructure

Byron Council are implementing a Zero Waste Strategy through implementing best practice waste avoidance, waste recovery and management. Measures underway include:

-improve the efficiency of the wastewater treatment plant (WWTP) and pump infrastructure

-improving water efficiency and maximizing the use of recycled water and alternative water sources

-encouraging events to utilize the Event Guide for sustainable events and emissions reduction. [31]

CLOSE BREAKOUT BOX

Fishery changes through time

The biology of some fish, shellfish, and shrimp (prawns) captured involves migration from freshwater or estuarine reaches to open ocean and along the coast between coastal estuaries. Hence, catch declines reported in the Richmond River, can be indicative of both declines in local productivity, but also from adjacent estuaries which have been impacted by a similar pattern of development. The inter-connectivity of the fisheries warrants management regimes to cover the entire geographic range of the individual species (160).

Freshwater species

Eastern Freshwater Cod (*Maccullochella ikei*)

31 https://www.byron.nsw.gov.au/Services/Environment/Climate-change/Climate-Change-Plans-and-Strategies?BestBetMatch=climate%20change%20emissions|d13b95b2-5146-4b00-9e3e-a80c73739a64|4f05f368-ecaa-4a93-b749-7ad6c4867c1f|en-AU

Eastern Freshwater Cod were once so abundant that early settlers were reported to have used them for pig feed as well as human consumption (161). In 1920 "Kid-O" wrote in Smith's Weekly published in Sydney "Any fisherman on the Richmond River will tell you that codfish of 6 and 8 lbs. are caught almost daily." They have been recorded to grow to 42kg in weight.

Around 1926, coinciding with the construction of the North Coast railway and an influx of workers, the Eastern Freshwater Cod was reported to have declined in abundance from over-fishing including use of dynamite and habitat degradation in the Richmond River with scarcely any captures at all after 1971[32]. Much of the critical habitat such as woody debris, deep pools and rocky caves have been lost.

The species was listed as Totally Protected under Section 19 of the *NSW Fisheries and Oyster Farms Act* in 1984 and subsequently also listed under the *Biodiversity Conservation Act 2016* and is on the IUCN Red List of Threatened Species 2019 (162).

Some attempts at restocking of hatchery bred Eastern Freshwater Cod took place in 1988-89 into locations which had suitable habitat. Post-stocking monitoring over the subsequent 5 years indicated some survival was achieved. However, no further surveillance has been undertaken to determine current status.

After listing as an endangered species in 2000, under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, a recovery plan was produced in 2004 by NSW Fisheries[33] and reviewed in 2016[34]. Today, there are priority actions which remain on the agenda however funding to support them has yet to be applied. This includes actions to minimize risk of habitat degradation. The species has yet to recover populations or expand back into historic areas of its range in the Richmond River with the ongoing sources of water pollution discussed above likely inhibiting this.

Figure 14: Eastern Freshwater Cod   Source: https://www.dpi.nsw.gov.au/fishing/threatened-species/what-current/endangered-species2/eastern-freshwater-cod

Freshwater eel-tailed catfish (*Tandanus tandanus*)

32 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/636399/Eastern-Freshwater-Cod-Recovery-Plan.pdf

33 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/636399/Eastern-Freshwater-Cod-Recovery-Plan.pdf

34 https://www.dpi.nsw.gov.au/fishing/threatened-species/what-current/endangered-species2/eastern-freshwater-cod/review-recovery-plan

Once common throughout the freshwaters of the Richmond River the species has a nest building reproductive habitat requiring clean gravel beds. The influx of sediment and contaminants in sediment have likely contributed to the decline of this species.

First-hand accounts from river residents reported catfish as prolific in freshwater reaches of the Wilson's sub-catchment (126). In the same stretches of river, fish are now a rarity. The once crystal-clear water is now turbid, with flows outside of rain events reduced due to increased extraction for agriculture, capture in dams and reduced groundwater flows due to catchment clearing and reduced groundwater recharge.

Purple-spotted gudgeon (*Mogurnda adspersa*)

These small fish were once widespread and abundant in the Richmond River freshwater reaches. Today they are only recognized in a small section of one tributary and are listed as endangered in NSW under the *Fisheries Management Act 1994* and the *Biodiversity Conservation Act 2016.* They are on the IUCN Red List of Threatened Species 2019 (163).

The fish are not subject to any commercial fishing pressure as they only grow to 12cm in length but can be the target of aquarium fish collectors. Their decline has been attributed to loss of habitat such as aquatic plants, which in turn is likely due to the combination of sediment, nutrient and herbicide pollution. Other threats include predation by the exotic introduced fish Gambusia (*Gambusia holbrooki*) and changes to water flow that impact reproduction and recruitment (164).

A Priority Action Statement[35] has been prepared which flags the need to implement relevant State policies and programs such as the NSW Diffuse Source Water Pollution Strategy to reduce water pollution particularly from agricultural chemicals. Priority rehabilitation tasks include sediment and erosion control, restoration of riparian vegetation and large woody debris, removal of cold-water pollution and barriers to fish passage. Habitat Action Grants have assisted in the restoration of some areas of riparian vegetation and removal of barriers to fish movement such as road crossings. However, monitoring of populations to determine if improvements have been achieved is yet to be commenced.

Figure 15: Purple spotted gudgeon (left), Oxleyan Pygmy perch (right) *Source: G. Schmida*

Oxleyan pygmy perch (*Nannoperca oxleyana*)

This small species commonly around 45mm and 2.8g was once widespread in the Richmond River coastal floodplain freshwaters. Now they survive only in small, fragmented populations. The declines

35 https://www.dpi.nsw.gov.au/fishing/threatened-species/what-current/endangered-species2/purple-spotted-gudgeon/priorities-action-statement-actions-for-the-purple-spotted-gudgeon

are reported to be due to coastal development, habitat degradation, water pollution and competition from introduced exotic species like Gambusia (*Gambusia holbrooki*) (165).

The species is listed as endangered under both the NSW *Fisheries Management Act 1994* and *Biodiversity Conservation Act 2016,* and under the Commonwealth *Environment and Biodiversity Conservation Act 1999* and is on the IUCN Red List of Threatened Species 2019 (166). The NSW Department of Primary Industries developed the Oxleyan Pygmy Perch Recovery Plan and background paper in 2005[36]. This was reviewed in 2015 [37] and a Priority Action Statement for the species[38] guides current actions as funding becomes available.

Migratory Species

The Richmond River has several catadromous fish species which spawn in marine water and live for periods in freshwater. Both the adults and larvae can move between estuaries along the coast.

Sea (Bully) Mullet (*Mugil cephalus*); Sand Mullet (*Myxus elongatus*); Flat-tail mullet (*Gracilimugil argenteus*)

Mullet was always an abundant and important species for First Nations people. They were also an important food source for early colonial settlers who reported catching them regularly with ease into the 1920's.

Upper catchment populations have declined dramatically over many decades as water quality declined and vegetative habitat and food web productivity was impacted. Mullet target zooplankton, microalgae, dead plant matter and detritus in the sediments on the bottom of the river for their food resources.

Settlers living on the floodplain reaches of the river recount the sound of many thousands of mullet moving down river in front of a flood, accompanied by the crashing sounds of schools of mulloway devouring the mullet- they sounded like a herd of cattle going past up until the early 1970's. Sea mullet were so abundant prior to the early 1970's in the lower river reaches, that fishing could still be practiced without using a net or a hook. Simply by hanging a lantern in a boat at night, the fish would jump towards the light and be batted into the boat. Catching 50 fish an hour, "mullet hopping" was common according to Auntie Phoebe (Mumbler), who had relations in the Aboriginal Community on Cabbage Tree Island in the Richmond River. Garfish were able to be scooped with a hand net, as they moved to the light.

36 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/636379/Oxleyan-Pygmy-Perch-Recovery-Plan.pdf

37 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/635455/Review-of-the-oxleyan-pygmy-perch-recovery-plan.pdf

38 https://www.dpi.nsw.gov.au/fishing/threatened-species/what-current/endangered-species2/oxleyan-pygmy-perch/priorities-action-statement-actions-for-oxleyan-pygmy-perch

Figure 16: Early mullet fishers from early 1900's filling their boat with their abundant catch Source: https://digital.sl.nsw.gov.au/delivery/DeliveryManagerServlet?embedded=true&toolbar=false&dps_pid=IE1697634&_ga=2.156721211.1668191916.1636930381-539801085.1636930381

Mullet have remained a critical component of the licenced commercial catch. Average catch estimates from 1941-1950 were ~175,000kg/year (93). Today catches are down to an average under 100,000kg/year.

While the State Government stock assessment considers current levels of catch at the aggregated State level to be “sustainable”, they are down by more than 50% from peaks in 1993/94 to catch recorded in 2018/19 (167). The mullet fishery is not currently subject to Quota or Total Allowable Catch (TAC) management measures. Catch in 2022 appears well down under 30 ,000kg (J Gallagher per comm 2022).

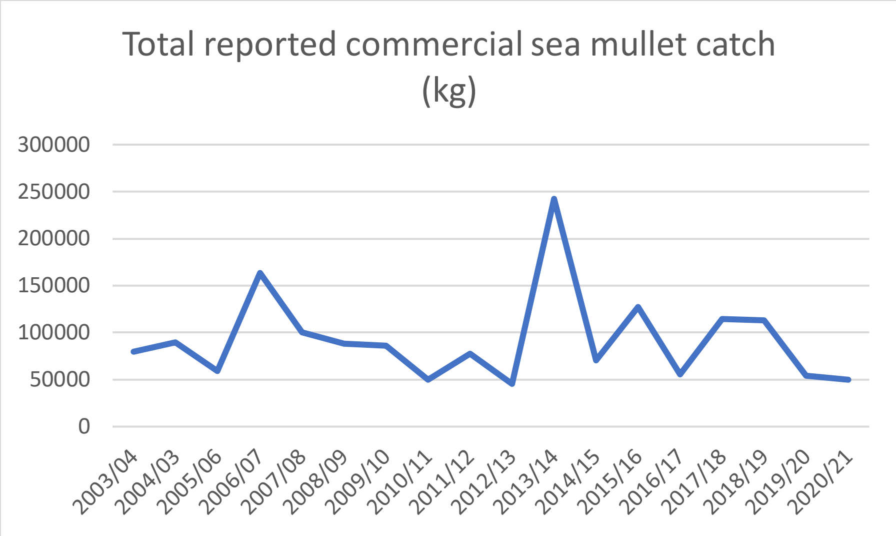

Figure 17: Historical Sea mullet commercial catch from the Richmond River (Data source: NSW DPI Catch Data)

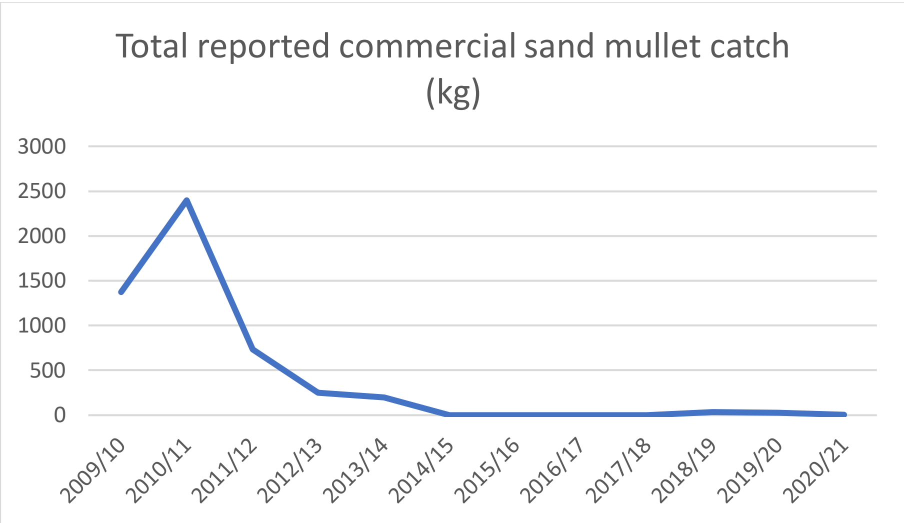

Figure 18: Historical sand mullet commercial catch data from Richmond River (Data Source: NSW DPI catch data)

Estuarine-Marine fish

Yellowfin bream (*Acanthopagrus australis*)

The estuarine fishery was still considered abundant in the 1920's. Mike Reardon, a commercial fisherman from 1930's relayed the detail of a large catch of nearly 11 tonnes of bream near the outlet of a floodplain swamp. Such catches are now totally unheard of.

Through the 1970's-1990's local commercial fisherman had reliable net fishing spots for bream adjacent the seagrass near the Tuckean broadwater. Today the seagrass in this area is gone. Sediment in-filling has caused substantial shallowing of the area and the area is no longer a reliable location for commercial fish catch (J Gallagher pers comm 2021).

By 1988 the total commercial annual bream catch was down to 2.6 tonne. Some commercial bream catch continues to the present, but due to poor water quality around 30% must be thrown back due to red spot skin ulcers in periods after rain (B Heynatz pers comm 2021).

The increased sediment load has changed the river's depth with many areas becoming shallow changing their suitability as fishery habitat. This shallowing has also altered the hydraulic flushing capacity achieved by tidal movement and thereby impacting on water quality and oceanic exchange.

Declines in fishery productivity became more evident into the 80's with estuary dependent species like mulloway, mullet and school prawn continuing to decline. (16)

Mulloway (*Argyrosomus japonicus*)

Historically, juvenile mulloway populated the deeper mid-estuary sections of the Richmond River. Adult fish also utilized the river and chased schools of mullet right up into the floodplain swamps where some were historically captured. The estuary food webs provide the feed resources for their juvenile recruitment. As they grow to a large size, they were a popular target for recreational and commercial fishers.

Commercial landings of mulloway across all of NSW declined from almost 400t in the mid-1970s to just 48 tonnes in 2018-19. The NSW Government stock assessment for mulloway in 2020 described the stock as depleted (168). The frequency of recreational catches of keen local anglers has uniformly declined over the past 40 years. The average size of each fish from commercial captures in recent years has increased (168), suggesting that there are less smaller fish surviving in the fishery, pointing to potential impacts occurring to recruitment.

School Prawn (Shrimp) (*Metapenaeus macleayi*)

Historically, school prawns were reliably caught in pocket nets by commercial river fishermen and offshore by trawler operators. School prawns have gone from being a reliable high-volume catch, to a sporadic lower volume catch over the past 30 years based on Ballina Fishermen's Cooperative catch data.

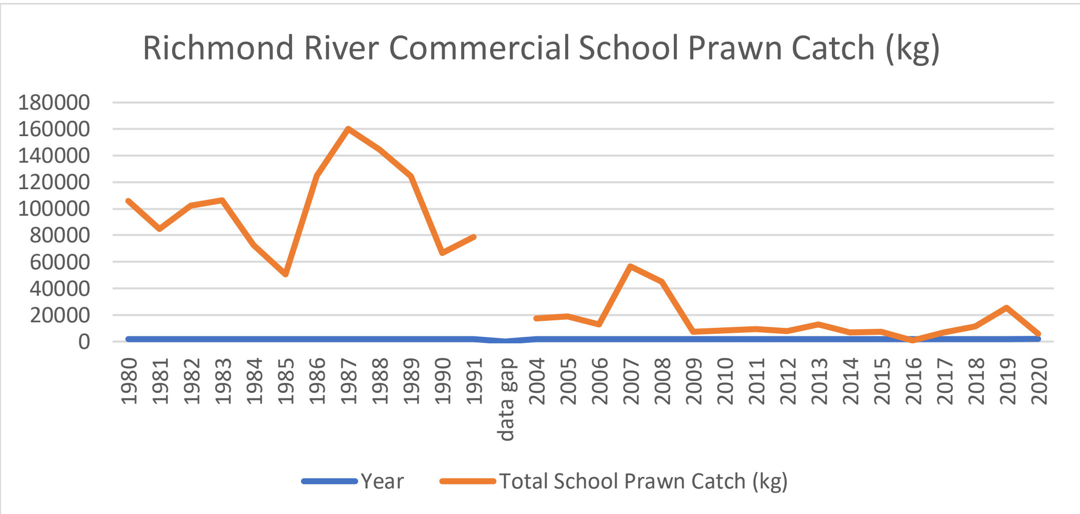

Figure 19: Historical commercial catch of school prawns from the Richmond River and adjacent ocean trawl fishery (Data sources: NSW DPI Catch Data and Ballina Fishermen's Co-operative).

School prawns utilise habitats such as seagrass and mangroves within the river for larval development. The decline in catches aligns with habitat destruction and escalating diffuse source pollution loads in the river.

Figure 20: Richmond River prawn trawler for ocean school prawns. Commercial prawning within the river performed with set pocket nets, not trawlers. Source: commons.wikimedia.org/wiki/File:Richmond_River_Prawn_Trawler.jpg

Dusky flathead (*Platycephalus fuscus*)

The past abundance of this species in NSW was clearly significantly higher than it is today. In 1908, using primitive fishing equipment compared to that used today, it was reported that "…about 525,000 pounds … is brought to market annually from all State waters, and in addition a very considerable quantity is captured by anglers using handlines." (169)

Dusky flathead catches used to be a reliable weekly supply through the Ballina Fishermen's Cooperative. Today the Co-op reports that catches are sporadic with at times, weeks passing between flathead coming in. Commercial fishers used to reliably catch them in the broadwater, but this area no longer supports commercial catches.

At the aggregated NSW State level commercial catch data over 68 years indicates stable catches of 150-250T/year across NSW. Commercial catches declined in the early 2000's to 118T in 2019 and have not recovered. Despite these clearly reduced catches, the catch is nevertheless reported by NSW Department of Primary Industries to be 'sustainable' (170). Recreational fishers may now be catching more aggregate volume than commercial fishers due to improvements in equipment and increased numbers of anglers, but they too are reporting declines in the frequency and abundance of captures in the Richmond River (pers comm A McDowell (local recreational angler)).

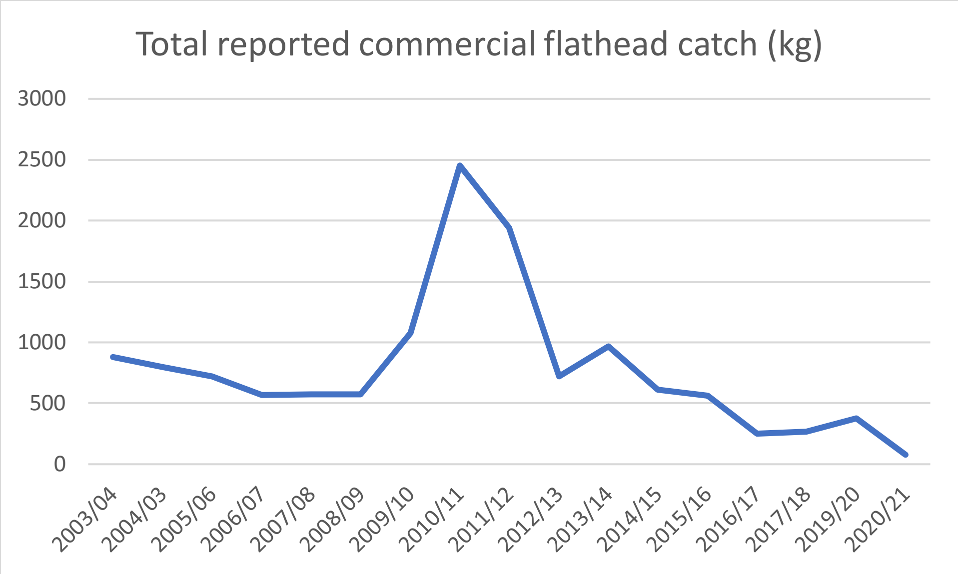

Figure 21: Historical commercial catch of flathead in the Richmond River (Data Source: NSW DPI Catch Data)

Estuarine Marine fish other species

Eastern Sea Garfish (*Hyporhamphus australis*) are occasionally captured in the lower Richmond River. River garfish (*Hyporhamphus regularis ardelio*) and freshwater Snub-nosed Garfish (*Arrhamphus sclerolepis*) have not formed a significant part of the commercial fish catch since the mid-1940's in the Richmond River. They are infrequently targeted by recreational anglers (171). The three species were described as overfished in late 1990's after significant declines in catches (172). Eastern sea garfish was moved under quota management. In 2021 catches were below the 45 tonne quota volume, well down from the catches of more than 150 tonne/year through the 1980's. Nevertheless, NSW DPI-Fisheries described the species as 'sustainably' fished.

Small populations remain, but they are only caught sometimes, whereas previously they were abundant (Anon commercial fisher pers comm 2021).

Garfish utilise seagrass habitats for food and for reproduction. With diffuse source pollutants destroying most of the seagrass in the river, it is unsurprising that catches have declined.

Figure 22: Snubnose garfish (Arrhamphus sclerolepis) Source: Lek / Bowerbird, http://www.bowerbird.org.au/. License: CC by Attribution-NonCommercial-ShareAlike

Estuary perch (*Percalates colonorum*) were observed to have suffered stock decline and were subsequently banned from commercial catch in the 1960’s. There remains no sign of their stock recovery today despite the absence of any commercial fishing pressure for them and little recreational effort targeting them.

Lived experience of commercial fishers

Interviews by the author with several retired and remaining commercial fishers noted declines in their lifetime of catch abundance. Some observed a sharp decline from when the first diseased fish with ‘red spot’ were caught in 1969-71. This coincided with wetland draining and floodgate installation and increased acid discharges. It also coincided with expansion of pesticide and fertilizer dependent agriculture in the drained low-lying areas.

Commercial fishers recognize the importance of habitat such as seagrass as critical food and cover for their target fish. Hence some fish were reliably targeted around these habitat areas. Commercial fishing data suggests that the activity of netting was not the cause of declines in seagrass in North Creek. When commercial fishing was removed from North Creek the seagrass cover has not recovered, rather it has continued to decline. It remains more likely that degraded water quality was the driver of seagrass loss, with low pH, elevated turbidity, herbicide run-off from roadside and drain spraying and discharges from the Ballina WWTP altering the resilience of the seagrass meadow.

The numbers of commercial fishermen working the river for a full-time job has steadily declined. In effect the numbers of fishers are a proxy for the productivity of the fishery. During 1960’s around 28 fishers derived their full-time income from commercial fishing the Richmond River (J Gallagher per comm 2021). This declined to around only 6 full-time fishers in the mid 1990’s (171). There are now no full-timers and only 10 part-time fishers left (Ballina Fishermen’s Cooperative pers comm 2021). The productivity of the fishery is simply no longer there to support a once thriving industry. Even accounting for improvements in gear like new lighter stronger nets, new outboards and trailer boats, and the increase in recreational fishing effort, the decline in catch volumes is indicative of substantial loss of productivity from the river. The continued decline points to ongoing impacts from diffuse source pollutants impacting the water quality, food web and habitat.

Will increased management of fish catch restore the fisheries of the Richmond River?

Limitations of traditional stock assessment

The Richmond River is a clear case where the fishery has declined in productivity and where overfishing appears to have played little, if any, significant role in contributing to this outcome. Shifting fishery management and land management regimes through time have thus far failed to support the conditions necessary to recover the former productivity of the fishery.

Emeritus Professor of Fisheries Management, Bob Kearney, on reviewing the Richmond River in 2015 stated commercial fishing pressure had declined to ~20% of historical levels based on unpublished Government Fisheries data. He concluded in relation to the acid discharges from wetlands that "…*the lack of comprehensive management of such a major and obvious problem that is largely fixable at a cost that appears reasonable in light of the resulting benefits,…casts a pall over the state-wide conservation priority setting process."*

He went on to say,

"The available evidence confirms that the management of habitat and water quality must be given higher priority than further regulation of fishing." (160)

Adding weight to this opinion in 2017, an evidence-based threat and risk assessment (TARA) for the NSW Government Marine Estate Authority was published (173). Agricultural diffuse source runoff and stormwater discharge rated as the top priority threats to estuaries in the analysis. The full priority list can be found in (Appendix 2- Threat and Risk Assessment for northern region of NSW Marine Estate extracted from WBM BMT report (173)).

At a time in Australia when there has never been more scientific understanding of fisheries, never been more opportunity to refine regulation and control threats, never been less commercial extraction, never been higher prices for seafood and a fishing industry with high levels of regulatory compliance, it is confounding to acknowledge that the available evidence suggests that the Richmond River fishery is not on a trajectory towards recovery.

The resource intensive traditional fishery management approaches taught through university undergraduate degrees (174) of licensing, gear management (net size/length), zone management (e.g. marine parks) and data collection via fishery-dependent and fishery-independent studies have not reliably managed to sustain fishery productivity in the Richmond River (160) nor elsewhere in Australia (Great Barrier Reef decline (175)), and the world (Newfoundland Atlantic cod (176) (177)).

Where stock assessment methodologies only consider the impact of fishing mortality (i.e. fish caught) on potential future catches, a substantial risk of reaching erroneous conclusions about the fish stock occurs. The inability to integrate the role and functionality of other parts of the ecosystem, which are being impacted by pollution, limits the ability of the managers to perform predictive assessments.

This is particularly the case where the insidious and invisible actions of the growing number of often unmeasured pollutants change the base and health of the food web (plankton and zooplankton), thereby impacting on the reproductive success of fish and prawns which are reliant on riverine and estuarine habitats and water quality to support their food resources to thrive.

In the case of the Richmond River, the scale of many of the pollutant loadings is not able to be verified due to a lack of data in most of the catchment, where most pollutants are diffuse source in origin.

Where traditional fishery management of catch effort and volumes cannot explain the observed fishery declines it is increasingly important to consider other plausible contributors. Pollutant impacts can be a major contributor to also consider through their role in causing recruitment failure and negatively affecting aquatic animal health and the health of fishery habitat.

Pollution impacts are most concentrated within riverine and estuary dependent fisheries due to their proximity to the pollution release sites and lack of dilution compared to the open ocean.

This report has assembled data which supports the view that Emeritus Fisheries Professor Bob Kearney's expressed in 2015, that the primary reason for the decline, is the sustained deterioration in water quality and loss of fishery habitat.

> "There can be little doubt that the accumulated impacts of direct and indirect human intervention on the aquatic systems of the Richmond River, …, represent a major threat to the use, and even the sustainability, of the fisheries resources of the River and other areas dependent on it."
>
> "It has also become apparent that while there is some awareness by the general public of declines in marine systems there is telling ignorance of the detail of the many problems, their causes (threats) and what needs to be done to address them. Public understanding of cause of effect is inadequate or even misguided due to the inadequacy of available in-depth analyses." (160)

Diffuse source pollution is highlighted as the number 1 priority in the NSW Marine Estate Management Strategy (MEMS) 2018-2028[39] with the Richmond River flagged for use as a case study area. The failure of governance of diffuse source pollutants is highlighted as the first area to be addressed by the priority action list:

Initiative "1.2 Improve the management of diffuse-source water pollution by:

- clarifying NSW Government and local government roles and responsibilities
- building capacity to implement the Risk-based framework
- using mechanisms within existing policy, planning and legislative frameworks to improve outcomes
- improving minimum requirements for industry standards and ensuring compliance with regulations and best-practice through social research, education campaigns and compliance programs."[40]

39 https://www.marine.nsw.gov.au/marine-estate-programs/marine-estate-management-strategy

40 https://www.marine.nsw.gov.au/__data/assets/pdf_file/0007/815596/Marine-Estate-Management-Strategy-2018-2028.pdf

While it is a slow process to achieve engagement of all relevant parties under the current regulatory regime, this is viewed by several of the current regulatory officers interviewed for this report, as a better path forward, than revising all legislation to change areas of responsibility.

An example of the positive change directed under the MEMS[41] towards improved control of diffuse source pollution has been supported by Ballina Council, 34 local landholders and DPI Local Land Services in the Emigrant creek sub-catchment to improve riparian vegetation and achieve bank stabilisation.

The significant resources required to tackle the rest of the catchment, which continues to contribute significant diffuse source pollution loads are not allocated at this time.

Governance structures which influence pollutant loads in the Richmond River

Water quality outcomes in the river are the collective consequence of the interface of many different levels of regulation and governance and the extent to which compliance and implementation are achieved (179).

The multitude of agencies and groups involved in the governance aspects that ultimately yield an outcome for the levels of water pollution in the Richmond River, highlights the complexity of the management challenge to achieve an environment that supports high levels of fishery productivity. The infographic in Figure 23 below highlights the stakeholders who need to agree on measures to restore the health of the river. The competing priorities held by different groups have contributed delayed on-ground action, thereby leading to ongoing pollution problems and fragmented efforts to restore water quality.

The long-standing degraded state of the river highlights the gap between intentions and the delivery of the desired outcome.

41 https://www.marine.nsw.gov.au/marine-estate-programs/marine-estate-management-strategy

Figure 23: 2019 Analysis of Stakeholders linked to Richmond River governance and investment (178)

A review of Governance and funding for restoration of the Richmond River was conducted in 2019 by Alluvium consulting (178) which has more detail on the State and local governance issues.

The summary below of International Conventions and selected parts of Commonwealth, State and Local Regulations in Appendix 3- Commonwealth, State and Local Legislation and regulation related to management of waterway pollution and fisheries briefly touch on the various legislation and guidance documents which have clear intentions to control the various, known sources of pollution for the Richmond River.

International commitments that influence pollution and fisheries

a. The Australian Government ratified the *Stockholm Convention on Persistent Organic Pollutants (POPs)* [42] in 2004. By doing so, Australia accepted the originally listed POPs, ('dirty dozen')[43] yet, it does not automatically adopt controls for newly listed POPs. Australia has yet to formally accept any of the new POPs including the 'forever chemicals, e.g., PFOS, PFOA, PFHxS.

   Objective of the Convention: To protect human health and the environment from persistent organic pollutants, through the identification and elimination of production, use, trade and release of POPs into the environment.

   Outcomes:

   POPs pesticides (e.g., DDT, dieldrin, heptachlor, mirex, endosulfan) are no longer permitted for use in Australia, yet their residues are still evident in the soils in the case study catchment particularly in areas used for intensive agriculture and horticulture [44]. Studies in 1987 and 1993 identified several organochlorines above detection limits in a range of fish species from the Richmond River (148)**.** No recent data are available.

   Other listed POPs such as the brominated flame retardants (e.g. decabromodiphenyl ether, hexabromocyclododecane) while not produced nationally may be imported in finished products such as extruded polystyrene used in building products and office equipment. When these products become waste, or are recycled, they represent another source of POPs emissions to the environment, via releases from landfill and in recycled products.

   While PFAS based POPs firefighting foams are restricted in some Australian states, monitoring and strict enforcement is lacking and there is evidence of ongoing use of historical stockpiles. There has been limited action to control environmental pollution from POPs compounds such as PFOS and PFOA. There is no environmental monitoring program for these significant POPs emission from wastewater treatment plants in the case study catchment despite their detection in wastewater treatment plants elsewhere in Australia (180).

   Australia permits higher human exposures to some POPs than U.S. or EU through drinking and recreational water guidelines. For example, US EPA set a combined health advisory of 0.07 ug/L (70 parts per trillion) for PFOA and PFOS in drinking water. While Australia has set a drinking water value of 0.07 ug/L for combined PFOS /PFHxS and 0.56 ug/L (in effect ppb) for PFOA alone; eight times the combined US Health advisory for PFOS / PFOA in drinking water.

   Seafood impacts are not prevented, rather, in high contamination sites, advisories on safe amounts of seafood to consume are issued. The impacts on the health and reproduction of exposed aquatic species are not monitored.

b. The Australian Government has ratified the *Basel Convention on the control of Transboundary Movements of Hazardous Wastes and their Disposal* 1992. [45]

42 http://www.pops.int/Home/tabid/2121/Default.aspx

43 POPs chemicals are toxic, bioaccumulative building up in living things including humans, persistent and capable of transboundary movement. Some POPs are highly persistent and do not break down in the environment, eg PFOS, PFOA and PFHxS

44 https://www.epa.nsw.gov.au/licensing-and-regulation/authorised-officers-and-enforcement-officers/resources-and-training/contaminated-agricultural-land

45 http://www.basel.int/

Objective of the Convention: To protect human health and the environment against the adverse effects resulting from the generation, management, transboundary movements and disposal of hazardous and other wastes.

Outcomes: Australia has not ratified the crucial Basel Ban Amendment which prohibits member states of the Organization for Economic Cooperation and Development (OECD) and the European Union (EU) from exporting hazardous wastes to developing countries or countries with economies in transition. While technically the amendment is only binding on countries that ratify it, all Basel Convention Parties including Australia must respect the import prohibitions of developing or transition countries that have ratified the Ban Amendment as their ratification automatically reflects their national import prohibition.[46] Australia's inability to export its hazardous waste to neighbouring Asian countries has driven a national push to develop waste to energy incinerator infrastructure; representing a further pollution risk to the catchment.

c. Australian Government has ratified the *Rotterdam Convention* in 2004[47].

Objective of the Convention: requires participating countries to provide prior informed consent before exporting hazardous chemicals to participating countries. The Rotterdam Convention includes a list of pesticides and industrial chemicals that have been severely restricted for health or environmental reasons.

Outcomes: Companies can still import the Rotterdam listed chemicals into Australia, some of which are permitted and used on crops grown in the case study catchment including multiple organophosphate and tributyl tin pesticides. Where monitoring has occurred outside of the Richmond River catchment detection of some of these in adjacent waterways has been reported such as Benomyl.

d. On 7 December 2021 Australian Government ratified the *Minamata Convention on Mercury 2013*.

Objective of the Convention: To protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds. It contains provisions that relate to the entire life cycle of mercury, including controls and reductions across a range of products, processes and industries where mercury is used, released, or emitted. The treaty also addresses the direct mining of mercury, its export and import, its safe storage and its disposal on becoming waste. Identifying populations at risk, boosting medical care and better training of health-care professionals in identifying and treating mercury-related effects will also contribute to implementing the Convention

Outcomes: In Australia, thousands of tonnes of mercury continue to be released to the atmosphere via emissions from coal-fired power stations. While none are in the case study catchment, the volatile emissions are highly mobile and many of which end up entering the aquatic food webs as they come back down**.** Historically, mercury was used in small-scale gold mining to separate the gold from unrefined ore resulting in widespread mercury contamination in Australia's old gold mining areas including around the mouth of the Richmond River. In 2020, the Australian government was one of the last countries to announce the withdrawal of the mercurial fungicide, Shirtan, which has been widely used by sugar cane growers in the case study

46 THE ENTRY INTO FORCE OF THE BASEL BAN AMENDMENT A Guide to Implications and Next Steps January 2020

47 http://www.pic.int/TheConvention/Overview

catchment resulting in likely contamination of soil and adjacent waterways. There has been no Government structured monitoring of mercury contamination levels in Richmond River or its fishery products, although one small pilot study performed by Southern Cross University found levels below health guidelines in oysters grown near the river mouth (data unpublished A Reichelt-Brushett pers comm 2018).

e. Australian Government has adopted the International Union for the Conservation of Nature's (IUCN) list of marine protected area management categories, which offer varying levels of protection. The Richmond River and its tributaries are not within a managed marine park. However, they are within the bioregion of the Byron Bay Marine Park. The formerly common resident species, Eastern Freshwater Cod, Purple Spotted Gudgeon and Oxleyan Pygmy Perch are on the IUCN Red List of Threatened Species 2019.

   Objective of the Convention: To provide information and analyses on the status, trends and threats to species in order to inform and catalyse action for biodiversity conservation.

   Outcomes: While some general habitat restoration actions have been taken by the State Government and Local Council in the Richmond River, there has been no monitoring within the catchment to determine if the scale of restoration has improved the status of the three listed species. While pollution is identified as one of the contributors to species decline by NSW DPI, there is little investment to monitor, control and reduce the various sources of diffuse source pollution (agricultural and stormwater run-off) that have contributed to decline of these species.

f. Australian Government is a signatory to *Ramsar Convention* on Wetlands[48].

   The Richmond River does not include any Ramsar listed wetlands. The Australian Government list of nationally important wetlands does include Tuckean Swamp[49], however it is not Ramsar listed.

   Objective of the Convention: To halt, and where possible reverse, the worldwide loss of wetlands and to conserve, through wise use and management those that remain[50].

   Outcomes: While not Ramsar listed, the major wetlands on the Richmond River (Tuckean, Bungawalbyn, Rocky Creek/Sandy Creek) remain in poor condition due to drainage, flood gating and the creation of substantial acid-sulphate hotspots. This largely prevents them from generating the aquatic food webs that help support migratory bird use and fishery productivity. After more than 25 years of research, reports and monitoring clearly highlighting the degeneration of the water quality (acid and deoxygenation) and loss of waterway connectivity for fish passage, caused by modification of the wetlands, there are yet to be substantial on-ground restoration activities to reinstate the ecological, hydrological and biodiversity attributes of these wetlands on the Richmond River. As such, the potential fishery productivity from these thousands of hectares of former functional wetland area has been lost. Worse still, the drained wetlands now contribute to further loss of fishery productivity by

48 https://www.environment.gov.au/water/wetlands/ramsar

49 http://www.environment.gov.au/cgi-bin/wetlands/report.pl

50 https://www.awe.gov.au/water/wetlands/publications/australias-obligations-under-ramsar-convention-legislative-support-wetlands-fact-sheet

contaminating the main flow of the river with toxic acidic deoxygenation water causing fish kills.

g. Australia signed the United Nations *Convention on Biological Diversity* in 1993.

Objectives of the convention: The conservation of biodiversity; the sustainable use of its components; and the fair and equitable sharing of the benefits arising from the use of genetic resources.

Outcomes: Australia's most recent report on the State of the Environment has highlighted that species extinction rates in Australia have accelerated, placing Australia in a leading global position for mammal extinctions. Within NSW as at December 2020, 18 more species were added to the threatened list since the last report in 2016. The overall diversity and richness of native species and communities in NSW remains under threat of further decline. 64% of native mammals have decreased ranges. Native fish indictors were described as poor and getting worse[51].

Failures of Commonwealth, NSW State and Local Governance to control pollutant entry and fisheries impacts in the Richmond River

NSW EPA release status reports of the condition of major environmental resources every three years. The reports describe pressures and trends and offer credible state-wide environmental information. The so called 'State of the Environment' reports over the past decade indicate continued decline in biodiversity and ecosystem health in the Richmond River. So, while the Act has bold aspirations to "protect and enhance" the coastal environment, these are not being realised, as the entry of multiple streams of pollutants to the river are not being controlled.

The Commonwealth Government has established separate regulators for the assessment of different types of chemicals including:

-Industrial Chemicals (Australian Industrial Chemicals Introduction Scheme (AICIS)[52]);

-Agricultural and Veterinary Chemicals (Australian Pesticides and Veterinary Medicines Authority (APVMA)[53]);

Pharmaceuticals (Therapeutic Goods Administration (TGA))

These bodies determine what chemical products can be used and how they may be used.

Industrial chemicals and AICIS

The AICIS "promote the safe use of industrial chemicals in order to protect human health and the environment".

51 https://www.soe.epa.nsw.gov.au/all-themes/biodiversity/native-fauna

52 https://www.industrialchemicals.gov.au/about-us/who-we-are-and-what-we-do#:~:text=AICIS%20replaced%20the%20National%20Industrial,NICNAS)%20on%201%20July%202020.&text=The%20Industrial%20Chemicals%20Act%202019,of%20industrial%20chemicals%20in%20Australia.

53

From July 2020, changes to Australia's industrial chemical legislation resulted in most new industrial chemicals being self-assessed by the company who wish to manufacture or import them. Companies introducing new industrial chemicals assess into which of five categories their chemical fits: currently listed; exempted; reported; assessed; or commercial evaluation authorization.

If the chemical is already listed on the Australian Inventory of Chemical Substances or is 'comparable' to an existing listed chemical or polymer, then the company may import or manufacture the chemical with no notification to the regulator. If the new chemical is not listed or is not comparable to an existing chemical on the inventory then a company can self-determine whether their chemical should be 'exempted', 'reported' or 'assessed' based on their assessment of the risks to human health and environment. There is minimal oversight for those assessed as 'low risk' chemicals and no requirement for public disclosure of information.

Despite an ongoing Existing Chemical Review program, a large historical backlog of unassessed chemicals currently exists, despite their listing (and hence availability for use) on the Australian Inventory of Chemical Substances, which number in excess of 30 000.

The absence of monitoring data does not allow any quantification of the risk of industrial chemicals impacting on fishery productivity in the Richmond. The desired aim of protecting the environment from adverse effects from these chemicals seems very optimistic in the absence of a more rigorous approval process that considers the fate of the compounds and their ability to combine to cause mixture toxicity, low dose, or endocrine effects on fisheries. The lack of monitoring of diffuse source inputs such as agriculture and stormwater, in addition to an absence of monitoring of wastewater effluent for contaminants leaves fisheries at risk.

The re-purposing of contaminated wastewater sludge as a biosolids agricultural input that can be applied to floodplain areas creates significant risks for contaminants to enter and impact aquatic ecosystems. An absence of monitoring after application of biosolids renders this risk unable to be quantified.

Agricultural and Veterinary Chemicals & APVMA

The APVMA vision seeks to be a "world leader" in "agvet chemical regulation that uses the best science" and to ensure "these chemicals work, but are also safe for people, animals and the environment".

A comparison of the level of assessment and range of chemicals permitted by the EU reveals significant differences in process and outcomes between the two international regulators. Environmental data from the EU suggests even though its regulations are more stringent than Australia, and have driven improved control of environmental residues, they have not yet gone far enough to protect and recover aquatic ecosystem health and productivity (181).

For example, the APVMA supports the use of a range of toxic pesticides including many organophosphates (e.g. diazinon, dichlorvos, malathion, fenitrothion), synthetic pyrethroid (e.g. cyhalothrin), and neonicotinoid (e.g. imidacloprid, clothianidin) insecticides and herbicides (e.g. atrazine diuron) which have been removed, or severely restricted from use in the EU.

While the assurances of a robust scientific risk assessment process offer the promise of safety for the environment (i.e. not cause harm to the environment), there are many flaws which have been highlighted in science journals (182), (183), (184), (185), (186), (187) that render the present system unable to deliver on its promise.

These include:

Selective use or omission of published data

Invalid dismissal or exclusion of adverse effects

Failure to adequately consider adverse effect end points such as endocrine disruption

Misuse of historical control data

Misuse of statistical analytical tools

Dismissing adverse effects based on alleged inconsistency of data

Misuse of the “weight of evidence” approach

Misrepresentation of research methodology

Plagiarism

Failure to assess toxicity of mixtures

Delay or failure to act to restrict use in response to adverse event reports from field use

Absence of mandatory regulatory review of compounds to ensure they comply with contemporary knowledge

Inadequate assessment of mobility and environmental fate of pesticides which fails to predict their movement into aquatic ecosystems.

Minimal or no post-market monitoring to ensure that product behaviour in the environment performs according to the conclusions reached in their risk assessments, such that use can be adjusted to ensure safety is achieved. Volumes of applications to catchments not monitored nor publicly reported. Exposures in waterway are not required to be monitored. Potential consequences of exposures are not monitored.

Even when environmental monitoring is performed showing exceedances above environmental protection trigger values, the regulatory process favors protection of the sustained agricultural uses rather than seeking to afford more protection from the unintended environmental consequences-including impacts on the aquatic food web.

A lack of transparency exists on which scientific data is considered, as much is claimed to be “confidential commercial information”.

Taking decades to respond to adverse monitoring data demonstrating levels of pesticides in the environment above National Water Quality Guidelines for ecosystem protection.

Allowing registrants to supply scientific “argument” in place of data

Failure through gaps in legislative coverage and administration

The inadequate controls for diffuse source pollution from stormwater and much of agriculture in the catchment represents a legislative gap. This contrasts with specific premises, such as wastewater treatment plants (WWTP), which the EPA can control through issuing license conditions to control release of pollutants to the river.

Most livestock enterprises in the catchment fall under the size requiring development assessment or EPA licensing. Hence, Council and NSW EPA are not able to place develop controls on these smaller scale farms even though they are numerous in number and in aggregate cover significant areas of the catchment. As such, their contribution to diffuse source pollution is functionally unregulated by council. Intensive horticulture (e.g. macadamia orchards, sugar cane plantation, blueberry orchards, avocado orchard, banana plantations etc) in rural zoned areas also do not require such development consent, thus generating further diffuse source pollution risk to the catchment.

While there are many agencies and many pieces of regulation which have connections to the outcomes of diffuse source pollution coming from stormwater and agricultural runoff, there is no single central body responsible for its control with sufficient head of powers. It has been acknowledged as difficult to control (178).

In 2017, the mid-term review of the Coastal Zone Management Plan (188) identified ineffective governance and administration as key barriers to improving the health of the Richmond River.

While the NSW Department of Environment Energy and Science (EES) have overall responsibility for diffuse source pollution, they lack the powers to control the activities which contribute diffuse source pollutants to the river. EES are in the process of updating a 2009 Diffuse Source Water Pollution Strategy[54]. The strategy relies on processes such as developing a priority action plan to inform investment funding. It also offers a mechanism to develop partnerships between stakeholders to coordinate priority management actions and reporting. The actions are substantially unfunded, and as a result are happening at a very slow pace. The strategy only recognises sediment and nutrients as priority pollutants.

Under the latest initiative of the Marine Environment Management Strategy 2018-2028, EES are endeavoring to reform the Governance of diffuse source nutrient and sediment pollution as a first step.

There are opportunities for better outcomes for water quality in planning developments through use of the NSW EPA Risk-based framework for considering waterway health outcomes in strategic land-use planning decisions (189). However, in relation to stormwater the focus is typically on nutrients rather than the potential load of contaminants and their potential impact on aquatic ecosystems.

Outcomes for ecosystem health and fishery productivity are not necessarily prioritized in this process, as community use and values are broadly defined. Common outcomes of these instruments include monitoring of faecal coliforms to advise the safety for people swimming, rather than setting water quality standards to maximize the health of the aquatic food web.

Thus, movement of sediment, fertilizer, manure, and pesticides into aquatic ecosystems occurs, without penalties necessarily being applied, nor corrective action being mandated on the sources of the pollution.

Under the POEO Act, a prevention order may be issued by local council in response to aquatic pollution. Typically, this is only triggered by ad hoc community complaints. Prevention orders are not used as a systematic tool to address the sources which are contributing to the degradation of water quality in the Richmond River.

54 http://extwprlegs1.fao.org/docs/pdf/aus181743.pdf

Failure by profit motivated influence

One of the difficulties in achieving truly science-based regulation of businesses which generate pollutants in a market-based economy, is that their drive for more profit may incentivize more pollution emissions. Where the economic benefit of such businesses to the country is measured, without accounting for their external pollution emissions, market forces inadvertently encourage increased pollution to aid the Government imperative of expanding economic growth.

This perverse incentive is contrary to the benefit of the wider community which is left to socialize the costs of the pollution.

The discipline of science is widely used to measure the impact of pollution and inform regulation. Science, without industry influence, generally seeks to generate knowledge to bring us closer to an accurate understanding of how something works.

Unfortunately, many polluting industries engage in different motivations for science which collectively seek to resist the implementation of tighter pollution regulation on their industries. They also seek to control the public's perception of their business and their profit such that the pollution is not the focus of attention (190).

Macro, meso and micro strategies used by industry to influence science and the use of science in policy and practice are highlighted in Table 2 (190).

Macro strategies	Meso strategies	Micro strategies
A. Influence the conduct and publication of science to skew evidence bases in industry's favour	1. Fund and undertake "safe" research	1.1 Fund and undertake "safe" research which distracts attention from industry harms, frames industry and industry products as part of the 'solution', and promotes interventions that minimise damage to product sales
		1.2 Commission lawyers and public relations firms to manage research programmes to ensure research is "safe"
		1.3 Fund and undertake research to identify or demonstrate public perceptions
	2. Covertly undertake or prevent "risky" industry research	2.1 Covertly undertake "risky" research so that it can be hidden or abandoned
		2.2 Prevent "risky" industry research from being undertaken
	3. Control design & analysis of industry-funded science to ensure favourable results	3.1 Control the design and analysis of industry-funded primary studies
		3.2 Control the design and analysis of industry-funded evidence syntheses
	4. Shape and undermine external research	4.1 Shape external (e.g. governmental) organisations' research priorities through access, funding, and political power
		4.2 Attempt to block the funding of potentially unfavourable independent research
		4.3 Deliberately obstruct independent data collection
	5. Ensure favourable research is heavily represented in the evidence base	5.1 Maximise the presence of industry-funded publications in the peer-reviewed literature
		5.2 Fund or create journals to have influence over what is published
		5.3 Create publications which emulate peer-reviewed/quality science
	6. Control reporting and suppress publication of unfavourable science	6.1 Control the way in which unfavourable industry science is reported within publications
		6.2 Suppress publication of unfavourable science
B. Influence the interpretation of science to undermine unfavourable science and create a distorted picture of the evidence base	7. Develop and promote criteria and concepts for critiquing science which can be used to further industry arguments	7.1 Develop criteria for the conduct and interpretation of science (including determining scientific "proof") with the intention that these can be used to undermine unfavourable science
		7.2 Adopt the concepts of "junk science" and "sound science" for use in undermining unfavourable science and promoting industry science
		7.3 Fund and coordinate public relations campaigns to promote these industry-friendly criteria and concepts to key stakeholders
	8. Obtain and re-analyse raw data from unfavourable science	8.1 Obtain raw data underlying unfavourable research by enabling data access legislation, and pressuring or litigating against scientists
		8.2 Re-analyse independent data including that acquired in these ways to refute unfavourable findings
	9. Attack and misrepresent science	9.1 Attack the methods of unfavourable science (tailoring the criteria depending on the nature of the science to be attacked)
		9.2 Label unfavourable science "junk"
		9.3 Misrepresent single pieces of evidence
		9.4 Misrepresent whole evidence bases
		9.5 Misrepresent expert consensus
	10. Monitor and attack scientists and organisations	10.1 Monitor the opposition in order to weaken it
		10.2 Attack individual scientists and whole cohorts of researchers
		10.3 Remove individual scientists from positions of power
		10.4 Attack organisations that create and disseminate science
C. Influence the reach of science to create an "echo chamber" for industry's scientific messaging	11. Use legal means to protect industry evidence from being discovered or accessed	11.1 Prevent research from being undertaken in countries where corporations are vulnerable to litigation based on legal advice
		11.2 Limit internal communication to mask industry knowledge of harms based on legal advice
		11.3 Store scientific documents in ways which would prevent their discovery based on legal advice
		11.4 Use "proprietary information" claims when pressed by courts to release industry evidence
		11.5 Attempt to embed mechanisms in trade and investment treaties which prevent access to industry evidence
		11.6 Silence plaintiffs using secret payments
	12. Contract messengers to create scientific "echo chambers"	12.1 Create front groups to amplify industry-friendly scientific messages
		12.2 Fund third parties in order to amplify or shape their scientific stances
		12.3 Recruit, fund, and train individuals to be trusted scientific voices for industry
		12.4 Strategically create and fund a multitude of voices to manufacture a picture of scientific consensus
		12.5 Build industry coalitions (both within an industry, and with allied industries) to demonstrate support for industry-friendly scientific stances
	13. Fund, produce and disseminate materials which package science in industry-favourable ways	13.1 Fund, produce and disseminate lobbying materials that summarise science in industry-favourable ways
		13.2 Fund, produce and disseminate textbooks, letters to the editor, practice guidelines and other educational or academic materials
		13.3 Fund, produce and disseminate "easily digestible" materials such as factsheets, newsletters, and product information materials
		13.4 Obtain and disseminate reprints of industry-favourable scientific publications
	14. Use education, events, and meetings to disseminate industry-favourable scientific messages to key stakeholders	14.1 Fund, organise and speak at "educational events" for key stakeholders
		14.2 Access policymakers through meetings and hearings
		14.3 Infiltrate decision-making contexts in order to ensure industry-friendly scientific stances are heard
		14.4 Train and use industry representatives to meet with health professionals
	15. Maximise press coverage of industry-favourable scientific messages	15.1 Create favourable media content
		15.2 Fund media outlets in order to influence what is disseminated
		15.3 Co-opt journalists through media training and conference funding
		15.4 Design events intended to maximise media coverage
		15.5 Demand media coverage of industry scientific arguments in the name of "balance"
D. Create industry-friendly policymaking environments which shape the use of science in policy decision-making in industry's favour	16. Implement and utilise industry-friendly standards of evidence in regulatory decision-making	16.1 Attempt to implement industry-friendly standards of evidence which set a high evidential bar within regulatory decision-making
		16.2 Utilise such standards in attempts to undermine the use of unfavourable science in regulatory decision-making
	17. Secure and utilise policymaking reforms which increase reliance on and provide a conduit for industry-favourable evidence	17.1 Secure the implementation and use of mandatory regulatory tools such as business impact assessments which increase reliance on industry data and prioritise evidence on economic impacts
		17.2 Secure and utilise changes to upstream policymaking architecture which embed industry's right to participate in policymaking processes
		17.3 Secure reductions in evidence requirements for some regulatory decision-making to maximise the use of industry-favourable evidence
E. Manufacture trust in industry and its scientific messaging	18. Manufacture a picture of industry credibility	18.1 Ensure and normalise industry's presence in academic settings in attempts to gain trust and scientific credibility within academia
		18.2 Promote industry's overt links with expert individuals and organisations to manufacture a picture of industry credibility more broadly
		18.3 Inflate the credibility of industry science, scientists, and scientific perspectives
	19. Conceal industry's involvement in science, scientific messaging and influence on policy reforms that affect the use of science	19.1 Conceal industry funding of science, production of science and recruitment of scientists
		19.2 Conceal industry dissemination of science and scientific messages
		19.3 Conceal industry attempts to shape ways in which science is used in policymaking

See S3 Appendix for fuller details on these strategies including purposes, supporting evidence and examples of micro-level detail.

https://doi.org/10.1371/journal.pone.0253272.t002

Table 2: The Science for Profit Typology- Macro, meso and micro strategies used by industry to influence science and the use of science in policy and practice. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0253272# Creative Commons Attribution 4.0 International Public License.

Failure through inadequate financial resource allocation

Within NSW wastewater treatment plants vary in their age and ability to remove pollutants from water. Due to the high costs associated with upgrading of these plants, it is common for them to continue operating at standards which result in some pollution of the receiving waterway.

Government budget allocations for investigation of pollution incidents are limited, thereby restricting the identification and correction of some reported pollution incidents.

Council budgets are stretched to cover the breadth of their responsibilities for assessment of development, maintenance of roads, rubbish, amenities and protection of the environment. Unfortunately, if environmental restoration is not seen as a high priority, under allocation of financial resources is a common outcome.

In 2017, Hydrosphere Consulting's mid-term review of the Coastal Zone Management Plan for the Richmond River (188) identified the lack of financial and staffing resources as a key barrier to improving the health of the Richmond River. A consulting report on the Richmond River Governance and Funding Framework in 2019 (178) reiterated this financial shortfall was interlinked with the Governance barriers to improvement.

While not directly in response to the EPBC Act, a small amount of Commonwealth investment is dispersed as grants for Land Care activities which can assist landholders in improving water quality through riparian zone replanting and wetland restoration for example. Although considerable volunteer effort has contributed to expand the benefit of these activities, the overall scale of works remains small. This work has yet to measurably alter the health of the lower reaches of the Richmond River.

Failure from inadequate license conditions

The conditions which are established by NSW EPA to control pollution from premises such as WWTPs in the Richmond River catchment do not require monitoring for contaminants, such as PFAS, PBDE, surfactants, estrogenic/androgenic potential and PCPP. The ability to manage these emerging water pollution threats is hindered when no monitoring data is required to meet EPA license conditions. Research science suggests there are valid concerns in some waterways in Australia in relation to endocrine activity of both wastewater discharges and other pollution sources to rivers (191)

The cost-benefit discussions around the costly upgrades of WWTP, could be better informed were such data mandatorily generated, particularly in areas of high population growth such as in the Richmond River catchment.

Failure through competing priorities- development vs environment and "ecologically sustainable development"

There are competing tensions between the development of land for urban and agricultural use and the protection of ecosystem services which control of pollution impacting the aquatic environment.

The aggregate of Commonwealth, State and Local regulation expresses a clear intent to manage pollution threats in terms of considering environmental, social and economic impacts and where identified restore ecological health. However, the operation of the legislation requires that decisions are contextualized in the notion of "ecologically sustainable development".

It is implicit that such development can occur endlessly which aligns to the Australian Government's fiscal aspiration for continuous economic growth. Both appear illusionary when viewed through the prism of limited natural resources. It is therefore difficult to see how the aspirations to control pollution and restore ecological health can meet with the reality of ever-expanding development.

The absence of any routine ecosystem monitoring in the catchment would also appear to make this legislative desire difficult to achieve. Further, the absence of a valuation of many ecosystem services, aquatic habitats and water quality precludes their use in economic appraisal of the merits of development or restoration proposals.

This incongruous situation of strong legislative scope for protection of water quality and fish habitat, yet ongoing poor outcomes (clear failures to meet ecosystem water quality guidelines), appears the result of the multitude of factors outlined in this report.

In the Richmond River catchment, the consequences of the legislation suggest that the economic development imperative commonly dominates the aspiration to preserve and restore the health of the environment. In the present model of regulation there is a disincentive for Councils and EPA administering the Acts to elevate the interests of environmental protection above the development imperative. This disincentive takes the form of greater costs for Government to undertake wider compliance (within a tight funding environment) and incurs greater risk of provoking adversarial responses from the landholders who could be forced to change their land management.

Compounding these issues of where priority is placed on development, is the lower priority status afforded to ensuring that the pollution control measures are fully implemented. With limited resources for compliance and the lack of a profit driver to achieve optimal pollution control, the aquatic ecosystem suffers from "death by a thousand cuts".

Such an understanding better explains how riverine conditions can be so demonstrably poor today and have persisted in a such a poor state for so long, without an effective restoration taking place, even when legislative controls, Government aquatic ecosystem guidelines, community intentions and industry best practice guidelines clearly flag the direction for restoration and protection.

An example of these competing priorities playing out occurs under coastal planning regulation[55]. A development consent is required for development within, or in 'proximity area' of coastal wetlands that requires clearing of native vegetation, or harm to marine vegetation or may require earthworks, construction of a levee, draining the land or environmental protection works. The consent authority must be satisfied that the quantity and quality of surface and groundwater flows to and from the coastal wetland is not significantly impacted.

Most wetland areas in the Richmond River have been historically drained and much of this area has had flood gate infrastructure installed. Small scale restoration has seen around 50ha return to function in recent years. However, around the township of Ballina development of urban and industrial areas through in-filling of former wetland areas is continuing.

55 https://legislation.nsw.gov.au/view/html/inforce/current/epi-2018-0106

The challenge appears no longer a case of protecting what is left of wetland ecosystem services, but rather one of restoring areas to their former functionality through facilitating changes in land-use. Robust mechanisms to promote such changes at scale are yet to be developed.

Another example where a pro-development agenda collides with aspirations for environmental protection and restoration is the recent review of Agricultural and Veterinary chemical regulation which sought to support a National Farmers Federation development target to reach $100 billion in farm gate value for Australian agriculture[56]. While the environment was considered in the process by the consultants and subsequently the Department of Agriculture, the net effect was to expand the speed and range of agricultural and veterinary chemicals available to farmers, While failing to tighten any areas of assessment of their risks. The result is likely a net increased risk to the receiving environment.

Development appears currently prioritized, with the role of ecosystem services and pollution control measures secondary considerations. As development expands the pollution footprint also expands.

It appears the local community and industry will need to embolden the political will to improve pollution control, such that substantial resource reallocation can be used to support the repair the catchment.

Cumulative impacts under-assessed

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*[57] was recently reviewed[58] and provides sharp critique of the adequacy of Australia's protections for the environment. The Independent Review found that "Australia's natural environment and iconic places are in an overall state of decline and are under increasing threat…… The current environmental trajectory is unsustainable." And that "Good outcomes for the environment, including heritage, cannot be achieved under the current laws." ",..cumulative impacts on the environment are not systematically considered." (192)

This is also evident in the risk assessments for pharmaceutical, industrial and agricultural and veterinary chemicals which are undertaken on a one-by-one basis. The fact that there is an ever-growing range of products and ever more volume of total use is not reflected appropriately in the risk assessment of the safety of products prior to their approval for use.

The failure to adequately account for cumulative impacts, is also evident in the creep of urban development, whereby each development is assessed on its individual merits. The current system appears inadequate to control the cumulative increasing demand for water supply, the increased storm water effluent load, the reduced groundwater recharge, changes to hydrology from runoff and simultaneously sustain aquatic ecosystem productivity.

Words alone do not deliver aquatic ecosystem protection

56 https://www.aph.gov.au/About_Parliament/House_of_Representatives/About_the_House_News/Media_Releases/A_$100_billion_agriculture_sector_by_2030

57 https://www.legislation.gov.au/Details/C2021C00182

58 https://epbcactreview.environment.gov.au/resources/final-report/executive-summary

The *Biodiversity Conservation Act 2016* seeks to maintain a healthy productive and resilient environment for the greatest well-being of the community now and into the future.

Yet, significant degradation of aquatic biodiversity and abundance of macroinvertebrates was recorded across most of the catchment when widely surveyed in 2014 (109). The loss of functioning floodplain wetlands, seagrass meadows and saltmarsh has also significantly impacted the aquatic biodiversity and terrestrial fauna which previously relied on the high level of aquatic productivity to provide a substantial feed resource. Largely uncontrolled diffuse source pollution from agriculture and stormwater continues to generate outcomes which appear contrary to the aims of this Act as highlighted in the Regional State of the Environment Report 2016 and 2020 (137).

The listing of the three threatened species of fish in the Richmond River catchment requires that under the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)* a recovery plan be prepared for them. For example, the NSW DPI Review of Eastern Freshwater Cod Recovery Plan 2016[59].

However, the EPBC Act, nor State legislation do not require that funding is made available to complete the actions, which have been identified as a priority to achieve recovery of the species. Further the EPBC Act provisions do not necessarily place an obligation on the Commonwealth to assess the need for controls within a new development, unless the impact has potential to cause a significant impact of national environmental significance, such as a fish population could be affected at the species level.

Another example is the listing of Tuckean wetland as a “Nationally Important Wetland” by the Commonwealth Government, however, this does not qualify it for the protections offered under the *EPBC Act*, which are confined to Ramsar listed wetlands. It’s status as a nationally important wetland is yet to correct the drainage issues which have caused substantial degradation of its ecological value through massive acid impacts.

Local environment plans[60] specify that consideration must be given to the impact and cumulative impact of developments on biodiversity and ecosystems, including coastal waterbodies. by councils or monitoring to determine whether negative effects from run-off are occurring. The consent authority must be satisfied that any effluent will not have a negative effect on the water quality of the sea, or any beach, estuary, coastal, coastal creek or other similar body of water or a rock platform and that no untreated stormwater will be discharged into the sea, creek or river.

These aspirations appear difficult to achieve when there is presently no measurement undertaken by local councils of the “conservation of ecosystems” and best practice river health initiatives are not supported by the Standard Local Environment Plan (178).

Environmental offsets which do not replace what is lost, resulting in net loss

Environmental offsets were supposed to be a planning tool to compensate for environmental destruction which occurs as the result of land use changes in development as a choice of last resort. Through use of environmental off-sets urban and industrial development has continued in areas that

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have reduced critical natural fishery habitat including wetlands and saltmarsh in the Richmond River catchment.

The review of the EPBC Act highlighted that compliance around the creation of the offsets is poor and rarely enforced (192). Within the context of the Richmond River, it is questionable whether the loss of natural wetlands at certain locations in the river can be replaced by offsets in different parts of the river, due to the hydrological differences. It is not immediately possible to replicate the function of a working piece of fishery habitat in a catchment, somewhere else in the catchment due to the many differences in topography, hydrology and geology.

Voluntary guidance for pollution control

A range on voluntary guidance tools and financial support for farmers are available to help reduce water pollution. Where adopted the guidelines generate significant improvements, however, given the measures are not compulsory, achieving high levels of compliance is difficult.

Examples include:

Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2018[61]These guidelines include some toxicant default guideline values and methods for deriving such values to assist with the management of water quality for natural and semi-natural water resources in Australia and New Zealand. The guidelines are not enforceable standards.

Industry Best Management Practices, providing advice to limit sediment, nutrient, pesticide pollution and guide resource stewardship.

i. Rural Landholder Initiative- Book 01 healthy landscapes and waterways[62]
ii. NSW Macadamia integrated orchard management drainage 2017[63].
iii. Macadamia integrated orchard management practice guide 2016[64].
iv. Macadamia plant protection guide 2021-22[65].
v. Rural Landholder Initiative-Book 03 Macadamia and other orchards[66]
vi. Rural Landholder Initiative- Book 04 Floodplain cropping[67]

61 https://www.waterquality.gov.au/anz-guidelines

62 https://lismore.nsw.gov.au/files/Rural_Landholder_Initiative_Book_1.pdf

63 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/731462/macadamia-integrated-orchard-management-drainage-2017.pdf

64 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/567157/macadamia-integrated-orchard-management-practice-guide-2016.pdf

65 https://app-ausmacademia-au-syd.s3.ap-southeast-2.amazonaws.com/resource/1627624944_Macadamia-plant-protection-guide-2021-22.pdf

66 https://lismore.nsw.gov.au/files/Rural_Landholder_Initiative_Book_3.pdf

67 https://lismore.nsw.gov.au/files/Rural_Landholder_Initiative_Book_4.pdf

vii. Forest soil and water protection- a manual for forestry operators[68].

viii. Rural Landholder Initiative-Book 02 Beef grazing and dairying[69]

ix. Environmental management guidelines for the dairy industry 2008[70].

x. Responsible sustainable beef production[71]

xi. Avocado best management practices and internet-based information delivery 2015[72]

xii. Berry plant protection guide 2021-22[73]

xiii. Erosion and sediment control for blueberry growers: A best management practice guide[74]

b. Farm scale planning

i. Voluntary programs operated by local council encourage improved land management[75].

Steps towards restoration of productivity

Applying ecosystem fishery management could help

Recent fishery models have begun to tackle the challenge of incorporating more data to inform an ecosystem-based approach to fisheries management. While incorporating climate modelling may improve predictions (193), more data inputs will be needed to account for the role of numerous other pollution sources which alter the aquatic food web in diverse ways and impact on fish recruitment. The climate models will also need to interact with data pollutants, as their mobilization and fate will be modified by climate change. With pollution loads expanding with global population, industrial activity and consumption, the baseline health of the ecosystem is degrading.

The emerging capability through cheap environmental sensors and big data analytics may open new opportunities up to better manage fisheries into the future.

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68 https://www.forestrycorporation.com.au/__data/assets/pdf_file/0003/449904/D00087687-Forest-Soil-and-Water-Protection-A-Manual-for-Forestry-Operators-2000.pdf

69 https://lismore.nsw.gov.au/files/Rural_Landholder_Initiative_Book_2.pdf

70 https://www.dairyingfortomorrow.com.au/wp-content/uploads/Environmental-management-guidelines-for-the-dairy-industryNSW.pdf

71 https://www.dpi.nsw.gov.au/animals-and-livestock/beef-cattle/husbandry/general-management/production

72 https://www.horticulture.com.au/globalassets/laserfiche/assets/project-reports/av10002/av10002-final-report-333.pdf

73 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/566349/Berry-plant-protection-guide-2021.pdf

74 https://www.lls.nsw.gov.au/news-and-events/news/nc-news/2020/newsletters/winter-2020/working-with-blueberry-growers-to-improve-environmental-impact

75 https://www.byron.nsw.gov.au/Business/Key-industry-sectors/Agriculture

Blue carbon funding to support wetland restoration

Australia has commenced some blue carbon programs[76], where the carbon sequestration value of aquatic environments such as seagrass, mangroves, saltmarsh and wetlands are recognized. The further development of the carbon market could assist in offering an economic option to support restoration of wetlands, seagrass, mangroves and saltmarsh. Not only providing benefits in mitigation of climate change, but also enhancing aquatic productivity and assisting in control of aquatic pollution.

Focusing on prevention at the source of pollution

The Australian Drinking Water Guidelines emphasized in 2004[77], that "*prevention of contamination provides greater surety than removal of contaminants by treatment, so the most effective barrier is protection of source waters to the maximum degree practical*." Yet since 2004, there has been little improvement, indeed some sub-catchments have further deteriorated as a review conducted for Rous Water in 2015 noted (194).

There is no lack of knowledge of what needs to be done to improve water quality. Only a lack of implementation.

Marine Protected Areas need critical revision

One of the mooted benefits of nearby Cape Byron Marine Park, established in 2002 to create marine protected areas (MPA), was to generate populations of fish within the MPA which would move out of the MPA and augment the nearby fisheries, referred to as the 'spill over effect'. (195). There have not been any surveys undertaken to determine if this has been achieved for species which share the marine park and the Richmond River habitat, such as bream, flathead, school prawns and garfish. Anecdotal recreational fishing accounts and the commercial Richmond River catch records do not suggest such a benefit has occurred. As Emeritus Professor of Fisheries Management Bob Kearney and Dr Graham Fairbrother (formerly University of Tasmania) stated in their 2014 paper:

> "*Unfortunately, the nuance of the titles 'marine park' and 'MPA', and in particular the absolute and past-tense implication of 'protected', has been used to support public perception of 'mission accomplished'. This misconception has been continuously nurtured by governments in incorrectly definitive statements such as the Ministerial pronouncement, 'Australia's precious marine environments have been permanently protected' by marine parks (Burke, 2012). The continued overstatement of what has actually been achieved has diminished public scrutiny of the adequacy and appropriateness of the management action taken and what has been proposed. The resulting lack of scrutiny has continued to help conceal the limitations of what management has been provided.*" (175)

NSW Marine Protected Areas claim to address threats including harvesting, loss of biomass, wildlife interactions and disturbance, fishing-related marine debris, climate change and those that impinge on resource use conflicts (NSW Marine Estate Management Authority, 2017)[78].

The threat posed by water quality deterioration from all forms of pollution has been a notable omission from headlining the list of threats assembled prior to 2017. The threat from diffuse source

76 https://www.awe.gov.au/water/wetlands/publications/wetlands-australia/national-wetlands-update-february-2019/govt-initiatives-blue-carbon

77 https://www.eh.org.au/documents/item/735

78 https://www.marine.nsw.gov.au/__data/assets/pdf_file/0007/1374874/Marine-Protected-Areas-technical-report-biological-and-ecological-review-MEEKP-2020.pdf

pollution was picked up in the BMT WBM Threat and Risk Assessment in 2017[79] but, then did not feature in the knowledge gaps section of the Evaluation of the performance of NSW MPAs in 2020. It is also unclear how the MPAs do anything to protect the marine estate from climate change risks. No convincing data of a wider fishery benefit was presented in the 2020 Evaluation of the performance of the NSW MPAs[80].

Reflection is perhaps warranted as to whether MPAs are the most efficient method to achieve the desired protection of habitat and biodiversity under their current operation at these locations.

Consideration of the wider potential social benefits and values which are cultivated from having protected places for nature should form elements of the discussion. Widening the regulatory scope of the threats to include water pollution in all its forms, such that marine park managers are empowered to address these, including where the source may be outside the park boundary, could improve the likelihood that marine parks could live up to their aspirations of delivering protection, conservation and restoration of fishery biomass.

Alternatively, redirection of expenditure towards controlling water pollution and habitat losses at their source might yield better economic and social outcomes compared to further investment in MPA expansions as some researchers (196) are calling for.

Solutions and Recommendations

Preamble

The change could perhaps be accelerated with a societal shift in how humanity views the natural world. Presently much of humanity tower over the aquatic domain and look down upon it from a self-appointed position of authority. It is viewed as something for us to control and use. Instead with education we could come to see the world from the water, as a central part of our existence. And with more humility and empathy we could understand that millennia ago humans evolved from animals that moved from the sea to the land. If we viewed the aquatic world as our own place of origin, our own mother, then perhaps we'd support the restoration of it as the precious life-giving resource that it truly is. Perhaps then when we enjoy the seafood harvested from this aquatic ecosystem, or just watch the rest of life, outside of ourselves, thriving in the river we can appreciate the critical importance that clean unpolluted water plays in supporting the viability and amenity of these systems. It is all on us to ensure its restoration and protection in perpetuity.

Recommendations

1) Reconcile with First Nations people expanding their leadership role in land and water resource management through recognizing their cultural knowledge and integrating their cultural value systems.
2) Collect and assemble the historical environmental baselines of productivity through engagement with citizen science, schools, commercial fishers, Government agencies and community.
3) Require detailed monitoring of all water quality threats and mandate actions for restoration and remediation funded via "polluter pays" principle.

79 https://www.marine.nsw.gov.au/__data/assets/pdf_file/0011/1352666/NSW-Marine-Estate-Threat-and-Risk-Assessment-Final-Report.pdf

80 https://www.marine.nsw.gov.au/__data/assets/pdf_file/0007/1374874/Marine-Protected-Areas-technical-report-biological-and-ecological-review-MEEKP-2020.pdf

a. Require all wastewater contaminant chemical removal costs to be paid by the manufacturer of the chemical through requiring whole-of-lifecycle chemical management.

b. Require costs of removal of agricultural chemicals from water and sediment to be paid by chemical manufacturers and users.

4) Create an economic value for fish habitat and fishery productivity in addition to its blue carbon (carbon sequestration potential). Adjust existing regulatory funding allocations and augmenting these with new, local sources of revenue such that it becomes economic to:

    a. Pay farmers to grow native vegetation- restore wetlands, repair riparian zones, change practices to avoid pollutant entry to river, increase biodiversity, sequester carbon (197) and eliminate diffuse source pollution.

    b. Consider land buy-back of low value agricultural land, such as acid impacted wetlands, to manage the area as an environmental asset to support expanded fishery productivity.

    c. Better utilise recreational and commercial fishers to be environmental monitors for catchments and fishery.

5) Reform fisheries management to focus on ecosystem and environmental variables which contribute to fishery productivity such that predictive power is improved.

6) Reform marine protected area (MPA) management to include a focus on the threat of incoming water pollution to the park and consider where MPAs are the most efficient management tools to achieve the goals.

7) Implement zero waste circular economy (https://zerowasteaustralia.org/) to cease the continued escalation of pollution. Designing products explicitly for recycling can reverse the trend of them becoming waste streams and environmental pollutants.

8) Transition agricultural production through incentives and research expansion to regenerative and organic farming methods which are not dependent upon agricultural chemicals and focus on eliminating diffuse and point source water pollution and restoring biodiversity.

9) Explicitly include “water” as a defined fish habitat under the *Fisheries Management Act 1994*, to provide fishery managers more direct recourse for control of water pollution.

10) Require regulation of agricultural chemicals to review endpoints every ten years to ensure they reflect contemporary knowledge and are highly protective of ecosystem health, function and productivity. In the absence of adequate data, market accessed should be denied. Ensure definition of what is an ‘unreasonable adverse effect’ includes reduction of fishery productivity or resilience.

11) Harmonise all Council Local Environment Plans aims with respect to the stringency of protection to the highest standard for protection of water quality from all forms of pollution and ensure that this takes precedence over other aims should a conflicting situation arise.

12) Increase resourcing to fast-track improved governance arrangements to hasten stakeholder interactions to support improved administration of catchment restoration building on previous planning work.

13) Shift citizen litigation under the POEO Act to be moved under the NSW Civil and Administrative Tribunal (NCAT) to remove some of the financial disincentive to launch litigation created by having litigation placed within the ‘costs’ jurisdiction of courts. This could also ensure that

success is measured by 'fixing' the environmental issue rather than in terms of the magnitude of financial payout.

Challenges beyond regulation- social re-imagining

Some of the possible fixes to the Richmond River involve the restoration of natural wetland hydrology to areas of the floodplain (36). While these are acknowledged to provide the best outcomes for fishery health and productivity, they are of sufficient social impact, as to be unlikely to be realistic options. The way in which, poor historical landscape modification, which leads to chronic pollution, becomes entrenched as subsequent social necessity is problematic to restoration efforts.

A re-imagining of a more productive and healthier outcome is needed, and one that offers a win-win to existing landholders and the rest of the community. This is about building social capital to realise the need to reverse the trend of running down the health of the ecosystems.

Harnessing the goodwill of local citizens and volunteers to educate and promote better controls of pollution and improvements to river health can be powerful. The founding chapter of OzFish Unlimited started on the Richmond River and has elevated the visibility of the plight of the river driving new actions to restore habitat, educating school children, helping farmers and landholders to better understand how their actions affect others downstream[81].

A good deal of improvement in ecosystem health and fishery productivity could be achieved if prevention of water pollution were to be made a central priority in governance, rather than narrow secondary economic considerations within a pro-development agenda.

[81] https://ozfish.org.au/projects/saving-our-saltmarsh/

References

1. *Shifting baseline syndrome: causes, consequences, and implications.* Soga, M and Gaston, KJ. 4, 2018, Fronteirs in Ecology and the Environment, Vol. 16, pp. 222-230.

2. *Primary production ultimately limits fisheries economic performance.* Marshak, AR and Link, JS. 2021, Scientific Reports, Vol. 11, p. 12154.

3. *Comments on Edgar et al. (2018) paper for south-western Australia.* Gaughan, D, et al. 2019, Aquatic Conservation Marine and Freshwater Ecosystems, Vol. 29, pp. 1380-1381.

4. *River flows and estuarine ecosystems: Implicaitons for coastal fisheries from a review and a case study of the Logan River, southeast Queensland.* Loneragan, NR and Bunn, SE. 1999, Australian Journal of Ecology, Vol. 24, pp. 431-440.

5. *What are the impacts of flow regime changes on fish productivity in temperate regions? A systematic map protocol.* Rytwinski, T, et al. 13, 2017, Environmental Evidence, Vol. 6.

6. *Mobilization and transport of pesticides with runoff and suspended sediment during flooding events in an agricultural catchment of Southern Brazil.* Didone, EJ, et al. 2021, Environmental Science and Pollution Research.

7. *Nitrogen and phosphorus movement from agricultural watersheds.* Burwell, RE, et al. 1977, Journal of soil and water conservation, pp. 226-23.

8. *Effect of riparian vegetation on diatom assemblages in headwater streams under different land uses.* Hlubikova, D, et al. 2014, Science of the Total Environment, Vol. 475, pp. 234-247.

9. *Riparian zone, stream, and floodplain issues: a review.* Bren, LJ. 1993, Journal of Hydrology, Vol. 150, pp. 277-299.

10. *Effects of urban multi-stressors on three stream biotic assemblages.* Waite, IR, et al. 2019, Science of the Total Environment, Vol. 660, pp. 1472-1485.

11. *Deoxygenation potential of the Richmond River estuary floodplain, Northern NSW, Australia.* Eyre, BD, Kerr, G and Sullivan, LA. 9, 2006, River Research and Applications, Vol. 22, pp. 981-992.

12. *Estuarine acidification: impacts on aquatic biota of draining acid sulphate soils.* Sammut, J, et al. 1, 1995, Australian Geographical Studies, Vol. 33, pp. 89-100.

13. *Centuries of anadromous forage fish loss: consequences for ecosystem connectivity and productivity.* Hall, CJ, Jordaan, A and Frisk, MG. 8, 2012, BioScience, Vol. 62, pp. 723-731.

14. Astles, KL, et al. *Experimental study of the effects of cold water pollution on native fish. A final report for the Regulated Rivers and Fisheries Restoration Project. NSW Fisheries Final Report Series No. 44.* Cronulla : NSW Fisheries, 2003. p. 55. ISSN 1440-3544.

15. Fairfull, S and Witheridge, G. *Why do fish need to cross the road? Fish passage requirements for waterway crossings.* Cronulla : NSW Fisheries, 2003. p. 16. ISBN: 1 920812 00 8.

16. *Synopsis of biological, fisheries and aquaculture-related information on mulloway Argyrosomus japonicus (Pisces: Sciaenidae), with particular reference to Australia.* Silberschneider, V and Gray, CA. 2008, Journal of Applied Ichthyology, Vol. 24, pp. 7-17.

17. *Seagrass meadows globally as a coupled scoial-ecological system: Implications for human wellbeing.* Cullen-Unsworth, LC, et al. 2, 2014, Marine Pollution Bulletin, Vol. 83, pp. 387-397.

18. *Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus.* Partridge, GJ and Michael, RJ. 2010, Journal of Fish Biology, Vol. 77, pp. 227-240.

19. *Spreading dead zones and consequences for marine ecosystems.* Diaz, R and Rosenberg, R. 2008, Science, Vol. 321, pp. 926-929.

20. Kolding, J, et al. Are the Lake Victoria Fisheries Threatened by Exploitation or Eutrophication? Towards an Ecosystem-based Approach to Management. [ed.] G BIanchi and HR Skjoldal. *The Ecosystem Approach fo Fisheries.* Rome : CAB International and Food and Agriculture Organization of the United Nations, 2008, 19, pp. 309-354.

21. *Seagrasses and eutrophication.* Burkholder, JM, Tomasko, DA and Touchette, BW. 2007, Journal of Experimental Marine Biology and Ecology, Vol. 350, pp. 46-72.

22. *Bivalve response to estuarine eutrophication: the balance between enhanced food supply and habitat alterations.* Carmichael, RH, Shriver, AC and Valiela, I. 1, 2012, Journal of Shellfish Research, Vol. 31, pp. 1-11.

23. *Impacts of nutrient enrichment on coral reefs: new perspectives and implication for coastal management and reef survival.* D'Angelo, C and Wiedenmann, J. 2014, Current Opinion in Environmental Sustainability, Vol. 7, pp. 82-93.

24. *Ammonia toxicity in fish.* Randall, DJ and Tsui, TKN. 2002, Marine Pollution Bulletin, Vol. 45, pp. 17-23.

25. Glibert, PM and Burkholder, JM. The complex relationships between increases in fertilization of the Earth, coastal eutrophication and proliferation of harmful algal blooms. [ed.] E Grandeli and JT Turner. *Ecological Studies.* Berlin Heidelberg : Springer-Verlag, 2006, Vol. 189.

26. Berry, J. Cyanobacterial toxins in food webs: Implications for human and environmental health. [ed.] AJ Rodriguez. *Current Topics in Public Health.* s.l. : Intech Open, 2013, pp. 531-589.

27. *Human health risk assessment related to cyanotoxin exposure.* Funari, E and Testai, E. 2008, Critical Reviews in Toxicology, Vol. 38, pp. 97-125.

28. *Declining oxygen in the global ocean and coastal waters.* Brietburg, D, et al. 46, 2018, Science, Vol. 359, p. eaam7240.

29. *Histological and feeding response of Sydney Rock Oysters Saccostrea glomerata, to acid sulfate soil outflows.* Dove, MC and Sammut, J. 2, 2007b, Journal of Shellfish Research, Vol. 26, pp. 509-518.

30. *Carbon dioxide dynamics driven by groundwater discharge in a coastal floodplain creek.* Atkins, ML, et al. 2013, Journal of Hydrology, Vol. 493, pp. 30-42.

31. *Aphanomyces species associated with red spot disease: an ulcerative disease of estuarine fish from eastern Australia.* Fraser, GC, Callinan, RB and Calder, LM. 1992, Journal of Fish Diseases, Vol. 15, pp. 173-181.

32. *Dermatitis, branchitis and mortality in empire gudgeon Hypseleotris compressa exposed naturally to runoff from acid sulfate soils.* Callinan, RB, Sammut, J and Fraser, GC. 2005, Diseases of Aquatic Organisms, Vol. 63, pp. 247-253.

33. *The effect of chronic arsenic exposure in zebrafish.* Hallauer, J, et al. 5, 2016, Zebrafish, Vol. 13, pp. 405-412.

34. Winberg, PC and Heath, T. *Ecological impacts of floodgates on esturaine tributary fish assemblages- Report to the Southern Rivers Cartchment Management Authority.* Nowra : University of Wollongong Shoalhaven Marine and Freshwater Centre, 2010.

35. *Redistribution of monosulfidic black oozes by floodwaters in a coastal acid sulfate soil floodplain.* Bush, RT, et al. 2004, Australian Journal of Soil Research, Vol. 42, pp. 603-607.

36. Moore, A. *Blackwater and Fish Kills in the Richmond River Estuary-Defining the issues-assessing the risks-providing management options- Report for Richmond Floodplain Commitee for Richmond River County Council.* Lismore : Southern Cross University, 2006.

37. *Worldwide pesticide usage and its impacts on ecosystem.* Sharma, A, et al. 2019, SN Applied Sciences, Vol. 1, p. 1446.

38. *Pesticides in Queensland and Great Barrier Reef waterways- potential impacts on aquatic ecosystems and the failure of natinal management.* Brodie, J and Landos, M. 2019, Estuarine, Coastal and Shelf Science, Vol. 230, p. 106447.

39. *Experimental evidence for neonicotinoid driven decline in aquatic emerging insects.* Barmentlo, SH, et al. 44, 2021, PNAS, Vol. 118, p. e2105692118.

40. *Worldwide decline of the entomofauna: A review of its drivers.* Sanchez-Bayo, F and Wyckhuys, KAG. 2019, Biological Conservation, Vol. 232, pp. 8-27.

41. *Neonicotinoids disrupt aquatic food webs and decrease fishery yields.* Yamamuro, M, et al. 2019, Science, Vol. 366, pp. 620-623.

42. *A fish of many scales: extrapolating sublethal pesticide exposures to the productivity of wild salmon populations.* Baldwin, DH, et al. 8, 2009, Ecological Applications, Vol. 19, pp. 2004-2015.

43. *The impacts of modern-use pesticides on shrimp aquaculture: An assessment for north eastern Australia.* Hook, SE, et al. 2018, Ecotoxicology and Environmental Safety, Vol. 148, pp. 770-780.

44. *Olfactory toxicity in fishes.* Tierney, KB, et al. 2010, Aquatic toxicity, Vol. 96, pp. 2-26.

45. *The organophosphate pesticide -OP- malathion inducing thyroidal disruptions and failures in the metamorphosis of the Sengalese sole, Solea senegalensis.* Ortiz-Delgado, JB, Funes, V and Sarasquete, C. 2019, BMC Veterinary Research, Vol. 15:57.

46. *Herbicide-induced macrophyte-to-phytoplankton shifts in Japanese lagoons during the last 50 years: consequences for ecosystem services and fisheries.* Yamamuro, M. 2012, Hydrobiologia, Vol. 699, pp. 5-19.

47. *Herbicides increase the vulnerability of corals to rising sea surface temperature.* Negri, AP, et al. 2, Limnology and Oceanography, Vol. 56, pp. 471-485.

48. *Herbicides implicated as the cause of severe mangrove dieback in the Mackay region, NE Australia: consequences for marine plant habitats of the GBR World Heritage Area.* Duke, NC, et al. 2005, Marine Pollution Bulletin, Vol. 51, pp. 308-324.

49. *Synergistic effects of glyphosate formulation and parasite infection on fish malformations and survival.* Kelly, DW, et al. 2010, Jourrnal of Applied Ecology, pp. 1-7.

50. *Trematode infection causes malformations and population effects in a declining New Zealand fish.* Kelly, DW, et al. 2009, Journal of Animal Ecology, Vol. 79, pp. 445-452.

51. *The effects of three organic chemicals on the upper thermal tolerances of four freshwater fishes.* Patra, RW, et al. 7, 2007, Environmental Toxicology and Chemistry, Vol. 26, pp. 1454-1459.

52. *From silent spring to silent night: Agrochemicals and the anthropocene.* Hayes, TB and Hansen, M. 57, 2017, Elementa Science of the Anthropocene, Vol. 5.

53. *Pesticides with potential thyroid hormone-disrupting effects: a review of recent data.* Leemans, M, et al. 2019, Frontiers of Endocrinology, Vol. 10.

54. *Endocrine-disrupting activities in vivo of the fungicides Tebuconazole and Epoxiconazole.* Taxvig, C, et al. 2, 2007, Toxicological Sciences, Vol. 100, pp. 464-473.

55. *Demasculinization and feminization of male gonads by atrazine: Consistent effects across vertebrate classes.* Hayes, TB, et al. 2011, Journal of Steroid Biochemistry & Molecular Biology, Vol. 127, pp. 64-73.

56. *Achieving a high level of protection from pesticides in Europe: Problems with the current risk assessment procedure and solutions.* Robinson, C, et al. 2020, European Journal of Risk Regulation, Vol. 11, pp. 450-480.

57. *Commentary: Novel strategies and new tools to curtail the health effects of pesticides.* Benbrook, C, et al. 2021, Environmental Health, p. 20:87.

58. *Thresholds and endocrine disruptors: An endocrine society policy perspective.* Demeneix, B, et al. 10, 2020, Journal of the Endocrine Society, Vol. 4, pp. 1-7.

59. *PFAS exposure pathways for humans and wildlife: a synthesis of current knowledge and key gaps in understanding.* De Silva, AO, et al. 3, 2021, Environmental Toxicology and Chemistry, Vol. 40, pp. 631-657.

60. *A review of the pathways of human exposure to poly- and perfluoroalkyl substances (PFASs) and present understanding of health effects.* Sunderland, EM, et al. 2019, Journal of Exposure Science & Environmental Epidemiology, Vol. 29, pp. 131-147.

61. *Long-term effect of a binary mixture of perfluorooctane sulfonate (PFOS) and bisphenol A (BPA) in zebrafish (Danio rerio).* Keiter, S, et al. 2012, Aquatic Toxicity, Vols. 118-119, pp. 116-129.

62. *Bioaccumulation and trophic transfer of polybrominated diphenyl ethers (PBDEs) in biota from the Pearl River Estuary, South China.* Yu, M, et al. 2009, Environment International, Vol. 35, pp. 1090-1095.

63. *A review on the effects of PBDEs on thyroid and reproduction systems in fish.* Yu, L, Han, Z and Liu, C. 2015, General and Comparative Endocrinology, Vol. 219, pp. 64-73.

64. *Sources, presence and potential effects of contaminant of emerging concern in the marine environments of the Great Barrier Ref and Torres Strait, Australia.* Kroon, FJ, et al. 2020, Science of the Total Environment, Vol. 719, p. 135140.

65. *Long-term and transgenerational effects of nonylphenol exposure at a key stage in the development of Crassostrea giga. Possible endocrine disruption?* Nice, HE, et al. 2003, Marine Ecology Progress Series, Vol. 256, pp. 293-300.

66. *Endocrine disruption of parr-smolt transformation and seawater toelrance of Atlantic salmon by 4-nonylphenol and 17B-estradiol.* McCormick, SD, et al. 2005, General and Comparative Endocrinology, Vol. 142, pp. 280-288.

67. *Nonylphenol induced changes in trophic web structure of plankton analysed by multivariate statistical approaches.* Hense, BA, et al. 2005, Aquatic Toxicology, Vol. 73, pp. 190-209.

68. *Effects of nonylphenol on the growth and microcystin production of Microcystis strains.* Wang, J, Xie, P and Guo, N. 2007, Environmental Research, Vol. 103, pp. 70-78.

69. Scott, PD. *Investigation of endocrine disruption in Australian aquatic environments-Thesis.* Gold Coast : Griffith University, Griffith School of Environment, 2014.

70. *Microplastic ingestion by zooplankton.* Cole, M, et al. 2013, Environmental Science and Technology.

71. *Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health.* Carbery, M, O'Connor, W and Thavamani, P. 2018, Environment International, Vol. 115, pp. 400-409.

72. *Microplastics in fish and fishmeal: an emerging environmental challenge.* Thiele, CJ, et al. 2021, Scientific Reports, p. 11:2045.

73. *Chemical pollutants sorbed to ingested microbeads from personal care products accumulate in fish.* Wardrop, P, et al. 2016, Environmental Science and Technology, Vol. 50, pp. 4037-4044.

74. *Microplastics as vehicles of environmental PAHs to marine organisms: combined chemical and physical hazards to the mediterranean mussels, Mytilus galloprovincialis.* Pittura, L, et al. 103, 2018, Frontiers in Marine Science, Vol. 5.

75. *Comparative effects of ingested PVC microparticles with and without adsorbed benzo(a)pyrene vs. spiked sediments on the cellular and sub cellular processes of the benthic organism Hediste diversicolor.* Gomiero, A, et al. 99, 2018, Frontiers of Marine Science, Vol. 5.

76. *Ingested microplastic as a two-way transporter for PBDEs in Talitrus saltator.* Scopetani, C, et al. 2018, Environmental Research, Vol. 167, pp. 411-417.

77. *Combined effects of microplastics and chemical contaminants on the organ toxicity of zebrafish (Danio rerio).* Rainieri, S, et al. 2018, Environmental Research, Vol. 162, pp. 135-143.

78. *Impacts to larval fathead minnows vary between preconsumer and environmental microplastics.* Bucii, K, et al. 2021, Environmental Toxicology and Chemistry, pp. 1-11.

79. *Fate of road-dust associated microplastics and per-and polyfluorinated substances in stormwater.* Pramanik, BK, et al. 2020, Process Safety and Environmental Protection, Vol. 144, pp. 236-241.

80. *A ubiquitous tire rubber-derived chemical induces acute mortality in coho salmon.* Tian, Z, et al. 2020, Science.

81. *Polycyclic aromatic hydrocarbons in surface water from the seven main river basins of China: Spatial distribution, source apportionment, and potential risk assessment.* Yu, H, et al. 2021, Science of the Total Environment, Vol. 752, p. 141764.

82. *Water quality concerns due to forest fires: polycyclic aromatic hydrocarbons (PAH) contamination of groundwater from mountain areas.* Mansilha, C, et al. 2014, Journal of Toxicology and Environmental Health, Part A, Vol. 77, pp. 806-815.

83. *Photo-induced toxicity following exposure to crude oil and ultraviolet radiation in two Australian fishes.* Sweet, LE, et al. 5, 2018, Environmental Toxicology and Chemistry, Vol. 37, pp. 1359-1366.

84. *A novel cardiotoxic mechanism for a pervasive global pollutant.* Brette, F, et al. 2017, Scientific Reports, Vol. 7, p. 41476.

85. *Photo-induced toxicity of Deepwater Horizon slick oil to blue crab (Callinectes sapidus) larvae.* Alloy, MM, et al. 9, 2015, Environmental Toxicology and Chemistry, Vol. 34, pp. 2061-2066.

86. *A review of pollutants in the sea-surface microlayer (SML): a unique hbaitat for marine organisms.* Wurl, O and Obbard, JP. 2004, Marine Pollution Bulletin, Vol. 48, pp. 1016-1030.

87. *Marine heatwaves under global warming.* Frolicher, TL, Fischer, EM and Gruber, N. 7718, Nature, Vol. 560, pp. 360-364.

88. *Marine heatwaves threaten global biodiversity and the provision of ecosystem services.* Smale, DA, et al. 2019, Nature Climate Change, Vol. 9, pp. 306-312.

89. Daley, LT. *Men and a River- A history of the Richmond River District 1828-1895.* Melbourne : Melbourne University Press, 1966.

90. Hoff, J. *Bundjalung Jugun: Bundjalung Country.* Lismore : Richmond River Historical Society, 2006.

91. Ainsworth, J. *Reminiscences-Ballina in the Early Days: 1847-1922.* Ballina : Beacon Printery, 1922.

92. *Burials in the Ballina shell mounds.* Tooby, L. 2018, Journal of the Australian Association of Consulting Archaeologists, Vol. 6, pp. 1-11.

93. *The role of molluscs in coastal economies: the results of midden analysis in Australia.* Bailey, GN. 1975, Journal of Archaeological Science, Vol. 2, pp. 45-62.

94. Attenbrow, V. *Sydney's Aboriginal past: investigating the archaeological and historical records.* Sydney : University of New South Wales Press, 2002. p. 226.

95. *From North Creek to Lennox Head no.162.* s.l. : Richmond River Historical Society Bulletin, 1999.

96. *The disappearance of oyster reefs from eastern Australian estuaries-impact of colonial settlement or mudworm invasion?* Ogburn, DM, White, I and McPhee, DP. 2007, Coastal Management, Vol. 35, pp. 271-287.

97. Smith, GS. *The Queensland oyster fishery- an illustrated history.* Brisbane : Queensland Department of Primary Industries, 1985. p. 111.

98. Gahan, K. *A land use history snapshot, North Creek, pre1788-2020 Ballina Shire Council.* Ballina : Ballina Shire Council, 2021.

99. Kijas, J. *An Echo of Wings: A History of the Tuckean Swamp.* Ballina : Self-published, 2019. p. 78.

100. *The conflict between financial decision making and indigenous Australian culture.* Wagland, S and Taylor, S. 2015, Financial Planning Research Journal, pp. 33-54.

101. *Oyster culture in esturay worlds of Southern Queensland.* Frawley, J. s.l. : Rachel Carson Center, 2017, RCC Perspectives-Visions of Australia-Environments in History, pp. 11-18.

102. Black, AB. *Report on the Camden haven Fishery- In Oyster Culture Commission.* Sydney : Report to the Royal Commmission, appointed on 29th September, 1876 to inquire into the best mode of cultivating the oyster together with the minutes of evidence, and appendices., 1876. p. 73.

103. *History, status and future of Australia's native Sydney rock oyster industry.* Schrobback, P, Pascoe, S and Coglan, L. 2014, Aquatic Living Resources, Vol. 27, pp. 153-165.

104. Roughley, TC. *Oyster culture on the Georges River, New South Wales. Technical Education Series 25.* s.l. : Technical Museum, 1922. p. 69pp.

105. *Historical epidemiology indicates water quality decline drives loss of oyster (Saccostrea glomerata) reefs in Moreton Bay, Australia.* Diggles, BK. 2013, New Zealand Journal of Marine and Freshwater Research, Vol. 474, pp. 561-581.

106. Dwyer, P. *Historical harvesting of River Mangrove for use as 'oyster sticks' in NSW.* Ballina, NSW, Australia : s.n., 6 January 2014.

107. *Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative valuation.* Peterson, CH and Grabowski, JHl Powers, SP. 2003, Marine Ecology Progress Series, Vol. 264, pp. 249-264.

108. Star, Northern. *Early days of cedar-getting on the Richmond.* 23 June 1938.

109. Ryder, D, et al. *Richmond Ecohealth Project 2014: Assessment of River and Estuarine Condition-Final Technical Report.* Armidale : University of New England, 2015.

110. Skorulis, A. *Historical riparian vegetation changes in Eastern NSW.* Wollongong : University of Wollongong, School of Earth and Environmental Science, 2016.

111. *The influence of land use in a highly modified catchment: Investigating the importance of scale in riverine health assessment.* Oeding, S, et al. 2017, Journal of Environmental Management, Vol. 206, pp. 1007-1019.

112. Smith, E and Baldwin, J. *A landuse history of Tuckean Swamp- Technical Report #6, Tuckean Swamp Study.* Alstonville : Self-published, 1997.

113. *Interpreting long-term patterns of seagrasses abundance: how seagrass variabilityis dependent of genus and estuary type.* West, GJ and Glasby, TM. 2021, Estuaries and Coasts.

114. *A global crisis for seagrass ecosystems.* Orth, RJ, et al. 12, 2006, Bioscience, Vol. 56, pp. 987-996.

115. *Accelerating loss of seagrasses across the globe threatens coastal ecosystems.* Waycott, M, et al. 30, 2009, Proceedings of the National Academy of Sciences of the United States of America, Vol. 106, pp. 12377-12381.

116. *The impact of increased flooding occurrence on the mobility of potentially toxic elements in floodplain soil- A review.* Ponting, J, et al. 2021, Science of the Total Environment, Vol. 754, p. 142040.

117. *Flood related loss and recovery of intertidal seagrass meadows in southern Queensland, Australia.* Campbell, SJ and McKenzie, LJ. 2004, Estuarine coastal and shelf science, Vol. 60, pp. 477-490.

118. *Predicting seagrass recovery times and their implications following an extreme climate event.* Nowicki, RJ, et al. 2017, Marine Ecology Progress Series, Vol. 567, pp. 79-93.

119. GeoLink. *Review of Pesticide Residue Water Sampling Program - Rous Water 2003/04.* Lennox Head : Self-published Ref:0574263, 2004.

120. Rous Water-Technical Services. *2009/2010 Pesticide Residue Water Sampling and Analysis program: Emigrant Creek and Wilsons River Water Supply Systems.* Lennox Head : Self-published 138/06, 2010.

121. *pesticide residues in drinking water in the North Coast Region of New South Wales, Australia, 1986-87.* Ang, C, Meleady, K and Wallace, L. 1989, Environmental Contamination and Toxicology, Vol. 42, pp. 595-602.

122. *Assessing the additive risks of PSII herbicide exposure to the Great Barrier Reef.* Lewis, SE, et al. 2012, Marine Pollution Bulletin, Vol. 65, pp. 280-291.

123. *Combined effects temperature and the herbicide diuron on Photosystem II activity of the tropical seagrass Halophila ovalis.* Wilkinson, AD, et al. 2017, Scientific Reports, p. 7:45494.

124. Hendersen, G&M. HIstory: The start of the Northern Rivers sugar industry. *Northern Star.* 8 August 2016.

125. Henderson, M. Sugar Mills and Tram Lines No. 718. *Published in The Northern Star.* Lismore, NSW, Australia : Richmond River Historical Society Inc, 15 August 2011.

126. Stephens, N. *Assessing changes to fish habitat in the Richmond River, NSW using historical photographs and oral histories.* Lismore : Southern Cross University, 2003.

127. *When toxic chemicals refuse to die- An examination of the prolonged mercury pesticide use in Australia.* Schneider, L. 1, 2021, Elementa Science of the Anthropocene, Vol. 9.

128. *Sublethal toxicity of orchard stormwater runoff in Sacramentio splittail (Pogonichthys macrolepidotus) larvae.* Teh, SJ, et al. 2005, Marine Environmental Research, Vol. 59, pp. 203-216.

129. Williams, R. *Water Quality in the Richmond River-Northern Rivers Study No. 4.* Sydney : State Pollution Control Commission, 1987.

130. *The presence of contaminants in sewage sludge- The current situation.* Fijalkowski, K, et al. 2017, Journal of Environmental Management, Vol. 203, pp. 1126-1136.

131. *A mass estimate of perfluoroalkyl substance (PFAS) release from Australian wastewater treatment plants.* Gallen, C, et al. 2018, Chemosphere.

132. Campbell, R. *Rous County Council Bulk Water Supply.* Ballina : Hydrosphere Consulting, 2020. p. 142pp.

133. *Climate change impact on Rous Water supply.* Kirono, D, et al. s.l. : Journal of the Australian Water Association, 2007, Water, pp. 68-72.

134. Government, NSW. *Water sharing plan for the Richmond River unregulated, regulated and alluvial water sources- background document for amended plan 2016.* s.l. : NSW Department of Primary Industries, Water, 2016.

135. Silberstein, RP, et al. *The effect of clearing of native forest on flow regime- Technical Report.* s.l. : Cooperative Research Centre for Catchment Hydrology, 2004.

136. *A contribution to the management of the historic shipwreck heritage: the environmental context of the Richmond River mouth shipwreck hertiage at Ballina, New South Wales.* Boyd, WE, Charter, CJ and Cotter, MM. 1, 1995, Bulletin of the Australian Institute for Marine Archaeology, Vol. 19, pp. 37-44.

137. Group, North Coast Region State of the Environment Report Working. *Regional State of the Environment Report Summary 2020.* Coffs Harbour : North Coast Region State of the Environment Report Working Group, 2021. p. 50pp.

138. *Suspended sediment transport dynamics in the sub-tropical micro-tidal Richmond River estuary, Australia.* Hossain, S, Eyre, B and McConchie, D. 2001, Estuarine, Coastal and Shelf Science, Vol. 51, pp. 529-541.

139. FIsheries, NSW. *Eastern (Freshwater) Cod (Maccullochella ikei) Recovery Plan.* Threatened Species Unit, NSW Fisheries. Nelson Bay : NSW Fisheries, 2004. p. 45.

140. *Stemflow runoff contributes to soil erosion at the base of macadamia trees.* Keen, B, et al. Brisbane : s.n., 2010. World Congress of Soil Science, Soil Solutions for a Changing World. pp. 240-243.

141. Reid, G. *Soil and nutrient loss in macadamia lands: a pilot study-Report 98011.* Alstonville : Horticulture Australia, 2002.

142. *Water quality changes in an episodically flushed sub-tropical Australian estuary: A 50 year perspective.* Eyre, B. 1997, Marine Chemistry, Vol. 59, pp. 177-187.

143. *Anthropogenic forcing of estuarine hypoxic events in sub-tropical catchments: Landscape driver and biogeocehmical processes.* Wong, VNL, et al. 2011, Science of the Total Environment, Vol. 409, pp. 5368-5375.

144. *The effects of acid sulphate run-off on a subtidal estuarine macrobenthic community in the Richmond River, NSW, Australia.* Corfield, J. 2000, ICES Journal of Marine Science, Vol. 57, pp. 1517-1523.

145. *Impacts of estuarine acidification on survival and growth of sydney rock oysters Saccostrea glomerata (Gould 1850).* Dove, MC and Sammut, J. 2, 2007, Journal of Shellfish Research, Vol. 26, pp. 519-527.

146. *Is there evidence of arsenic movement at cattle tick dip sites?* Kimber, SWL, Sizemore, DJ and Slavich, PG. 2002, Australian Journal of Soil Research.

147. *Organochlorine insecticide residues in fish and birds from three river sstems on the North Coast Region of New South Wales.* McDougall, KW, et al. 6, 1989, Bulletin of Environmental Contamination and Toxicology, Vol. 42, pp. 884-890.

148. *Levels of selected chlorinated hydrocarbons in edible fish tissues from polluted areas in the Georges/Cooks Rivers and Sydney Harbour, New South Wales, Australia.* Roach, AC and Runcie, J. 5, 1998, Marine Pollution Bulletin, Vol. 36, pp. 323-344.

149. Hydrosphere. *Richmond County Council Pesticide Risk Assessment.* Ballina : Hydrosphere, 2020.

150. Pratt, K. *Review of RCC Pesticide Monitoring Program- Rous County Council.* Ballina : Hydrosphere, 2020.

151. *Total mercury concentration in some fish and shellfish from NSW estuaries.* Williams, RJ, et al. 1976, Food Technology Australia, Vol. 28, pp. 8-10.

152. *Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2019-20. Report for the Great Barrier Reef Marine Park Authority.* Waterhouse, J, et al. Townsville : Great Barrier Reef Marine Park Authority, 2021, p. 226pp.

153. *Investigating the distribution of polybrominated diphenyl ethers through an Australian wastewater treatment plant.* Clarke, BO, et al. 2010, Science of the Total Environment, Vol. 408, pp. 1604-1611.

154. Toms, L, et al. *Assessment of concentrations of polybrominated diphenyl ether flame retardants in aquatic environments in Australia.* Department of the Environment and Heritage. s.l. : Australia Government, 2006. p. 69.

155. *Pharmaceuticals and personal care products (PPCPs) in Australia's largest inland sewage plan, and its contribution to a major Australian river during high and low flow.* Roberts, J, et al. 2016, Science of the Total Environment, Vol. 541, pp. 1625-1637.

156. *Municipal sewage sludge as a source of microplastics in the environment.* Rolsky, C, et al. 2020, Current Opinion in Environmental Science and Health, Vol. 14, pp. 16-22.

157. *Recycled wastewater as a potential source of microplastics in irrigated soils from an arid-insular territory (Fuerteventura, Spain).* Perez-Reveron, R, et al. 2022, Science of the Total Environment, Vol. 817.

158. Group, North Coast Region State of the Environment Report Working. *State of the Environment 2016.* Coffs Harbour : Coffs Harbour City Council on behalf of the participating councils and agency, 2016.

159. *Assessment of future climate change impacts on hydrological behavior of Richmond River Catchment.* Al-Safi, HIJ. 3, 2017, Water Science and Engineering, Vol. 10, pp. 197-208.

160. Kearney, R and Farebrother, G. *FRDC Project No. 2013/029The comparative performance of the management of the individual threats to marine environments and fisheries resources.* Canberra : Fisheries Research and Development Corporation, 2015.

161. Rowland, S. *The Codfather.* Perth : Self-published, Optima Press, 2020.

162. *Maccullochella ikei. The IUCN Red List of Threatened Species 2019.* Butler, G. s.l. : International Union for Conservation of Nature and Natural Resources, p. e.T12573A123378170.

163. *Mogurnda adspersa. The IUCN Red List of Threatened Species 2019.* Bice, C, et al. s.l. : International Union of Conerservation of Nature and Natural Resources, 2019, p. e.T13609A123378372.

164. Industries, NSW Department of Primary. *Primefact 1275- Purple Spotted Gudgeon - Mogurnda adspersa.* Port Stephens : NSW Department of Primary Industries, 2013.

165. —. *Primefact 181 October 2016 - Oxleyan Pygmy perch- Nannoperca oxleyana- Second edition.* Threatened Species Unit, Port Stephens Fisheries Institute. s.l. : NSW Department of Primary Industries, 2016. p. 3.

166. *Nannoperca australis. The IUCN Red List of Threatened Species 2019.* Pearce, L, et al. s.l. : The International Union for Conservation of Nature and Natural Resources, 2019, p. e.T123358579A123382811.

167. Stewart, J. *NSW Stock Status Summary 2018/19-Sea Mullet (Mugil cephalus).* s.l. : NSW Department of Primary Industries. Fisheries, 2020. p. 10.

168. Hughes, J. *Stock Status Summary 2021 - Mulloway (Argyrosomus japonicus).* s.l. : NSW Department of Primary Industries. Fisheries NSW, 2020. p. 13.

169. Stead, DG. *Edible fishes of New South Wales: Their present importance and their potentialities.* Sydney : WA Gullick, Government Printer, 1908.

170. Broadhurst, M and Stewart, J. *NSW Stock Status Summary 2019/20- Dusky Flathead- (Platycephalus fuscus).* s.l. : NSW Department of Primary Industries, 2021. p. 9.

171. McDonald, B. *A report on the Impact of Habitat Variation and Fish Kills on Fish Catches in the Richmond River.* s.l. : self-published, 2001.

172. Stewart, J, et al. *FRDC Project No. 2001/027 March 2005 -Life history, reproductive biology, habitat use and fishery status of eastern sea garfish (Hyporhamphus australis) and river garfish (H. regularis ardelio) in NSW waters.* Sydney : NSW Dpeartment of Primary Industries, 2005. ISSN 1449-9967.

173. Fletcher, M and Fisk, G. *NSW Marine Estate Statewide Threat and Risk Assessment.* NSW Government Marine Estate Management Authority. s.l. : BMT WBM, 2017. p. 344.

174. McPhee, D. *Fisheries Management in Australia.* Sydney : The Federation Press, 2008. ISBN 978 186287 684 2.

175. *Chapter Seven: Inadequate evaluation and management of threats in Australia's Marine Parks, including the Great Barrier Reef, Misdirect marine conservation.* Kearney, B and Farebrother, G. 2014, Advances in Marine Biology, Vol. 69, pp. 253-281.

176. *Rapid worldwide depletion of predatory fish communities.* Myers, RA and Worm, B. 2003, nature, Vol. 423, pp. 280-283.

177. *Lessons for stock assessment from the northern cod collapse.* Walters, C and Maguire, JJ. 1996, Reviews in Fish Biology and Fisheries, Vol. 6, pp. 125-137.

178. Alluvium. *Richmond River Governance and Funding Framework. A Report for the NSW Department of Planning, Industry and Environment and supporting local governments.* Alstonville : s.n., 2019.

179. *Avoiding implementation failure in catchment landscapes: A case study in governance of the Great Barrier Reef.* Dale, AP, et al. 1, 2017, Environmental Management, Vol. 62, pp. 70-81.

180. *Removal of PFOS, PFOA and other perfluoroalkyl acids at water reclamation plants in South East Queensland Australia.* Thompson, J, et al. 2011, Chemosphere, Vol. 82, pp. 9-17.

181. *Occurrence and toxicity of 331 organic pollutants in large rivers of North Germany over a decade (1994 to 2004).* Schafer, RB, et al. 14, 2011, Environmental Science & Technology, Vol. 45, pp. 6167-6174.

182. *Like oil and water: the politics of (Not) assessing glyphosate concentrations in aquatic ecosystems.* Hendlin, YH, et al. 3, 2020, European Journal of Risk Regulation, Vol. 11, pp. 539-564.

183. *Achieving a high level of protection from pesticides in Europe: problems with the current risk assessment procedure and solutions.* Robinson, C, et al. 3, 2020, European Journal of Risk Regulation, Vol. 11, pp. 450-480.

184. *Commentary: Novel Strategies and new tools to curtail the health effects of pesticides.* Benbrook, C, et al. 2021, Environmental Health, Vol. 20:87.

185. *Endocrine-disrutping chemicals: economic, regulatory, and policy implications.* Kassotis, CD, et al. 2020, The Lancet, Vol. 8, pp. 719-730.

186. *Regulatory assessment and risk management of chemical mixtures: challenges and ways forward.* Bopp, SK, et al. 2019, Critical Reviews in Toxicology.

187. *Pesticides, corporate irresponsibility, and the fate of our planet.* Goulson, D. 2020, One Earth, Vol. 2, pp. 302-305.

188. Consulting, Hydrosphere. *Mid-term review of the Coastal Zone Management Plan (CZMP).* s.l. : unpublished, 2017.

189. Dela-Cruz, J, Pik, A and Wearne, P. *Risk-based framework for considering waterway health outcomes in strategic land-use planning decisions.* Office of Environment and Heritage, State of NSW. Sydney : Office of Environment and Heritage, 2017.

190. *The science for profit model- how and why corporations influence science and the use of science in policy and practice.* Legg, T, Hatchard, J and Gilmore, AB. 6, 2021, PLoS ONE, Vol. 16, p. e0253272.

191. *An assessment of endocrine activity in Australian rivers using chemical and in vitro analyses.* Scott, PD, et al. 2014, Environmental Science Pollution Research, Vol. 21, pp. 12951-12967.

192. Samuel, G. *Independent Review of the EPBC Act - Final Report.* Canberra : Commonwealth of Australia, 2020. p. 252.

193. *Skilful prediction of cod stocks in the North and Barents Sea a decade in advance.* Koul, V, et al. 2021, Communications Earth & Environment, pp. 1-10.

194. Pratt, K and Howland, M. *Rous Water: Review of the Rous Water Catchment Monitoring Program-Water Quality Assessment and Monitoring Program Review-Final Report.* Ballina : Self-published, 2016.

195. Kenchington, R, Ward, T and Hegerl, E. *The benefits of Marine Protected Areas.* s.l. : Commonwealth of Australia, 2003.

196. *Rebuilding marine life.* Duarte, CM, et al. 2020, Nature, Vol. 580, pp. 39-51.

197. *Complementary land use in the Richmond River catchment: Evaluating economic and environmental benefits.* Beardmore, L, Heagney, E and Sullivan, CA. 2019, Land Use Policy, p. 104070.

198. *Organochlorine pesticide residues in soils and sediments of the herbert and Burdekin River Regions, North Queensland-Implications for contamination of the Great Barrier Reef.* Cavanagh, JE, et al. 1-12, 2000, Marine Pollution Bulletin, Vol. 39, pp. 367-375.

199. *River flows and estuarine ecosystems: Implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland.* Loneragan, NR and Bunn, SE. 1999, Australian Journal of Ecology, Vol. 24, pp. 431-440.

200. *What are the impacts of flow regime changes on fish productivity in temperate regions? A systematic map protocol.* Rytwinski, T, et al. 13, 2017, Environmental Evidence, Vol. 6.

201. *Automobile tires- a potential source of highly carcinogenic dibenzopyrenes to the environment.* Sadiktsis, I, et al. 6, 2012, Environmental Science & Technology, Vol. 46, pp. 3326-3334.

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Appendix 1- Pesticides used in Richmond River catchment

Pesticides (unshaded) identified as risks for water contamination in Richmond River catchment for Rous County Council by Hydrosphere consulting **(109)**. Shaded additions to table based on current industry pest control guidelines published by NSW DPI (see Governance chapter above) to table.

2,4 D	Herbicide
Abamectin	Avermectin insecticide
Acephate	Organophosphate foliar insecticide
Acetamiprid	Neonicotinoid Insecticide
Alpha-cypermethrin	Pyrethroid insecticide
Aminopyralid	Herbicide
Azinphos-methyl	Organophosphate insecticide
Azoxystrobin	Fungicide
Beta-cyfluthrin	Pyrethroid insecticide
Bifenazate	Miticide
Bifenthrin	Pyrethroid insecticide
Boscalid	Carboxamide fungicide
Bromoxynil	Herbicide
Bupirimate	Hydroxypyrimidine fungicide
Buprofezin	Thiadiazine insecticide
Captan	Phthalimide fungicide
Carbaryl	Carbamate insecticide
Carbendazim	Benzimidazole fungicide
Chlorothalonil	Chloronitrile fungicide
Chlorpyrifos	Organophosphate insecticide
Clethodim	Herbicide
Clofentezine	Tetrazine insecticide miticide
Clothianidin	Neonicotinoid insecticide

Copper hydroxide or cupric hydroxide	Fungicide
Copper oxychloride	Fungicide
Copper sulphate	Fungicide
Coumatetralyl	Rodenticide
Cyprodinil	Anilinopyrimidine fungicide
Deltamethrin	Pyrethroid insecticide
Diazinon	Organophosphate insecticide
Dicamba	Herbicide
Difenoconazole	Triazole fungicide
Dimethoate	Organophosphate Insecticide
Diquat	Herbicide
Dithianon	Fungicide
Esfenvalerate	Pyrethroid insecticide
Fenbutatin oxide	Organotin miticide
Fenhexamid	Fungicide
Fipronil	Insecticide
Fluzifop-p-butyl	Herbicide
Fludioxonil	Phenylpyrrole fungicide
Flupyradifurone	Neonicotinoid Insecticide
Fluroxypyr	Herbicide
Fluxapyroxad	Pyrazole-carboxamide fungicide
Glufosinate-ammonium	Herbicide
Glyphosate	Herbicide
Halosulfuron-methyl	Herbicide
Haloxyfop	Herbicide
Hexythiazox	Thiazolodine insecticide, herbicide, adjuvant

Imidacloprid	Neonicotinoid insecticide
Indoxacarb	Oxadiazine Insecticide
Iprodione	Dicarboximide fungicide
Lamda-cyhalothrin	Pyrethroid insecticide
Maldison/Malathion	Organophosphate insecticide
Mancozeb	Dithiocarbamate fungicide & miticide
MCPA	Herbicide
Metalaxyl	Phenylamide fungicide
Methidathion	Organophosphate insecticide
Methomyl	Carbamate insecticide and acaricide
Methoxyfenozide	Carbohydrazide insecticide
Metolachlor	Herbicide
Metsulfuron-methyl	Herbicide
MSMA	Herbicide
Nonanoic acid	Herbicide
Oryzalin	Herbicide
Oxyfluorfen	Herbicide
Paraffinic oil	Acaricide, insecticide, herbicide, adjuvant
Paraquat	Herbicide
Pendimethalin	Herbicide
Penthiopyrad	Pyrazole carboxamide fungicide
Phenmedipham	Herbicide
Phorate	Organophosphate insecticide
Phosphorus acid	Ethylphosphonate fungicide
Picloram	Pyrimidine herbicide
Pirimicarb	Carbamate insecticide

Prochloraz	Fungicide
Procymidone	Dicarboximide fungicide
Prodiamine	Herbicide
Prometryn	Herbicide
Propiconazole	Triazole Fungicide
Pyraclostrobin	Quinone fungicide
Pyrimethanil	Anilinopyrimidine fungicide
Pyriproxyfen	Insecticide
Simazine	Triazine herbicide
Spinetoram	Spinosyn insecticide
Spirotetramat	Insecticide
Sulfometuron-methyl	Herbicide
Sulfoxaflor	Neonicotinoid Insecticide
Tebuconazole	Triazole Fungicide
Tebufenozide	Ecdysone agonist moulting hormone selective insecticide
Tetraniliprole	Diamide insecticide
Thiamethoxam	Neonicotinoid Insecticide
Trichlorfon	Organophosphate Insecticide
Triclopyr	Herbicide
Trifloxystrobin	Fungicide
Trifloxysulfuron sodium	Herbicide
Zinc phosphide	Phosphine (metal phosphide) rodenticide
Zineb	Dithiocarbamate fungicide
Chemicals no longer in use but may persist in catchment	
Endosulfan and metabolites	Organochlorine insecticide
Dieldrin	Organochlorine insecticide

DDTs	Organochlorine insecticide
Lindane	Organochlorine insecticide
Heptachlor epoxide	Organochlorine insecticide

Appendix 2- Threat and Risk Assessment for northern region of NSW Marine Estate extracted from WBM BMT report (173)

Ranked Priority Threats to Environmental Assets for the North Region	Ranked Priority Threats to Social, Cultural and Economic Benefits for the North Region	Shared Priority Threats across Assets and Benefits for the North Region
Estuary entrance modifications	Water pollution on environment values- urban stormwater discharge	Agricultural diffuse source runoff
Clearing riparian and adjacent habitat including wetland drainage (in estuaries)	Water pollution on environment values – Agricultural diffuse source runoff	Climate change stressors (sea level rise, altered storm/cyclone activity, flooding, climate and sea temperature rise, altered ocean currents and nutrient inputs)
Agricultural diffuse source runoff (in estuaries)	Water pollution on environment values – litter, solid waste, marine debris and microplastics	Habitat (physical) disturbance
Climate Change 20 years	Inadequate social and economic information	Urban stormwater discharge
Urban stormwater discharge (in estuaries)	Lack of compliance with regulations (by users) or lack of compliance effort (by agencies)	
Modified freshwater flows (in estuaries)	Reductions in abundance of species and trophic levels	
Recreation and tourism– boating and boating infrastructure (in estuaries)	Limited or lack of access infrastructure to the marine estate	***Please note that this column includes only those priority threats that are directly comparable between the environmental and social, cultural and economic TARAs. Other threats will overlap between the two TARA priority lists however they are not directly equivalent.***
Recreation and tourism - Four wheel driving	Anti-social behaviour and unsafe practices	
Foreshore development	Climate change stressors 20 years	
Navigation & entrance management and modification, harbour maintenance etc. (in estuaries)	Loss of public access (either by private development or Government area closures)	
Sewage effluent and septic runoff	Inadequate, inefficient regulation, over-regulation (agencies)	

Stock grazing of riparian and marine vegetation (in estuaries)	Loss or decline of marine industries	
Commercial fishing – Ocean Trawl (in coastal and marine)	Pests and diseases	
Recreational fishing -Shore-based line and trap fishing	Conflict over resource access and use	
Recreational fishing – Boat-based line and trap fishing	Habitat (physical) disturbance	
Commercial fishing – Ocean Trap and Line (in coastal and marine)	Overcrowding / congestion	
Commercial fishing – Estuary General (in estuaries)	Water pollution on environment values – septic runoff, point source pollution and sewage overflows (such as outfalls, STPs, etc.)	
Passive recreational use	Modified hydrology/hydraulics and flow regime	
Deliberate introduction of plants and animals (e.g.foxes, bitou bush)	Wildlife disturbance (shorebirds, turtles, whales) and impacts to ecological health by dog walkers, 4WD, marine vessels, etc.	
Recreational fishing- Hand Gathering	Lack of community awareness of the marine estate, associated threats and benefits, regulations and opportunities for participation	
Oyster Aquaculture (in estuaries)	Seafood contamination	
Commercial fishing – Ocean Haul (in coastal and marine)	Sediment contamination	
Charter activities – whale and dolphin watching	Lack of or ineffective community engagement or participation in governance	
Beach nourishment and grooming	Other water pollution/contamination affecting human health and safety	
Shipping – Small commercial (in coast and marine)	Excessive or illegal extraction	
Commercial fishing - estuary prawn trawl (in estuaries)	Wildlife interactions (e.g. shark bite, jellyfish, boat striking a whale)	

Appendix 3- Commonwealth, State and Local Legislation and regulation related to management of waterway pollution and fisheries

Commonwealth legislation	Objectives that relate to water pollution and fisheries
Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)[82]**.**	This Act is triggered when development or activities have a significant impact on one or more of the following matters of national environmental significance: World Heritage site; National Heritage place; national protected wetland (Ramsar wetland); nationally listed threatened species or ecological community; listed migratory species; and a Commonwealth marine area. It is the main environment protection Act.
Agricultural and Veterinary Chemicals (Administration) Act 1992[83]	This Act establishes the Australian Pesticides and Veterinary Medicines Authority (APVMA) for the regulation and control of agricultural and veterinary chemicals in Australia up to the point of retail sale.
Agricultural and Veterinary Chemicals Act 1994[84]	This Act enables the Agvet Code to have effect in each State and Territory of Australia and provides the Commonwealth the powers to review decisions taken under the Agvet Codes by the APVMA and empowers the Commonwealth Director of Public Prosecutions to prosecute for offences, even though they are offences against the laws of the states or territories.
Agricultural and Veterinary Chemicals Code Act 1994[85]	Details provisions to allow APVMA to evaluate, approve, register and review active constituents and agricultural and veterinary chemical products, to issue permits and license the manufacture of chemical products. It also contains provisions to regulate the supply and compliance to the Agvet Code.

82 https://www.environment.gov.au/epbc

83 https://www.legislation.gov.au/Series/C2004A04553

84 https://www.legislation.gov.au/Series/C2004A04712

85 https://www.legislation.gov.au/Series/C2004A04723

Industrial Chemicals Act 2019[86]	This Act establishes the Australian Industrial Chemicals Introduction Scheme (AICIS) as the regulatory scheme for importation and manufacture of industrial chemicals in Australia which are used in industrial processes or in products such as paints, adhesives, inks, plastics, glues, solvents, soaps and ingredients in cosmetics. The regulator may conduct risk assessments on the introduction and intended use of new industrial chemicals, however the majority of assessments will be effectively self-assessed, to issue certificates and authorisations for the introduction of some hazardous industrial chemicals in Australia. The process only considers the chemical, not the end products. It may make risk management recommendations to protect human health and the environment for consideration by state and territory Governments and monitors compliance and breaches of the Act.
New South Wales State Government legislation	**Objectives that relate to water pollution and fisheries**
Protection of the Environment Operations Act 1997 [87]	This Act aims to protect, restore and enhance the quality of the environment While having regard to the need to maintain ecologically sustainable development. Amongst other aims it seeks to reduce risks to human health and prevent the degradation of the environment by promoting: pollution prevention; cleaner production; reduction of pollutant substances to harmless levels prior to discharge; elimination of harmful wastes; progressive environmental improvements including the reduction of pollution at the source; and monitoring and reporting on the environmental quality at regular intervals. The POEO Act 1997 is administered by the NSW Environmental Protection Agency (NSW EPA) in relation to 'scheduled activities' such as issuing of licences (with conditions) to pollute (eg for wastewater treatment plant releases back to the environment). Licences are required to be reviewed by EPA once every 5 years. These are mostly for point source polluters. NSW EPA can issue Clean-up notices and Prevention notices and fees for cost recovery of their compliance activity. The Act makes available options for authorised officers to investigate, issue penalty notices and fines. The court can also apply gaol terms for offences under the POEO Act 1997. The Minister can issue a prohibition notice. Prevention notices can direct an activity to become "environmentally satisfactory" Local Councils are responsible for administering the 'non-scheduled' activities under the POEO Act 1997.

86 http://classic.austlii.edu.au/au/legis/cth/num_act/ica2019202/

87 https://legislation.nsw.gov.au/view/html/inforce/current/act-1997-156

	Any person may bring proceedings in the Land and Environment Court for an order to remedy or restrain a breach of the POEO Act or the regulations, or breaches of other Acts if the breach is causing or likely to cause environmental harm (s253)
Fisheries Management Act 1994[88]	To conserve, develop and share fishery resources of the State for the benefit of present and future generations. In particular, the objects of this Act include conserving fish stocks and key fish habitats, conserving threatened species and ecological communities of fish and marine vegetation, conserving biological diversity, While promoting ecologically sustainable development, commercial and recreational fishing and aquaculture. The Act aims to also provide social and economic benefits for the wider community of New South Wales and recognise the spiritual, social and customary significance to Aboriginal persons of fisheries resources and to protect and promote the continuation of Aboriginal cultural fishing. The Act prescribes catch size limits (minimum and maximum) and numbers for recreational fishers, who require licences to fish in NSW. There is no limit to the number of recreational licences able to be issued. There are penalties (fines and imprisonment) for possession of prohibited fish. It also defines a range of habitat which is protected under the Act including seagrass, mangroves and rocky reef. The Act does not specifically define "water" to be fish habitat, though it may be inferred. Some other water considerations such as water quality are covered in the *Water Management Act 2000* (below). The Act also defines threatening processes like degradation of native riparian vegetation. The numbers of commercial fishing licences which have endorsement to fish in the estuary general zone 1 (which includes the Richmond River) are controlled by the NSW Government. The fishery is not subject to quotas. Local commercial fisheries are not intended for export, so are not subject to the Commonwealth requirement for assessment for their ecological sustainability. All commercial fishers must be licensed as do their boats and their fishing gear.
Water Management Act 2000[89]	This Act provides for the sustainable and integrated management of the State's water sources for the benefit of present and future generations. The Act directs management to apply the principles of ecologically sustainable development. It aims to protect, enhance and restore water sources, their associated ecosystems, ecological processes and biological diversity and their water quality. It also seeks to recognise the benefits to the State from the sustainable and efficient use of water including benefits to the: environment; urban

88 https://legislation.nsw.gov.au/view/html/inforce/current/act-1994-038

89 https://legislation.nsw.gov.au/view/html/inforce/current/act-2000-092

	communities, agriculture, fisheries, industry and recreation; culture and heritage; Aboriginal people in relation to their spiritual, social, customary and economic use of the land and water. The Act seeks to provide for the orderly, efficient and equitable sharing of water with shared responsibility for sustainable and efficient use between the Government and water users. Water sharing plans outline water quality objectives and river flow objectives.
Pesticides Act 1999[90]	Aims to promote the protection and minimise risk to human health, the environment, property and trade in relation to the use of pesticides having regard to the principles of ecologically sustainable development. It is an offence under the Act to wilfully or negligently use a pesticide that materially harms a non-target animal, a threatened species, or non-target plant. The Environment Protection Authority can issue a prevention notice where they reasonably suspect that any pesticide has been used in an environmentally unsatisfactory manner. This may require ceasing use of a particular pesticide or method of application, ceasing an operation that requires use of a pesticide, monitoring, sampling, analysing and recording information that is relevant to the use of a pesticide, preparing and carrying out a plan of action to prevent any pesticide from being used in an environmentally unsatisfactory manner, installing, repairing, altering, replacing, maintaining or operating equipment or other machinery used in the application of pesticide. It is an offence not to comply to a prevention notice. The Environment Protection Authority can also issue a pesticide control order to protect public health, property, the environment or trade.
Environmentally Hazardous Chemicals Act 1985[91]	This Act creates a 17-member committee to advise the Environmental Protection Authority (EPA) on the co-ordination of administrative and enforcement activities in relation to the control of chemicals that are environmentally hazardous. It advised the Authority in relation to the assessment and control of chemicals that are or should be dealt with as, environmentally hazardous chemicals. It also advises on priority investigations of incidents involving the contamination of the environment by chemicals and chemical wastes. The committee can carry research into and report to the Authority upon any matter relating to legislation concentring the control of chemicals. The EPA can make chemical control orders to regulate the manufacture, processing, conveying, buying, selling or disposal of the chemical or declared waste.

90 https://legislation.nsw.gov.au/view/html/inforce/current/act-1999-080#sec.1

91 https://legislation.nsw.gov.au/view/html/inforce/current/act-1985-014

State Environmental Planning Policy (Primary Production and Rural development) 2019[92]	This Act requires intensive livestock above a certain scale to seek a development application including where potential for surface water and ground water pollution must be considered.
State Environmental Planning Policy No 71	Aims to protect and preserve the marine environment amongst other aims. It sets out matters which the consent authority must consider when preparing a local environment plan or determining a development application, such as measures to conserve threatened animals, plants and fish. Should a development result in effluent discharge that negatively affects water quality, or results in release of untreated stormwater then it should be rejected.
State Environmental Planning Policy (Coastal Management) 2018[93]	Aims of this policy are to manage development in the coastal zone and protect the environmental assets of the coast amongst other aims.
Coastal Management Act 2016 [94]	Seeks to manage the coastal environment in manner consistent with principles of ecologically sustainable development. It seeks to both protect and enhance coastal processes and coastal environmental values including natural character, scenic value, biological diversity and ecosystem integrity and resilience amongst a list of other objects.
Marine Estate Management Act 2014 [95]	Seeks to amongst other aims promote a biologically diverse, healthy and productive marine estate including through use of marine parks and aquatic reserves. This includes estuaries up to the area of tidal influence. It facilitates the maintenance of ecosystem integrity. The following NSW Government agencies manage the marine estate: NSW Department of Industry (includes Local Land Services, Crown Lands and Water, Destination NSW and NSW Department of Primary Industries (DPI)); NSW Department of Planning and Environment; NSW Office of Environment and Heritage; NSW Environment Protection Authority; Transport for NSW; Roads and Maritime Services.

92 https://legislation.nsw.gov.au/view/html/inforce/current/epi-2019-0137#sec.19

93 https://legislation.nsw.gov.au/view/html/inforce/current/epi-2018-0106#sec.3

94 https://legislation.nsw.gov.au/view/html/inforce/current/act-2016-020#sec.3

95 https://legislation.nsw.gov.au/view/html/inforce/current/act-2014-072#sec.3

State Environmental Planning Policy (Coastal Management) 2018[96]	Aims to manage development in coastal zone and protect environmental assets of the coast, providing a framework for land use planning consistent with the *Coastal Management Act 2016.* A development consent is required for development within, or in 'proximity area' of coastal wetlands that requires clearing of native vegetation, or harm to marine vegetation or may require earthworks, construction of a levee, draining the land or environmental protection works. The consent authority must be satisfied that the quantity and quality of surface and groundwater flows to and from the coastal wetland is not significantly impacted.
State Environmental Planning Policy - Sustainable Aquaculture[97]	Aims to encourage sustainable aquaculture (including oyster farming) in certain zones as identified in the NSW Land Based Sustainable Aquaculture Strategy, setting out minimum performance criteria and establish a graduated environmental assessment.
State Environmental Planning Policy Canal Estate Development (1997 EPI 596)[98]	Aims to prohibit this kind of development to ensure is not adversely affected by this kind of development.
Contaminated Land Management Act 1997[99]	Administered by NSW EPA to investigate and remediate contaminated land. Contaminated cattle dips in the Richmond River catchment have been subject to action under this Act.
Biodiversity Conservation Act 2016[100]	This Act aims to maintain a healthy, productive and resilient environment for the greatest well-being of the community, now and into the future, consistent with the principles of ecologically sustainable development. It seeks to maintain the diversity and quality of ecosystems and enhance their capacity to adapt to change and provide for the needs of future generations, and to establish market-based conservation mechanisms through

96 https://legislation.nsw.gov.au/view/html/inforce/current/epi-2018-0106

97 https://www.planningportal.nsw.gov.au/opendata/dataset/sepp-sustainable-aquaculture

98 https://legislation.nsw.gov.au/view/html/inforce/current/epi-1997-0596

99 https://legislation.nsw.gov.au/view/whole/html/inforce/current/act-1997-140

100 https://legislation.nsw.gov.au/view/html/inforce/current/act-2016-063

	which biodiversity values of proposed development and land use change can be offset at landscape and site scales, amongst other aims.
In addition to those Acts outlined above, the NSW EPA also administers the following Acts. Should a breach occur that is causing harm to the environment, then action to restrain the breach can be brought under the POEO Act. -Dangerous Goods (Road and Rail Transport) Act 2008 -Forestry Act 2012 (Parts 5A 5B only) -National Environment Protection Council (New South Wales) Act 1985 -Ozone Protection Act 1989 -Protection of the Environment Administration Act 1991 -Radiation Control Act 1990 -Recreational Vehicles Act 1983 -Waste avoidance and Resource Recovery Act 2001	Various elements could have a role in controlling water pollution. Details should be sought from the Original Acts online.
Local Government Regulation	**Objectives that relate to water pollution and fisheries**
Ballina Local Environment Plan 2012 (2013 EPI 20)[101]	Sets out what developments are, or are not, permitted in various zones of the local Government area. Development consent must give consideration to both the applications impact and cumulative impacts on

101 https://legislation.nsw.gov.au/view/whole/html/inforce/2016-08-05/epi-2013-0020

	how biodiversity and ecosystems can be conserved, including native vegetation, wildlife corridors, rock platforms, the water quality of coastal waterbodies and native flora and fauna and their habitats amongst other things. The consent authority must be satisfied that any effluent will not have a negative effect on the water quality of the sea, or any beach, estuary, coastal, coastal creek or other similar body of water or a rock platform and that no untreated stormwater will be discharged into the sea, creek or river.
Lismore Local Environment Plan 2012[102].	Aims to protect, sustain and enhance Lismore's natural environment, particularly native fauna and flora amongst other things
Kyogle Local Environment Plan 2012[103]	in relation planning provisions for land in Kyogle amongst other things it aims: "(a) to provide for the fair, orderly and sustainable use or development of air, land and water, (b) to promote the sustainable management, development and conservation of natural, social, economic, built and cultural resources and to ensure that choices and opportunities in relation to those resources remain for future generations."
Richmond Valley Local Environment Plan 2012[104]	Aims "To encourage the proper management, development and conservation of natural and man-made resources."
Byron Local Environment Plan 2014[105]	Aims: "(a) to progressively respond to changes in the natural, social and economic environment in a way that is consistent with the following principles of ecologically sustainable development— (a) the precautionary principle—this principle means that where there are threats of serious or irreversible damage to the community's ecological, social or economic systems, a lack of complete scientific evidence should not be used as a reason for postponing measures to prevent environmental degradation (In some circumstances this will mean actions will need to be taken to prevent damage even when it is not certain that damage will occur.),

102 https://legislation.nsw.gov.au/view/whole/html/inforce/current/epi-2013-0066

103 https://legislation.nsw.gov.au/view/html/inforce/current/epi-2013-0025#pt

104 https://legislation.nsw.gov.au/view/whole/html/inforce/current/epi-2012-0098

105 https://legislation.nsw.gov.au/view/whole/html/inforce/current/epi-2014-0297

	(ii) the principle of intergenerational equity—this principle means that the present generation must ensure that the health, integrity, ecological diversity, and productivity of the environment is at least maintained or preferably enhanced for the benefit of future generations, (iii) the principle of conserving biological diversity and ecological integrity—this principle aims to protect, restore and conserve the native biological diversity and enhance or repair ecological processes and systems, (iv) the principle of improving the valuation and pricing of social and ecological resources—this principle means that users of goods and services should pay prices based on the full life cycle costs (including the use of natural resources at their replacement value, the ultimate disposal of any wastes and the repair of any consequent damage), (v) the principle of eliminating or reducing to harmless levels any discharge into the air, water or land of substances or other effects arising from human activities that are likely to cause harm to the environment