FROM PRISTINE TO POLLUTED

HOW CHEMICALS AND POLLUTANTS DRIVE FISHERY DECLINES AND ECOSYSTEM COLLAPSE

a synthesis from three case studies

Richmond River, Australia
Mekong Delta, Vietnam
Fraser River, Canada

March 2024

NTN NATIONAL TOXICS NETWORK

IPEN for a toxics-free future

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Author: Dr. Matt Landos, BVSc (Hons I) MANZCVS, Director, Future Fisheries Veterinary Service Pty Ltd., Associate Researcher, Sydney University, Faculty of Veterinary Science

IPEN is a network of over 600 non-governmental organizations working in more than 125 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals.

www.ipen.org

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 was committed to a toxics-free future.

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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

KEY FINDINGS

Fishery managers strive for sustainability of fisheries natural resources, but declining fisheries is a global problem. While overfishing continues to be problematic, other significant causes of this decline remain dangerously overlooked. This report reviews the significant harmful effects on fisheries from toxic chemicals and demonstrates that chemicals and other pollutants worsen the productivity-degrading effect of overfishing.

KEY TAKEAWAYS FROM THE REPORT INCLUDE:

- The loss and devaluing of **Indigenous Peoples/First Nations' knowledge and values** following colonial occupation has been a significant driver of fisheries decline.
- The production of plastics and chemicals has **exceeded the "planetary boundaries"** for pollution, meaning that chemical pollution threatens the stability of the global ecosystem.
- The use of **pesticides and fertilizers**, toxic chemicals derived from fossil-fuels, is growing even as their use drives climate change, fisheries decline, and pollutes entire ecosystems.
- Corporate polluters benefit from current structures that allow them to **privatize profits while socializing the costs** of their destructive products, as the principle of "polluter pays" has rarely been adopted or enforced.
- Similarly, **governments favor corporate needs over environmental protection**, leading to weak or no regulations even in the face of dire consequences for fisheries. Fisheries are undervalued, with faulty, short-term economic arguments overriding the need for long-term sustainability.

RECOMMENDATIONS

IPEN and NTN urge global and national governments to adopt strong regulations to end the threats to fisheries from toxic chemicals and other pollutants. The Precautionary Principle should be the basis for legislation that fully implements the four pillars of sound chemical regulation:

- **Right to Know:** the community has a right to know what is, or has been used and released, and the level of contamination of public resources such as water and air.
- **No Data/No Market:** when there is no chemical information, or an absence of testing technologies, there should be no right to use or release a chemical into the market.
- **Substitution and Elimination:** if there is a safer, better way of achieving outcomes, then this should be mandatorily substituted for toxic risks.
- **Polluter Pays:** Where pollution is emitted the polluter must pay for the full impacts caused. By their toxic products and practices, with the scale of costs incentivizing the elimination of the production and release of the pollutant.

CONTENTS


B.S.C.

INTRODUCTION

One general aspiration of fishery managers is to achieve sustainable utilization of fisheries natural resources. This can include an intention to support First Nations/Indigenous People's rights and recreational access, in addition to generating an economic and social return and food security for communities from their natural fishery resources.

While overfishing is the most common reason cited for observed fishery declines, this is rarely the whole story, particularly in modern fishery declines in the post-industrial era and with the growing impacts of climate change and worsening chemical pollution. Overfishing continues to be problematic in some areas and efforts to address it are now seeing better managed fisheries in some countries (1).

Some fisheries management experts are concerned that the compelling narrative of overfishing, in its simplicity, has become overamplified, to the extent that other highly significant causes of fish declines are being dangerously overlooked.

Aquaculture is expanding rapidly and globally. By volume it has overtaken wild capture fisheries in supply of seafood for human consumption. In most instances of industrial aquaculture, it is not taking pressure off the wild capture fisheries. Rather it is seeking to exploit economic opportunities to privatize and utilize the natural resources of the aquatic domain.

The diets fed to aquaculture fish and shrimp commonly contain components of natural marine resources that have been captured and processed from the environment, such as fishmeal and fish oil. As such, the demand for these commodities to feed the expanding aquaculture industry has led to expansion of fishing effort in some areas to meet demand. The intensive nature of fish and shrimp aquaculture can add significant effluent pollution pressures onto the receiving aquatic environments.

This synthesis report explores the roles of factors, other than overfishing, which are reducing the health and productivity of river and estuary-linked fisheries. In particular, this review demonstrates that the effects of chemicals and other pollutants further degrade the productivity of overfished waters.

To identify and better understand the complex factors impacting fisheries, the report explores three case studies and considers the effectiveness of differing governance regimes in managing pollution stressors and other factors that contribute to fishery declines through time.

The cases studies cover a diversity of climatic and geographic fisheries and are indicative of changes around the world.

1. Subtropical: Richmond River, New South Wales, Australia
2. Tropical: Mekong River, Vietnam
3. Temperate, Cold water: Fraser River, British Columbia, Canada

Each case study looks at a range of referenced scientific resources, historical materials, and information from local governance agencies to document the land-use changes to the river's drainage catchment. Pollutant loads from agricultural run-off, urban and industrial wastewater, and stormwater discharge and fishery catches are considered through time to the present.

The emergence and role of numerous man-made chemicals and other pollutants are specifically considered in relation to their impacts on fish habitat, the trophic food web, and the health and reproduction of fish, prawns/shrimp, and shellfish.

The term water 'pollutant' is used in this report as a descriptor for all types of water pollution including agricultural chemicals, industrial wastes, surfactants, plastics, pharmaceuticals, nutrient, hydrocarbons, sediment, acid, thermal (climate), and others.

The numerous aquatic pollutant types and their impacts on the aquatic environment and fisheries have been examined in detail in two previous IPEN reports: *Ocean Pollutant Guide 2020*[1] and *Aquatic Pollutants in Oceans and Fisheries 2021.*[2]

Government regulations and industry guidance have been made to attempt to control, offset, or eliminate pollution threats to fisheries and water quality at the international, country, state and local levels.

The outcome of the governance structures which manage fishery catch and seek to control various pollution sources is contrasted with the current pollution status of the rivers from recent available data.

FUNCTIONING OF RIVER AND ESTUARY-LINKED FISHERIES IN THE MODERN WORLD

The productivity and health of fisheries is interdependent on a complex interplay of elements within healthy aquatic ecosystems. The bottom of the food web is foundational and built through the generation of abundant and diverse algae and microscopic invertebrates. The primary productivity of the bottom trophic layer of the aquatic food web ultimately sets the outputs that fisheries can produce (2). These are the food resources for the higher trophic species to convert into the fish and invertebrates (shellfish, crabs, prawns, squid, octopus) which are ultimately harvested by fishers, birds, seals, whales, bears, and other wildlife.

These aquatic food webs are created as water moves through terrestrial landscapes, where it collects nutrients, carbon, minerals, bacteria, protozoa and algae as it moves down the catchment. Diverse native vegetation in forests, grasslands, riparian zones and wetlands on the landscape helps filter water, store water and promote the infiltration of rainwater into the ground. This infiltrated water becomes the groundwater that later feeds streamflow persistence, to keep rivers flowing and to provide a drip feed of nutrients and minerals. Locally adapted resident and migratory fish, crustacea, mollusks, birds, and other predators develop complex seasonal lifecycles around the seasonal water cycle.

Terrestrial vegetation also provides habitat for insects that depend on waterways to complete their lifecycle and generate nutrient cycling and energy capture to move up the food web as they become critical prey items for fish and crustacea. Some insects have water-borne and sediment dwelling phases which can contribute to maintaining oxygenated sediments and assist in binding sediments together which stabilizes the riverbed. These effects promote clearer water, which in turn allows the energy of sunlight to penetrate and fuel the photosynthetic process of aquatic plants (micro and macroalgae) in the water column and in the riverbed. These aquatic plants can then become food resources for grazing insects, crustacea, mollusks and fish, transferring the energy from the sun, up the food web.

In the riverbed locally adapted bivalve shellfish can establish. There they help to filter the water, capturing algae and organic matter, and create more habitat and food resources for higher trophic predators.

Those plants which are tolerant of inundation colonize wetlands, river edges and suitable areas of the riverbed, creating protective nursery habitat and diverse feed resources for early life stages of crustacea, mollusks and fish.

Where rivers meet the tidal influence of the ocean they discharge their bounty of nutrients, minerals, carbon and all of the life created in the freshwater food webs. These join seamlessly into the marine food webs, helping support primary productivity in the marine ecosystem through marine microalgae, seagrass, coral and seaweed. The flows also help build bountiful oyster, clam and mussel reefs and beds, huge populations of crabs, shrimp and lobsters and a truly extraordinary quantity and diversity of inshore fish. The natural productivity of the healthy functioning ecosystem is immense.

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1 https://ipen.org/documents/ocean-pollutants-guide

2 https://ipen.org/news/chemical-pollution-causes-fish-declines

The global human population with their consumption and pollution footprints are threatening the productivity of fisheries.

The entry of land-generated sources of greenhouse gas emissions, agricultural, pharmaceutical, and industrial chemical pollutants via stormwater and wastewater to waterways are significant contributors to these processes altering the type and abundance of food and the health and viability of aquatic life.

Many of the world's most productive fisheries are within, or are tightly linked to, rivers and their estuaries. Many of these estuary-linked fisheries are suffering declines in catches of fish, shellfish, shrimp (prawns), and crabs with devastating consequences for people and animals who rely on them for high-quality food.

The reduced catches are reflective of degrading ecosystems. The impacts fall upon the livelihoods, recreation, tourism, and amenity that affords a sense of well-being to many communities who have developed alongside fisheries. It also impacts the wider animal kingdom which shares a dependency on the reliable production from natural fisheries.

AQUACULTURE

Aquaculture is rapidly expanding globally. It has created impacts that are in addition to the pressure exerted by the intensifying extraction of seafood for consumption and use in aquaculture feeds, through expansion into areas that were previously seagrass, wetland and mangrove habitats. By production volume, aquaculture has overtaken wild capture fisheries in supply of seafood for human consumption. The diets fed to aquaculture fish and shrimp commonly contain components of natural marine resources that have been captured and processed from the environment, such as fishmeal and fish oil, but also other derivatives of industrial agriculture systems such as poultry byproduct meal, wheat, soya, lupins and peas. World fishmeal production has been relatively stable over the last decade. The proportion of this production which is from whole fish, rather than fish by-products, has decreased through that period to now be around 50%. As such, the demand for these commodities to feed the expanding aquaculture industry has led to expansion of pesticide-dependent industrial agriculture inputs and the continued direction of fishing effort, and improved capture and reprocessing of fish wastes in some areas to meet demand.

In most instances, industrial aquaculture is not taking pressure off wild capture fisheries. Rather it is exploiting economic opportunities to privatize and utilize the natural resources of the aquatic domain. The intensive nature of fish and shrimp aquaculture can add significant effluent pollution pressures onto the receiving aquatic environments unless substantive remediation is in place.

KEY CATCHMENT DEVELOPMENT IMPACTS ON WATERWAYS

In many countries, including those of the three case studies, dramatic landscape changes were brought by colonial settlers over-riding First Nations/Indigenous people's management of natural environments and cultural values. In pursuit of agrarian visions, colonialism contributed to the destruction of wetlands, saltmarshes, and mangroves which were perceived as worthless, without recognizing the harm to fisheries and aquatic ecosystems. Globally between 1700 and 2000, 85% of the world's wetlands were lost to drainage and development[3] and with it their capacity for water filtration, carbon storage, biodiversity, refuge habitat, and food production were depleted.

Symbolically recognizing these missteps, the United Nations Environment Programme (UNEP) launched the Decade of Ecosystem Restoration[4] which has reframed wetlands as "unsung heroes of the planet," a far cry from the colonial view of them as unproductive dirty swamps. However, the traction of such programs relies upon governments implementing the recommendations.

As the human population has expanded exponentially in the last 100 years and global development continues at pace, a range of detrimental impacts to the natural landscapes have commonly occurred around the world. Ongoing discharges of pollutants associated with development and industry drain into waterways where it has a compounding effect that causes negative impact on fisheries and their critical habitats.

THREATS TO FISHERIES

Key threatening processes and their impacts include:

DEFORESTATION ALTERS STREAMFLOW

Upland deforestation tends to increase run-off and decreases groundwater recharge, leading to increased flood peaks but reduced streamflow persistence after rainfall stops. Reduced streamflow contributes to reduced dilution of pollutants which have entered waterways. The seasonal pattern and persistence of streamflow is broadly correlated to estuarine and inshore fishery productivity. The flow supports expanded production at the base of the food web, thereby increasing the opportunities for recruitment of commercially important species such as fish, oysters, and shrimp (prawns) (3) (4). Forestry management and replanting can involve the use of pesticides that can enter streams at levels toxic to parts of aquatic food webs (5).

REMOVAL OF NATIVE VEGETATION PROMOTES SEDIMENT AND CONTAMINANT RUNOFF

Removal of vegetation for agricultural cultivation exposes soil to erosive forces of rainfall driving up sediment runoff. Contaminants, like pesticides (6), animal manure, and fertilizers (7) are mobilized by runoff to enter into the draining waterways. Other factors which influence sediment mobilization include the quantity and intensity of rainfall, the soil type and amount of tillage, and the slope of landscape. Fertilizers and pesticides also contaminate groundwater of agricultural areas, contributing to river pollution loads when groundwater discharges into waterways (7). Where agricultural pollution occurs in headwaters, the downstream negative impacts on the diatom algae which form part of the base of the trophic food web are not corrected even where the downstream riverbank (riparian) vegetation can be in good condition. (8) This highlights the need for restoration from the top to the bottom of catchments.

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3 https://www.unep.org/news-and-stories/story/wetlands-unsung-heroes-planet

4 https://www.decadeonrestoration.org/

RIVERSIDE-RIPARIAN VEGETATION LOSS REMOVES FILTRATION, SHADE, AND FOOD RESOURCE FROM RIVER

Loss of native vegetation on the interface between the water and the land (riparian zone) causes destabilization of riverbanks, increasing sedimentation of waterways which in turn smothers critical fish habitat, like aquatic vegetation and shellfish reef. The loss of vegetation also removes in stream habitat like snags (fallen timber), depletes insect feed resources and promotes filamentous algal blooms (9). A reduction of shading from riparian vegetation loss, or silviculture thinning can increase river temperatures and increase the range of temperature variations (10) (11) (12). Major river systems of the world have become agricultural, industrial, and urban drains, steadily degrading their value as complex ecosystems.

WETLAND DRAINAGE REMOVES FILTRATION, CARBON STORAGE, FISH HABITAT, AND FOOD RESOURCES

Drainage of wetlands for construction of urban settlements create inflows of complex stormwater pollution. The multiple stressors can include plastics, car tire chemicals, fertilizers, pesticides, sediment, and many other contaminants. Collectively they can lead to stress on algae, invertebrates, and fish in the receiving waterways (13). The construction of urban settlements over former wetlands removes the ecosystem services they previously provided including carbon capture and sequestration (14), nutrient processing and capture, generation of food resources for aquatic food webs, and sediment trapping (15). The loss of wetlands and hard surfaces of urban environments reduce the recharge of groundwater also impacting natural hydrology.

DRAINED ACID SULPHATE WETLANDS CREATE METAL AND DEOXYGENATION POLLUTION

Drained wetlands are also often areas for expansion of agriculture and its accompanying pesticide and fertilizer use. Drained wetlands have facilitated the cultivation of plants which are not flood tolerant. During flooding such crops can decompose and deplete oxygen from the water, threatening the viability of resident aquatic animals (16). In many areas use of flood gates has contributed to triggering toxic releases of metals and acidic water from acid-sulphate soils (17). The loss of fish access to this habitat reduces feed and nursery areas for many fishery species. Pesticide concentrations are often elevated in agricultural drains (18).

MANGROVE AND SALTMARSH REMOVAL CAUSE LOSS OF SEDIMENT CAPTURE, CARBON STORAGE, HABITAT REFUGE, AND PRIMARY FOOD WEB PRODUCTION.

Removal of mangroves and saltmarsh for coastal urban, industrial, aquaculture and agriculture development fundamentally alter the functionality of the aquatic ecosystem (19). Following removal there is a loss of the ecosystem services of sediment stability, carbon and nutrient capture, prevention of coastal erosion, habitat refugia, and generation of significant aquatic food web and fishery production (20).

SEAGRASS LOSS REMOVES SEDIMENT STABILITY, HABITAT AND AQUATIC FOOD WEB PRODUCTION

Loss of aquatic vegetation such as seagrass which provides significant ecosystem services of sediment, nutrient and capture and stabilization, habitat refugia, prevention of coastal and riverine erosion, and generation of significant aquatic food web and fisheries production (21).

SEAGRASS MEADOWS support humans through providing food (fish and invertebrates), raw materials, and income. Some communities, such as the Pacific Island countries and territories, are so integrally linked to seagrass meadows that they are intrinsically sacred and spiritually significant in addition to the food and income security they provide (26). The effects of chemical pollution from agricultural runoff and other sources have led to declines in seagrass meadows in the Richmond River, Australia, leaving them at their lowest levels in living memory. Formerly productive fishing areas around these seagrass meadows no longer hold commercial catches of fish.

DAMS BLOCK FISH PASSAGE, CAUSE COLD WATER POLLUTION, AND ALTER NATURAL FLOWS

Dams have been constructed in many catchments to support town water supplies, agricultural irrigation, hydro energy, mining requirements, and to mitigate flood impacts on urban settlements and crops. Direct loss of the connectivity of habitat is destructive of fishery populations that have evolved to migrate up and down catchments from sea to the source (22). It also modifies the flow regime which disturbs fisheries that have often evolved complex reproductive strategies around natural seasonal flows. Water from many dams is often released from the bottom of the dam, where it is substantially colder than ambient flows, leading to cold water pollution for many kilometers downstream. Aquatic animals often require thermal triggers to complete their reproductive cycle and can be disturbed by a loss of such signals and suffer survival declines from exposure to unnaturally cold water (23).

The flow of water released from a dam Is actively managed to protect downstream urban and agricultural assets from flooding. However, for fisheries, changes in natural hydrology such as a reduction in flooding can reduce access to habitat, reduce stimulation of foundational food web resources, like zooplankton blooms, and interfere with the evolutionary spawning signals of some fish species (24).

ROAD CROSSINGS CAN ALTER HABITAT CONNECTIVITY

Road crossings and weirs similarly impair connectivity through physically blocking passage or creating a high-water velocity or turbulence by narrowing and streamlining the passage through a pipe or culvert, which small fish and larvae struggle to swim against, impairing their ability to move freely upstream to access habitat and food resources (25).

WATER EXTRACTION ALTERS NATURAL FLOW AND REDUCES DILUTION OF POLLUTION

Water extraction for town supply, irrigation, and industrial uses has altered the volumes of water and the timing of its movement through waterways. Periods of lower flow may contribute to the concentration of pollutants, harming the health of waterways.

MINING CAN ADD TOXIC TAILINGS AND DISTURB GROUNDWATER FLOWS

Mining has expanded to support the industrial demand for raw materials. The consequences for waterways downstream have frequently been harmful, with diversion of groundwater reducing stream flows, leakage of toxic tailings, and toxic discharges released when sites become flooded. The sites of smelters also contribute to significant local pollution impacting on aquatic ecosystem health.

COMMON POLLUTANTS AND THEIR EFFECTS ON FISHERIES

The extent of monitoring of pollutants varied between the three rivers in our case studies. The high cost of monitoring for pesticides and other contaminants meant these are neither comprehensively nor frequently performed. While nutrient pollution from wastewater plants in Canada and Australia had clearly improved over time, a wide range of contaminants including pharmaceuticals and personal care products remain incompletely removed from effluent even with the upgraded treatment technology.

Sources of diffuse source pollutants from storm water and agricultural runoff, such as pesticides, fertilizers, PDBEs, plastics, and a growing list of other contaminants remain poorly controlled and problematic for receiving waterways. There is a long lag between science publication, review, and updating national water quality guidance. The lowest dose health effects such as endocrine disruption and immunotoxicity are under-assessed. Thus, guidelines end up fostering a perception of safety, while allowing harmful levels of pollution. Water quality guidance documents do not mandate rectification actions when exceedances occur. Hence the governance systems remain permissive of a complex cocktail of pollutants causing degradation of aquatic food webs.

SEDIMENT

Elevated sediment loads which result from land clearance, exposure of soil to rainfall, removal of riparian (streamside) vegetation, and flooding can physically smother and impede light penetration to critical aquatic habitats such as seagrass and other native aquatic vegetation.

Losing these habitats has a knock-on effect and triggers the loss of the critical ecosystem services they provide such as boosting the aquatic food web, stabilization of benthic (bottom) sediments, cycling of nutrients, and the sequestration of carbon.

Where sediment carries other pollutants such as pesticides, metals, and industrial contaminants it can also decrease the abundance and diversity of exposed organisms through toxic mechanisms. The result is a reduction of the health of sediments on the bottom of rivers and wetlands and a loss of their diverse contributions to aquatic food webs and wider ecosystem services.

Elevated suspended sediment can also contribute to decreased larval survival as the pollutant particles can be confused for plankton and zooplankton and be ingested, costing energy to consume without then providing any nourishment to support larval development and survival (27).

NUTRIENTS

Excess nutrient (nitrate and phosphate) water pollution is referred to as eutrophication. The entry of nutrients from fertilizer, manure, wastewater, and changes to catchment vegetation and hydrology, can contribute to negative impacts on biodiverse fishery production from excessive nutrient enrichment of aquatic ecosystems (28) (29).

Mild eutrophication can change algal assemblages (types and abundance) and alter the primary productivity of this part of the aquatic food web. Initially, mild eutrophication can increase primary productivity of the plankton at the bottom of the food web, in some waterways (29). However, hyper eutrophication also has negative effects on fish habitats through promoting the smothering of seagrass leaves and reducing light availability (30), reducing survival in shellfish beds, (31) and lowering coral survival (32).

Municipal wastewater treatment plant (WWTP) effluent can contain levels of nitrogen in the form of ammonia[5] which can cause direct toxicity to aquatic biota (33). The impacts of eutrophication are further exacerbated by climate change with increased temperature and increased variability in rainfall amount and intensity promoting more harmful algal blooms. Many wastewater facilities are limited in their water storage capacity during periods of elevated rainfall, which can trigger releases of effluent which contain higher loads of nutrients.

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5 https://richmondvalley.nsw.gov.au/services/water-and-sewer/water-results/sewerage-treatment-plants/

Hyper-eutrophication contributes to increased frequency and geographic expansion of dense harmful algal blooms (34) dominated by cyanobacteria and dinoflagellates which outcompete healthy types of microalgae for a position at the base of the trophic food web. These dense blooms can also result in fish kills due to direct toxic effects on gill function, and production of neurotoxins leading to the prohibition on the harvesting and consumption of such toxic seafoods. Human health is also impacted by consumption of toxin-laden seafood (35), drinking water contamination and inhalation of, or skin contact with, algal blooms and their toxins (36).

When bloom density limits the algae's access to sunlight, or through depletion of nutrient availability, mass algae die-offs can occur. This increased organic load drives up biological oxygen demand as bacteria attempt to degrade the dying dense algal blooms. Hence, this hyper-eutrophication process promotes the creation of oxygen "dead zones." Such oxygen depleted areas are associated with fish kills and lose their ability to function. Globally, dead zone areas have quadrupled in size since 1950 (37). Dead zones are occurring in estuarine bays, such as Chesapeake Bay, USA that receive eutrophic inflows of water. In some cases, aquaculture has contributed to deoxygenation such as salmon farms in Macquarie Harbour in Tasmania, Australia (38). Even areas of the open ocean, such as the Gulf of Mexico, are impacted due to persistent very high nutrient discharge, from major rivers like the Mississippi River. In 2021 an unseasonal and more severe bottom water hypoxic event extended up the west coast of North America into Canada adjacent from the Fraser River along Vancouver Island (39). The frequency of such events is increasing globally with expanded nutrient runoff.

THE IMPACTS OF POLLUTANTS ON FISHERIES CAN BE BROADLY CONSIDERED AS:

DIRECT IMPACTS

- Mortality to any life stage from embryo to adult
- Deformity leading to impairment of survival
- Immune system damage rendering animal more vulnerable to disease
- Reproductive failure
- Behavioral change altering courtship, nest protection, and risk aversion

INDIRECT IMPACTS

- Availability of food resources such as plankton and zooplankton
- Composition of food organism communities
- Nutritional value of food resources
- Presence and health of habitat and refuge structures (eg seagrass, mangrove, saltmarsh, oyster reef)

ACID, METAL MOBILIZATION, AND DEOXYGENATION

Many floodplain wetlands around the world are underlain by acid-sulphate soils. Natural hydrology with sea level changes over geological time scales both created and helps stabilize these soils. Estuarine water provides access to buffering carbonates and maintains low oxygen concentrations by keeping the soils saturated with water. Oxygen is only sparingly soluble in water compared to the relatively high concentrations in air.

Changes to the natural hydrology caused by draining wetlands and installing flood gates to exclude saltwater can trigger unwanted geochemical reactions in the acid-sulphate soils. The lowering of water tables allows more oxygen to contact the reactive soils, as air penetrates the drained soil. This fuels the iron pyrite in the soil to react and create sulphuric acid. As well as being directly harmful to aquatic life, the acid alters the solubility of naturally occurring metals such as iron, copper and aluminum, and metalloids like arsenic in the soil. This makes them more bioavailable and thus more toxic to aquatic life (40).

The acid and metals re-enter the waterway through groundwater movement in addition to surface movement down drains. Rainfall inundation of drained wetlands can drive increased groundwater discharge of carbon dioxide enriched water into the river (41).

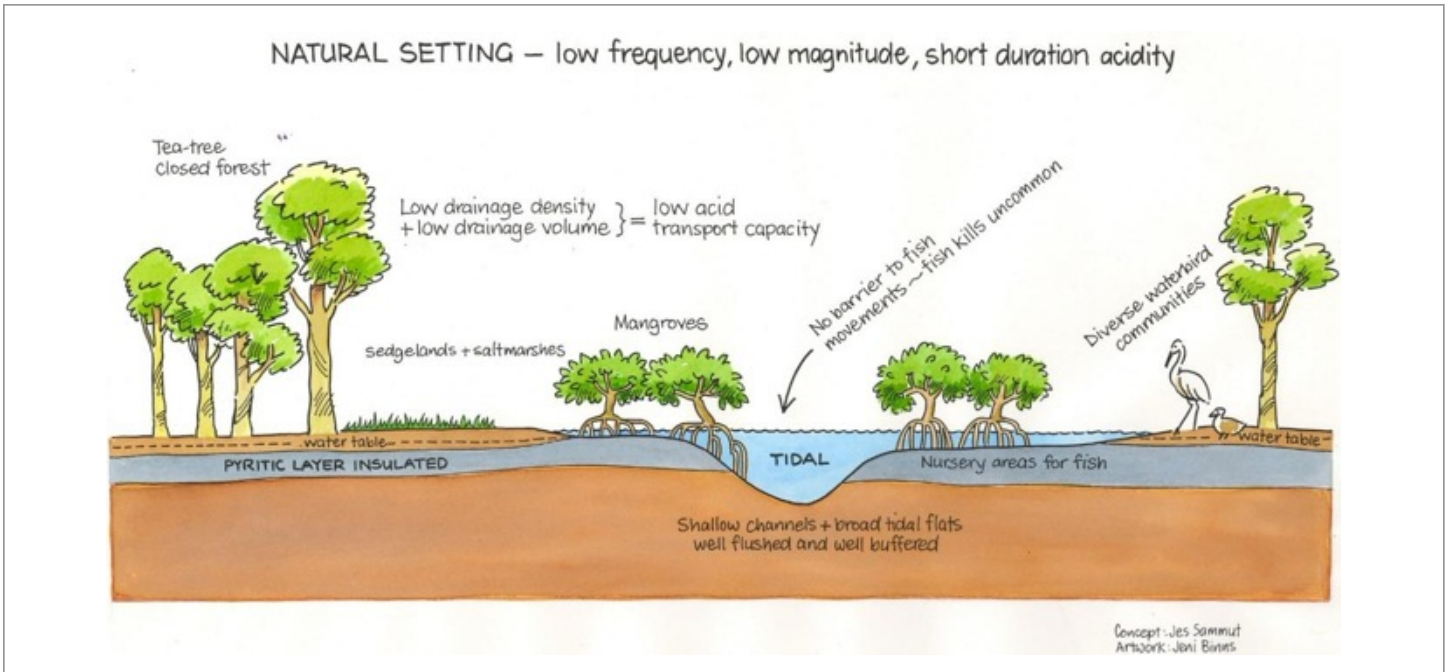

Figure 1 Natural wetland hydrology controlling acid generation and discharge risks from pyritic acid sulfate soils. Source: J Sammut

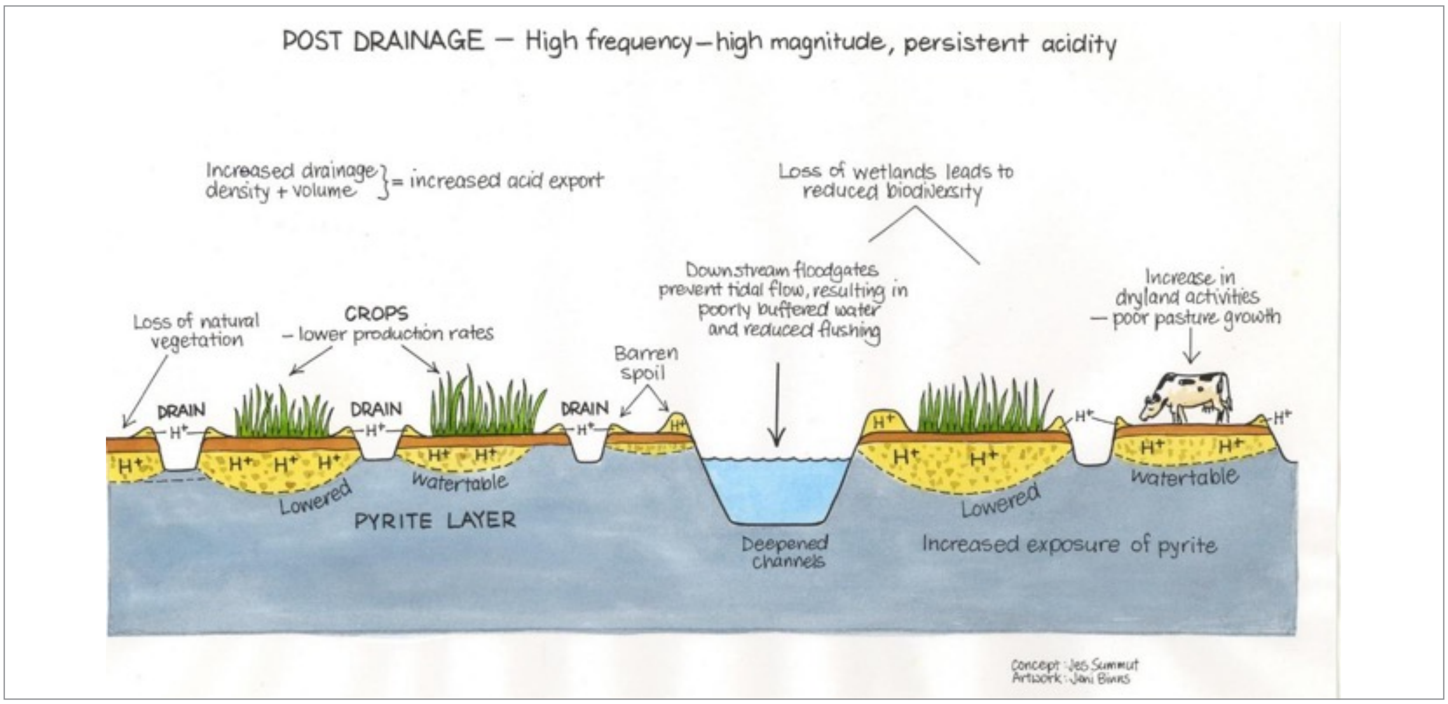

Figure 2 Post wetland-drainage modified hydrology promoting oxidation of pyrite, acid formation and export to river. Source: J Sammut

Fish which are exposed to acid runoff can have their skin immunity compromised leading to outbreaks of the fungal disease (42) known as 'Red Spot' (Figure 3) which can result in fish kills and loss of productivity in the fishery (43). This is a significant problem in the Richmond River, Australia and Mekong River, Vietnam where the acid-sulfate soils are more reactive compared to those in the Fraser River, Canada.

Elevated concentrations of metals including arsenic, aluminum, cadmium, chromium, mercury, zinc, and lead can be identified in surface sediments downstream of acid runoff. These can have major implications for the health of organisms living in the sediments (44) and their productivity to support the aquatic food web. The mobilized metals can also enter aquatic food webs and can have negative impacts on the development, behavior, and reproduction of aquatic animals through toxic effects on gill function, nervous system, and endocrine (hormone) effects (40) (45) (46).

The chemical reactions within the soil and in the base of drains in rotting vegetation generate monosulfidic black ooze (MBO) (47). This material can be mobilized by rainfall washing it out of drains into waterways. It rapidly reacts to cause deoxygenation and blackwater events that can trigger mass fish kills if fish become entrapped in this deoxygenated water (16). It can also have more chronic impacts by causing sub-lethal stress and impacting on fish migration, feeding and reproduction. Repeated events drive down the productivity of the fishery (48).

These changes in affected wetlands turn areas of previously critical habitat and abundant food web productivity into uninhabitable barren areas.

Figure 3 Yellowfin bream (Acanthopagrus australis) with a Red Spot ulcer caused by infection by fungus (Aphanomyces invadans) after exposure to acid water pollution in Richmond River, Australia. Source: J Larsson

PESTICIDES

Pesticides are widely applied to agricultural and urban landscapes around the world. They are also used inside our homes and workplaces, and on our pets and gardens. Around 2 million tonnes of pesticides were estimated to be used in 2019 globally and a UNEP paper citing FAO says "Global use of pesticides in agriculture increased from about 2.3 million tons of active ingredient in the early 1990s to more than 4 million tons in 2016 (49). Climate change is also predicted to drive increased pesticide use through higher volumes, higher doses, greater frequency of application, and different products (50).

Pesticides include many compounds designed to have biocidal activity against weeds, insects, rodents, fungi and bacteria. Applications are generally targeted to a particular pest, weed or disease with the intention that off-target impacts are minimized. The off-target secondary movement of pesticides as a result of agricultural run-off, wastewater effluent, volatilization after application, and spray drift all commonly cause unintended exposures of non-target organisms to pesticides.

Pesticides are frequently found in the aquatic environment adjacent and downstream of sites of use (51). Modern sensitive laboratory testing have identify their presence at levels which are known to have toxic effects on aquatic plants and animals. Over the past 25 years the applied toxicity of pesticides has increased considerably against invertebrates as more potent active ingredients such as pyrethroids and neonicotinoids have been added to the armory for agriculture (52).

The impact of pesticide exposures can cause acute or chronic mortality damaging the microscopic end of the food web, through harming microalgae, zooplankton, and emerging aquatic insects (53). The effects on terrestrial insects have been a profound reduction in species biodiversity and abundance (54). Many terrestrial insects contribute to food resources in aquatic environments as they fly and fall in from overhanging vegetation. Such loss of critical food resources can have profound knock-on effects for higher trophic order fish which rely on these resources. Hence the global collapse of terrestrial insect populations, driven by the use of pesticides, climate change, and habitat loss (55) contributes to reduced food resources in fisheries. The neonicotinoid insecticides have been identified as contributing to fishery declines through this mechanism (56).

Pesticide exposures can cause sub-lethal impacts such as reductions of feed intake and growth (57) or interrupting the molting cycle of crustaceans which reduce their resilience and survival (58). The behavior of fish can also be altered, leading to the loss of flight behaviors or reproductive cues. Pesticides can also impact the sense of smell (olfaction) (59) which fish use to help them navigate to critical habitat. Organophosphate insecticides have been demonstrated to alter the development of flat fish, for example, (60) resulting in the failure of eyes to form on the upper surface of the fish. Herbicides can stress and contribute to the death of seagrass (61), coral (62), and mangroves (63). They can impair the immune function of fish leading to increased parasite loadings (64) and contribute to the decline of fish species (65).

Sub-lethal pesticide exposures render both fish (66) and other aquatic organisms like coral (62), less resilient to elevated water temperatures leading to fish kills and coral bleaching. Pesticides are also known to interfere with reproduction of aquatic animals by acting as endocrine disruptors at extremely low exposure doses (67). The cumulative mixture effect of the cocktail of chemicals, including pesticides such as organophosphate and pyrethroid insecticides (68), azole fungicides (69) and triazine herbicides (70) can interfere with critical cell signaling during development, molting in crustacean and on thyroid hormone function. These can result in diminished or a complete loss of reproductive output. Development of gonads can be disturbed resulting in intersex fish where ova develop within the testes of male fish.

Pesticides are not robustly assessed for their endocrine, mixture, and low dose effects as part of the standard regulatory approval processes which underpin their use (71) (72) (73). Regulatory agencies do not appropriately consider all relevant data, and in some cases the data does not exist.

PER- AND POLYFLUORINATED ALKYLATED SUBSTANCES (PFAS)

PFAS are manufactured chemicals that are used in numerous products that resist heat, oil, stains, and water. They are highly persistent substances in the environment and animals and are commonly referred to as 'forever chemicals' since they do not break down. PFAS can be found in fire-fighting foams, fast food packaging, pesticides, mining, and oil well surfactants, paints, cosmetics and personal care products, non-stick cookware, floor polish, aviation hydraulic fluid, mist suppressant in metal plating industry, and stain resistant clothing and products.

Major PFAS releases to the environment have been demonstrated to come via ground and surface water from use on airports in fire-fighting training, and via release from wastewater in effluent and sludge (74).

The compounds can accumulate in fish tissues and cause deleterious effects to immune and reproductive function and cause transgenerational negative changes to survival of fish (75). Increased disease rates and reduced reproductive outputs contribute to declining fishery productivity.

POLY BROMINATED DIPHENYL ETHERS (PBDE)

PBDEs are included in products such as fabrics, car fittings, mattresses, and insulation products as flame retardants. They enter the environment from industrial emissions and stormwater and wastewater discharges. PBDEs are persistent and accumulate in the environment. Through trophic food web transfer, PBDEs bioaccumulate in fish and shellfish (76). They have a mode of toxicity recognized to be mediated through impacting on thyroid and reproductive function as endocrine disrupting chemicals (77).

Negative impacts from exposures include reduced egg production, reduced sperm maturation and motility, reduced spawning, reduced fertilization, reduced hatching success, reduced larval survival, inhibited growth, and neurological toxicity (77).

IPEN and The Endocrine Society produced a report for policy makers on Endocrine Disrupting Chemicals[6] which is a useful entry resource to comprehend this mode of chemical toxicity.

SURFACTANTS

Surfactant (e.g., ethoxylated alkylphenols) compounds have many industrial applications and are used in inks, paints, and as wetting agents in pesticide applications. They were common in household detergents and while some countries have now phased them out, they remain common contaminants in aquatic environments from industrial and wastewater discharges and have been identified as risks to the marine environment (78). Metabolites such as nonylphenol are known to be endocrine disruptors that can alter reproduction and development of shellfish (79) and fish (80) and modify the structure of plankton trophic web (81). They have also been reported to enhance cyanobacterial blooms and toxin production (82). The outcomes from toxic exposures can be behavior change, reduced reproductive outputs, delays to molting and growth, thereby diminishing the productivity of the fishery (83).

PHARMACEUTICALS AND CHEMICALS FROM PERSONAL CARE PRODUCTS

Use of pharmaceuticals and personal care products that contain toxic chemicals continues to increase globally. Wastewater treatment plants are not engineered to completely remove these chemicals. The effluent streams produced from their use re-enter waterways via wastewater discharges, leachate from landfill, agricultural discharge, and via biosolids (sludge) mobilization after agricultural use.

Modern laboratory analytical methods are increasingly able to identify their presence in waterways and sediments in rivers at biologically active levels in most global rivers (84) (85). Monitoring data is sparse but sufficient to raise concerns about the impact on aquatic ecosystems (78).

Numerous chemicals such as UV filters from sunscreens and preservatives such as triclosan, benzylkonium chloride, and parabens can adversely impact aquatic animals by contributing to endocrine disruption, immune system toxicity, behavioral modification, and physiological stress (78).

The National Toxics Network produced a report on *Pharmaceutical Pollution in the Environment, Issues for Australia, New Zealand and Pacific Island Countries*[7] as a useful assembly of knowledge of these pollutants.

PLASTICS AND ADHERED CONTAMINANTS

Plastics are made from fossil fuels and chemicals. There are thousands of chemicals used in plastics, including many known, or suspected, to be highly toxic. These chemicals can leach from plastics and are released into the environment throughout the plastics life cycle, from production, transport, use, recycling, and waste disposal. Nano, micro and macroplastics enter the aquatic environment from terrestrial sources such as stormwater run-off, agricultural run-off, and wastewater discharges.

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6 https://ipen.org/sites/default/files/documents/ipen-intro-edc-v1_9a-en-web.pdf

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

Aquaculture and commercial fishing industries are recognized as sources of macroplastics from their polystyrene use in buoys, polyethylene cage supports and oyster baskets, nylon nets, and polypropylene ropes (86).

Microplastics are now found in wild fish tissues and aquaculture products around the world, with the highest loads aligning with major rivers, such as the Mekong River, which accumulates its plastic loads as it courses through countries including Cambodia into Vietnam to discharge through the Mekong delta (88) (89).

Zooplankton and fish can confuse the microplastic particles as food and mistakenly ingest them (87).Inside aquatic organisms microplastics take up space in the gut which should be filled with nutritious food, leading to reduction in growth of zooplankton and knock-on effects up the trophic layers of the food web (90). Microplastics are also appearing in fish meals used in aquaculture feeds thereby exposing farmed fish in aquaculture settings (91).

Microplastics also adsorb other contaminants such as polybrominated diphenyl ethers (PDBEs) (92) which can combine when ingested to cause sub-lethal toxic effects to immunity and cell function in the aquatic shellfish, benthic worms, zooplankton, and fish (93) (94) (95) (96) (97). Such sub-lethal effects are likely to reduce the resilience of the ecosystem to other perturbations.

Bisphenol A (BPA), phthalates, UV stabilizers, and other additives are combined with plastic polymers to give manufactured products useful properties for industrial and consumer uses. These compounds can also move from the plastics into aquatic organisms and have toxic effects including endocrine disrupting effects[8].

IPEN and The Endocrine Society collated a report on Plastics, EDCs and Health[9] to inform public policy which covers in more detail the range of toxic threats posed by these now ubiquitous aquatic pollutants.

STORMWATER POLLUTANTS

The run-off water from roads commonly carries a variety of contaminants including polyaromatic hydrocarbons (PAHs), rubber tire preservative chemicals and their toxic metabolites, herbicides from roadside spraying, PFAS and plastics (98). This cocktail of pollutants can contribute to acute toxicity to exposed fish and other aquatic animals when it enters waterways (99).

Shipping and air borne deposition from fossil fuel (100) and bushfire (101) combustion events also contribute PAH contamination to waterways. Some PAHs can be highly persistent in sediments contributing to long term toxicity risks to exposed aquatic animals.

PAH's are known to adversely affect the development and function of the heart of embryonic and larval fish (102) (103) and developing crustacea like crabs (104), thereby reducing their survival and subsequent fitness.

Chlorinated, petroleum and polycyclic aromatic hydrocarbon compounds, organotins, and heavy metals can concentrate in the surface microlayer of water by up to 500 times compared to the underlying bulk water concentration (105). This same location places them where many aquatic early life stages (eggs and larvae) inhabit, triggering potentially toxic exposures. There is also movement into the food web of these compounds as they can move into algae, shellfish, and fish, so pathways of exposure are both by ingestion and through immersion.

8 https://ntn.org.au/wp-content/uploads/2016/05/NTN-Contaminants-in-Marine-Plastics-Report-April-2016-1-1.pdf

9 https://ipen.org/sites/default/files/documents/edc_guide_2020_v1_6ew-en.pdf

GREENHOUSE POLLUTANTS

Global data confirms a consistent trend of rising climate change gases of carbon dioxide, methane and nitrous oxide concentrations based on CSIRO Cape Grim data[10].

Most carbon dioxide is absorbed by the ocean and in so doing creates carbonic acid that lowers the pH of marine water. This can potentially alter the ability of some microscopic zooplankton at the bottom of food webs, such as copepods, to survive as they can have altered development, reproduction, and survival with altered predatory and anti-predatory behaviors (106). Ocean acidification broadly reduces survival and development success in a range of mollusks, corals, crustacea, and echinoderms through impairing exoskeleton calcification.

Climate change also poses thermal threats to fishery productivity from extreme heat and impacts to the flow from floods and droughts. The frequency of global aquatic heatwaves has doubled between 1982 and 2016 (107). Both excessive heat and variability can alter development speeds and subsequent survival of fish (108). Heatwaves are already causing kills of inter-tidal shellfish that get cooked to death.[11] The thermal stress compounds other contaminant driven stressors on aquatic life, triggering outbreaks of disease and mortality in fish and corals around the world, threatening biodiversity and ecosystem services (109).

Climate change's contribution to sea level rise, drought frequency and severity is contributing to altering salinity in coastal floodplains like the Mekong delta impacting areas of rice and freshwater fish farms (110). Major implications could stem from an 11% reduction in viable farming area for catfish, which constitute a major industry for Vietnam (111).

The remobilization of persistent organic pollutants [POPs] from melting ice caps driven by climate change are another expanding threat to aquatic ecosystems (112).

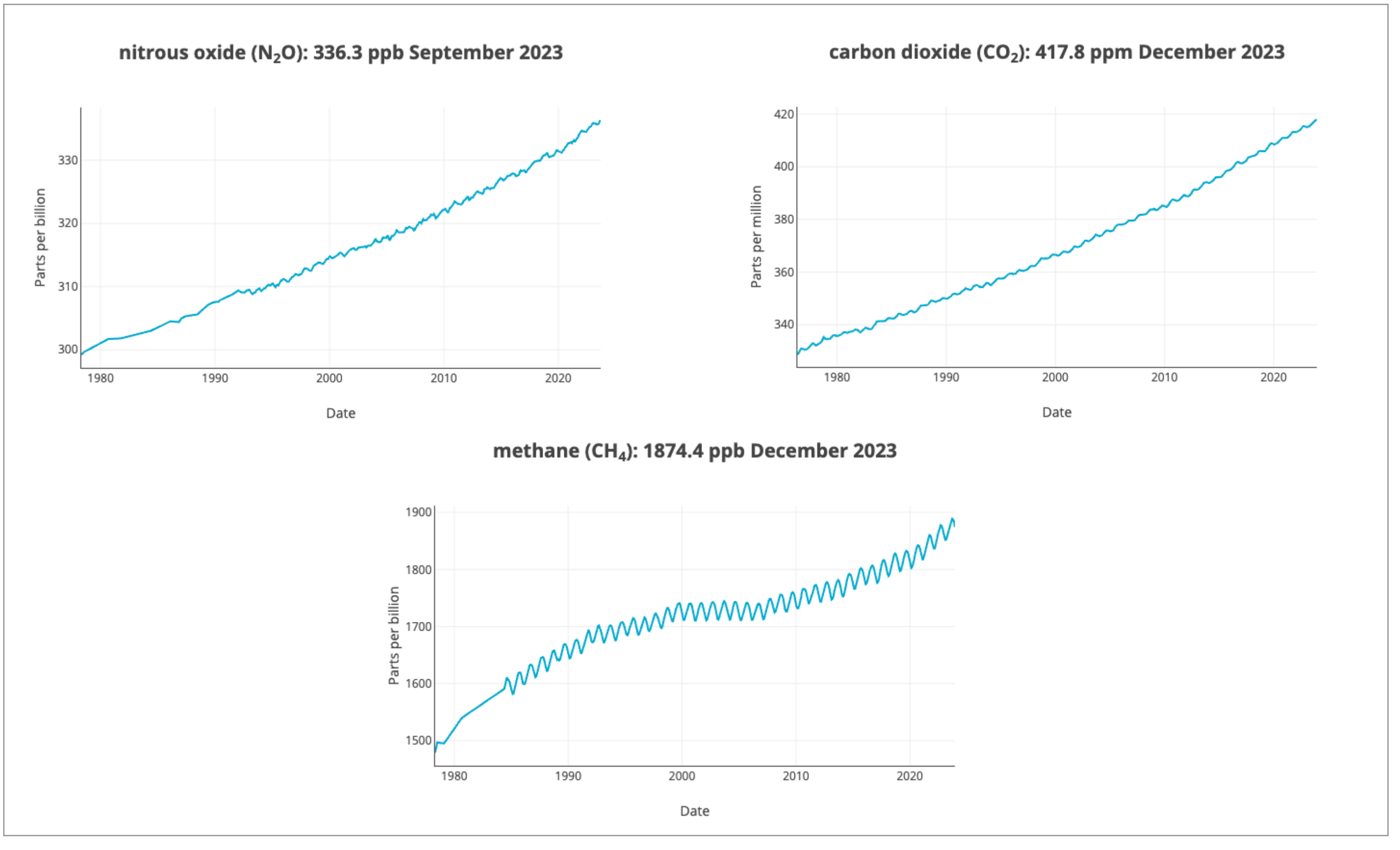

Figure 4 CSIRO Cape Grim Australia data on nitrous oxide, carbon dioxide and methane levels in air September and December 2023

10 https://www.csiro.au/en/research/natural-environment/atmosphere/latest-greenhouse-gas-data

11 https://www.kuow.org/stories/extreme-heat-cooks-shellfish-alive-on-puget-sound-beaches

RESPONDING TO FISHERY DECLINE

Declines in catches and emergent science have triggered fishery managers to alter the governance of fishery stocks through time. Central to the management effort has been attempts to assess the status and size of fishery stocks. Managers then seek to use this information to inform adjustments to the catch volume, through modifying fishing effort, fishing gear, numbers of fishers, and areas where fishing is excluded, such as marine protected areas (MPAs).

Fishery managers are only just beginning to gain a better understanding of the substantial effects that habitat loss and water quality degradation, from a wide range of pollution sources, have on the productivity of fisheries.

With a global increase in demand for healthy seafood occurring at the same time as ongoing degradation of aquatic environments, it is critical that further adaption of fisheries management, at both a local and planetary scale, is urgently implemented to meet the goal of sustaining highly productive fisheries into the future.

Attempts to manage fisheries are often restricted by access to sufficient and reliable data. Fishers often supply *fishery dependent data* such as their catch volumes, sizes and units of time spent fishing. Researchers can supplement this through collecting their own *fishery independent data* to inform their estimates of fish abundance and size. Present methods of fish stock assessment structurally exclude information on other factors which contribute to fish mortality, beyond the fishers catch. Factors such as reproductive success, habitat integrity, water quality, water flow and the impacts of an expanding cocktail of pollutants do not generally form part of the analysis.

Traditional fishery analysis focuses on attempting to predict future fishery catch, using historical catch data, without embracing the changes to baseline health of the ecosystem which intrinsically support sustained fishery productivity. This can lead to **shifting baseline syndrome**. [see box, below]

SHIFTING BASELINE SYNDROME

People's experience of environmental conditions changes through time and with each generation there is an acceptance of local conditions which come to define what they consider to be normal. As humanity's impact on the environment has expanded with increasing human population and consumption, the baseline output for what is viewed as sustainable fishery production has drifted lower. This phenomenon is referred to as 'shifting baseline syndrome' and is pervasive within fishery management, (113) leading to the common outcome of declining productivity from estuary-linked fisheries. The development of farming of seafood within aquaculture enterprises is often perceived as adding to an existing seafood supply from natural fisheries, however its growth can obscure the decline occurring in some wild fisheries. In some cases, aquaculture can contribute to the losses which are occurring in natural seafood production, through habitat destruction and release of nutrient and chemical effluents.

In the Richmond River in the early 1970s, local residents reported the noise of the huge schools of mullet and crashing of larger predatory mulloway passing down the river on spawning migrations. The noise was as loud as a passing herd of cattle. Few can imagine this level of abundance today. Reliable catches of tens of tonnes of school prawns are now infrequent, and in the single digits. The reporting of these stocks as "sustainable" does not assist in appreciating this shifting baseline.

The extent to which sustained productivity can be achieved depends upon correctly identifying and managing the threats to the fishery and water quality which have profound impacts on fish growth and survival.

In fisheries management, factors other than fish catch are often implicitly assumed to be stable. This report shows clearly that this assumption is not supported by the available evidence across three different catchments in Australia, Vietnam, and Canada.

One difficulty fishery managers have is that they do not typically have direct regulatory control over the many pollution threats to the fishery they are seeking to sustain.

One of the responses has also been to take production of seafood somewhat out of nature's hands and to develop aquaculture farming enterprises. Unfortunately, in some areas like the Mekong Delta this has contributed to the acceleration of loss of critical habitats that supported wild fishery productivity such as mangroves, as they became replaced by farmed shrimp ponds.

So rather than aquaculture being an industry to help support wild capture fishery recovery, it has in some instances contributed to its further decline.

It should be noted that some forms of aquaculture do have the potential to benefit the wider fishery's health. These include shellfish and seaweed farms which can lower organic loads in water and do not require additional feed inputs and create habitat to support marine and freshwater ecology.

GOVERNANCE OF FISHERIES AND WATER POLLUTION

The effectiveness of governance arrangements in protecting and restoring fisheries is highly dependent on a number of factors including all pollution threats being correctly identified, the control measures being sufficient to remove the pollution threats, recognition of the problems by all stakeholders, and the level of compliance to regulatory measures by residents, industry, and government managers.

There were differing levels of governance across the three case study countries. The most stringent protection was in relation to activities on salmon catchments in Canada, such as an array of measures on worksites that were close to salmon rivers, to avoid sediment and chemical pollution. Australian regulation also seeks to protect and restore water quality and fisheries habitat. However, **in all case studies the intention of the many pieces of legislation and industry guidance documents had not been sufficient to avoid the degradation of water quality and fisheries habitat in the rivers.**

The complex challenge of implementing legislation in a multi-stakeholder environment cannot be underestimated. Some factors like climate change were not able to be controlled by local regulation in any single jurisdiction.

The perception that the waste assimilative capacities of waters were a natural resource to be exploited have led to regulatory control and administration acting to determine the distribution of waste discharge allocations (Keeling A. , 2004). Regulation has often been predicated on the ability of scientists to define pollution, analytical technologies to measure it, and the choices of critical bioassay endpoints which are used to assess discharges. The political domain influences the creation of such policy variably influenced by the opposing forces of industry and environmentalists.

INTERNATIONAL CHEMICAL AND WASTE CONVENTIONS THAT INFLUENCE POLLUTION AND FISHERIES

There are international obligations for the management of hazardous chemicals and wastes set out in certain international chemical and waste conventions, including

- *Stockholm Convention on Persistent Organic Pollutants* 2001: the aim of the Convention is to protect human health and the environment from persistent organic pollutants (POPs).
- *Basel Convention on Control of the Transboundary Movements of Hazardous Wastes and their disposal* 1989: the aim of the Convention is to protect human health and the environment from the adverse effects of wastes, in particular taking into account the vulnerabilities of developing countries.
- *Rotterdam Convention on Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade* 1998: the aim of the Convention is to promote shared responsibilities in relation to importation of hazardous chemicals.
- *Minamata Convention on Mercury* 2017: the aim of the Convention is to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds.

As well as calling for an end to the production and use of some of the world's most toxic substances, the conventions also

- provide the rules for trade in hazardous chemicals and waste;
- actively promote information exchange and technical capacity building;
- guide monitoring; and
- provide some financial assistance for developing countries or countries with economies in transition.

In this way, they cover the key elements for the effective life-cycle management of hazardous chemicals.

Combined, these conventions aim to protect human health and the environment from the adverse effects of toxic chemicals such as persistent organic pollutants (POPs), through the elimination of production, trade, use and release of POPs into the environment; from hazardous waste risks resulting from the generation, management, transboundary movements and disposal of hazardous and other wastes, taking into account the vulnerabilities of developing countries and from anthropogenic emissions and releases of mercury and mercury compounds.

Current governance models are demonstrably not generating the required economic catalysts to achieve compliance with regulations that seek to deliver sustained fisheries productivity. This is leaving fisheries exposed to expanding pollution threats which are further degrading their productivity and social values.

GLOBAL DRIVERS OF EXPANDED POLLUTION RISK TO FISHERIES

The assembly of the three case studies identified some remarkably common drivers of aquatic pollution across the three countries. The risks were considered in light of scientific peer reviewed literature. Interviews were also performed in person, through internet meetings, and via email communications with relevant governance authorities, researchers, and other stakeholders.

LOSS AND DEVALUING OF FIRST NATIONS/INDIGENOUS KNOWLEDGE AND VALUES

The health and productivity of fisheries is central to the survival and cultures of many First Nations/Indigenous people. These cultures maintained the aquatic ecosystems in a pristine state over thousands of years of management. This is perhaps a reflection of their cultural values where personal wealth accumulation was not seen as a mark of merit, rather that sharing was central. It also speaks to their deep cultural respect for their natural environment which was embedded in their stewardship of the landscape.

The earliest colonial influences resulted in profound changes of land management in both Canada and Australia, whereby First Nations/Indigenous people were dispossessed of their land, prior to promoting rampant clearing of native vegetation to promote agrarian pursuits.

ON THE RICHMOND RIVER assessments of mounds of oyster shells known as middens indicate that First Nations/Indigenous people harvested around 17 tonnes of oysters from the river per year for at least 1,700 years prior to colonial arrival (114). In just 50 years under colonial management all sub-tidal natural oyster reef production had been lost through over-harvesting, with sediment and nutrient pollution promoting disease in the wild stocks. The first oyster reef recovery projects commenced in 2022.

EXCEEDING PLANETARY BOUNDARIES

Expanding human population and consumption footprints, particularly in developed economies within globalized linear economies have driven us to the point of exceeding planetary boundaries. In a 2022 study, an international group of scientists concluded that the scientific evidence shows that we have broken through the “planetary boundaries” for chemical and plastics pollution, meaning that production and emissions may be threatening the stability of the entire global ecosystem.

Increasing chemical production has exceeded the capabilities of monitoring and regulation and the accumulated load of toxicity is increasing. The cocktail effect of mixtures of stressors is creating biological problems of ever greater complexity. As the aquatic ecosystem receives the drainage and precipitation from land-based pollution it is inevitably impacted.

In no country does regulation require all chemical production to ensure, both by design and through independent demonstration of scientific data, that the full life cycle of the compound will be safe for humans and the environment.

Similarly, global pollution from fossil fuel derived plastics that contain toxic chemicals is now everywhere, and production is projected to expand beyond 300 million tonnes per year.[12] A linear economy based on fossil fuel extraction is fundamental to the ever-expanding pollutant load impacting aquatic ecosystems. From single use packaging to chemical fertilizers and diesel fueled agriculture- all will need to fundamentally change to slow the load of pollutants impacting fisheries.

The boundaries of climate change, nutrient emissions, biodiversity (118) and land use change (117) are also considered to be now exceeded.

12 https://www.unep.org/interactive/beat-plastic-pollution/

Biologists agree that we have now entered the sixth mass extinction (115). The fragility of humanity's existence and its complete dependence on the health of the biosphere are underappreciated. The 2021 review of progress towards 2030 Sustainable Development Goals notes we are on track to miss the environmental targets in relation to addressing biodiversity decline and climate change[13]. (116)

As social values can shape where societies place effort, it appears that a seismic shift in societal values is required to underpin the scale of change that could result in regeneration and restoration of environmental health.

THE EULACHON is a small-bodied fish that once migrated in tremendous numbers up and down the Fraser River in British Columbia Canada. It was treasured by First Nations/Indigenous people for its high oil content, which came from the fish and was traded between tribes along the inland so-called "grease trails." When dried, the fish could be lit and used as a candle, leading to its colloquial name of candle fish. The combination of development effects on the catchment such as drainage of wetlands, forestry, paper mills, agriculture and their attendant pollutant flows have impacted spawning fish and contributed to its dramatic decline. The expansion of shrimp trawling may have also contributed to its decline, with eulachon becoming caught as bycatch during trawling (119).

FOSSIL FUEL DEPENDENT FOOD PRODUCTION

Since the so-called Green Revolution beginning in the 1950s, the industrialization of global food production has become increasingly reliant on fossil-fuel derived agricultural chemical inputs of pesticides and synthetic fertilizers. The entire food production system is now designed around the application of toxic pesticides with year-on-year use expanding both in terms of area of application and total volumes. This is making entire landscapes toxic to nature. The water which runs off the treated landscapes is toxic, harming aquatic ecosystems and moving into groundwater.

While the United Nations Biodiversity directives call for reduced pesticide use, the trends in the application of these chemicals in Australia, Vietnam, and Canada are all going in the opposite direction.

THE EXPANSION OF PESTICIDE AND FERTILIZER DEPENDENT HIGH YIELDING RICE VARIETIES, with increasing diesel driven mechanization in the Mekong Delta of Vietnam has contributed to a significant decline in the productivity of the freshwater fishery. The modern fossil fuel dependent methods differed from traditional rice culture where manual labor was integrated with fish production into the co-culture with rice. While rice yields were lower, there was also a dividend of healthy fish harvested from the paddies where they had contributed to maintaining the health of the rice through controlling its pests and fertilizing it naturally. Traditional rice farming methods did not release toxic pesticides and excess nutrients back into the river, unlike the fossil fuel dependent crops.

13 https://www.unep.org/news-and-stories/press-release/world-set-miss-environment-related-sustainable-development-goals-un

PRIVATIZED PROFITS, SOCIALIZED COSTS

Many agricultural and industrial businesses are net emitters of various forms of pollution. One of the difficulties in achieving science-based regulation of pollution in a global neoliberal market-based economy is that the relentless drive for more profit incentivizes expanding pollution emissions, where the costs of the pollution emissions are neither quantified nor borne directly by the polluter. Where the environment bears the cost of the pollution, the corporation's profit margin is artificially inflated.

Where the economic benefit of business activity to a country is measured, without accounting for their external pollution emissions, market forces inadvertently encourage increased pollution driven by government imperatives to continue expanding economic growth to underpin standards of living and service ever expanding debt.

This perverse incentive is contrary to the benefit of the wider community. The community ends up socializing these costs through increased health costs, needing to fund cleanups, losing access to abundant fisheries, and living in a degraded environment. Through shifting baseline syndrome, society to a large extent has normalized the costs of the pollution, thereby passively accepting their negative impacts to human and ecosystem health.

THE POOREST CITIZENS OF THE MEKONG DELTA have suffered the worst impacts of the development of the Mekong Delta as a center of intensive rice and aquaculture production of species such as catfish and shrimp. They had been reliant on capture of wild fish to support their food security. So ironically, while Vietnam is now a globally significant exporter of rice, the poorest have seen their food security deteriorate as the high nutrient value wild fish have dramatically declined (120).

CORRUPTED SCIENCE

The discipline of science is widely used to measure the impact of pollution and offer insights to inform regulation. Unfortunately, many polluting industries now engage in science or pseudo-science. Their differing motivation can be to seek to sustain profit through resisting the implementation of tighter pollution regulation on their industries to avoid bearing the costs.

Such businesses and industries can seek to control the public's perception of their operations and their profit such that the pollution is not the focus of attention (121), thereby facilitating the continuity of their polluting emissions without alarming the impacted community.

Strategies deployed by polluting industries to delay and soften regulatory impact on their operations are numerous and complex and include:

- influencing the conduct and publication of science to skew the evidence base;
- influencing the interpretation of science;
- controlling the reach of science;
- using legal challenges to delay, control, or prohibit access to industry data for regulatory decision making; and
- undermining independent studies and scientists, through misrepresenting their research and discrediting their standing (121).

CONCERNS ABOUT UNINTENDED IMPACTS OF NEONICOTINOID PESTICIDES ON NON-TARGET INVERTEBRATES led to the EU removal of all outdoor uses of neonicotinoid pesticides in 2020, but the Australian pesticide regulator continues to support their widespread use, claiming they are safe to use according to label directions. The movement of applied neonicotinoids into waterways has been shown on several continents to create serious risks to aquatic invertebrates. A recent study showed levels of the neonicotinoid imidacloprid that are expected to cause harmful chronic effects to 42% of exposed aquatic species, in numerous rivers draining into the Great Barrier Reef lagoon (122). The chemical regulatory system claims to protect the environment from harm and claims to use science-based methodology, yet to date in this instance the Australian agricultural and veterinary medicine regulator has failed to protect aquatic species from dangerous exposures. A July 2023 review of the regulator identified numerous signs of industry capture.[14]

COMPETING PRIORITIES

There is a competing tension between the clearing and development of land for urban, industrial, and agricultural uses and the protection of ecosystem services which can control pollution impacting the aquatic environment.

For example, in Australia, the combined Commonwealth, State, and Local regulation expresses (at least in words) a clear intent to broadly manage pollution threats in terms of considering environmental, social, and economic impacts, and were identified to restore ecological health in relation to waterways. However, the operation of the legislation requires that these decisions are contextualized around the notion of "ecologically sustainable development." [ESD]

It is implicit that such development can occur limitlessly which aligns to the Australian government's fiscal aspiration for continuous economic growth. Wherever and whenever this economic growth is uncoupled from the reality of its environmental consequences, a continuous and cumulative load of impacts is borne by the environment, ultimately grinding down the productivity and resilience of aquatic ecosystems.

Such country level motivations for economic growth were also evident in the Vietnam and Canada case studies. If the environment is not placed first in terms of the paramount importance of its protection, then it becomes only a secondary consideration to the desire to develop an industrialized economy.

The notion of "ecologically sustainable development" appears illusory when viewed through the prism of limited natural resources and planetary boundaries for ecosystem functionality. It is therefore difficult to see how any aspirations to control pollution and restore ecological health of aquatic ecosystems can meet with the reality of ever-expanding development.

In the Richmond River catchment case study in Australia, under the present model of regulation there is a disincentive for regulators (Local Councils and NSW Environment Protection Authority administering the Acts) to elevate the interests of environmental protection above a development imperative. This disincentive takes the form of greater costs for government to undertake wider compliance activities, within diminishing budgets and at increased risk of provoking adversarial legal responses from landholders or industries who could be forced to change their management and bear the costs of their pollution generation.

Such an understanding better explains how globally riverine conditions are mostly in decline, without effective restoration taking place, even when legislative controls, government aquatic ecosystem and water quality guidelines, community intentions, and industry best practice guidelines clearly flag the direction for restoration and protection.

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14 https://www.agriculture.gov.au/sites/default/files/documents/APVMA%20-%20Strategic%20Review%20Report.PDF

Another example where a pro-development agenda collides with aspirations for environmental protection and restoration is the recent Australian 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.[15] While the environment was considered in the process by the consultants and subsequently the Commonwealth 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 any receiving environment.

Since 2006 there has been an emerging area of law globally that seeks to recognize the intrinsic rights of nature such that *'personhood status'* could be applied to a river or forest. Some rivers in New Zealand, India, and the USA have been granted this status already. However, in each case study the development of these laws was yet to reach a stage of controlling present pollution inputs and impacts.

IN 1986 VIETNAM made major political and economic reforms to facilitate changing from a centrally planned economy to one that embraced more free-market incentives and encouraged foreign investment. In the decades prior there was a food shortage and government distributed rations, and at the time the country was a net importer of rice. Aggressive agriculture and subsequent aquaculture policies to intensify production were pursued and have lifted many out of poverty and malnutrition. However, the regulation of such rapid expansion has not kept pace, leading to significant contamination of drinking water that is harvested from the river (123). The desire for industrial zones as economic development drivers to be populated and create employment inevitably weighed against regulating their management of wastewater to completely prevent contaminant flows into the river (124), raising risks to fisheries. Various loopholes and grey areas could be exploited to appear compliant to environmental law, but not deliver safety to the environment. The outcome of the governance structures was that the "paradigm of economy over environment" prevails in Vietnam's industrial zones (124).

DIFFUSE SOURCE POLLUTION

The challenge of controlling diffuse source pollutants from agricultural and stormwater landscapes from entering aquatic ecosystems remains unsolved at a policy and regulatory level. The consequence is evident in expanding eutrophication of freshwater (125) and nearshore marine water, increasing fish kills, increased harmful algal blooms, (126) and expanded areas of oxygen depletion (37).

The OECD has proposed some elements of policy formulation in a report in 2017[16] based on their principles of water quality management: pollution prevention, treatment at source, the polluter pays, and the beneficiary pays principles, equity, and policy coherence.

Some of the suggested policy elements are already in place such as water quality standards, farm advisory services, best practice guidelines, and environmental labelling. However, the degraded water quality in the three case study rivers demonstrates that current policy settings in each country have been unable to adequately control diffuse source pollution to avoid ongoing degradation of aquatic ecosystems.

Other policy elements proposed by OECD, which are not actively exercised include: payment for ecosystem services; pollution taxes on diffuse source pollutant inputs such as pesticides, fertilizers, plastics, pharmaceuticals, and personal care products. Barriers to their implementation were considered to include difficulties with identifying and targeting polluters; a lack of scientific data from monitoring to reliably inform costs and economic modelling; poor enforcement of existing regulations and strong political opposition.

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

16 https://www.oecd.org/environment/resources/Diffuse-Pollution-Degraded-Waters-Policy-Highlights.pdf

The ecosystem benefits of the natural capital in the Fraser River have been enumerated in a high-level report in 2010 (127). However, they are yet to translate into shifts in regulation that alter aquatic pollutant loads.

The EU reviewed the status of natural capital accounting in 2017 (128) showing progress, however implementation into global economic systems has yet to occur.

POINT SOURCE POLLUTION

In developed nations significant improvements to wastewater treatment plants have resulted in improvements in the effluent water quality, particularly in relation to nutrient emissions, however the control of other pollutants from wastewater and the sludge generated in treatment plants remains inadequate to protect the aquatic ecosystems from adverse impacts.

In efforts to recover valuable phosphorus and nitrogen nutrients wastewater sludge is increasingly sought to be reused in agriculture. However, this process redistributes the microplastics, PFAS, metals, and other contaminants back into open systems, where run-off can force them back into aquatic ecosystems.

Advanced analytical testing has now confirmed that pharmaceutical contamination is present in most global rivers (84). Research science suggests there are valid concerns in some waterways in Australia (129), Vietnam, (130) and Canada (131) in relation to endocrine activity of both wastewater discharges and other pollution sources to rivers.

Improving wastewater treatment plants to remove the growing suite of contaminants and identify safe disposal pathways was not identified as a priority by authorities across the case studies. The significant economic costs associated with such technological upgrades appear powerful disincentives for rapid change. Old technology wastewater treatment trickle plants are much less efficient at removal of some endocrine disrupting compounds compared to modern wastewater activated sludge treatment plants. However, even the activated sludge plants only reach efficiencies of 90-95% treatment.

CUMULATIVE IMPACTS UNDER-ASSESSED

The impact which takes place on aquatic ecosystems is from the sum of stressors. Hence, different pollutants can have *additive* or *synergistic effects* on the health and productivity of aquatic habitats and fisheries. Over time these impacts can accumulate, so while each individual impact may be dismissed as temporary or minor, when they occur repeatedly, their combined cumulative impact contributes to a loss of resilience and productivity from aquatic ecosystems. This cumulative impact is often missed in regulatory development which tends to focus only the latest development, without considering the load from all the previously approved developments and changes to land-use.

While there were different levels of pollution monitoring operating in the three case studies, all suffered from **significant data gaps** in relation to knowledge of the frequency, type, and concentration of pollutants entering the rivers. Wastewater treatment effluent entering the Richmond and Mekong rivers was not subject to any routine analysis for contaminants such as pesticides, pharmaceuticals and personal care products, PBDEs, microplastics, or other contaminants. The sum of potential toxicity was not assessed in these discharges. This differs from the approach in major wastewater treatment plant effluents discharged into the Fraser River where formal toxicity tests are performed on trout and fat head minnows.

At all case study sites problems exist in laboratory testing capability. Shortfalls exist in being able to test for all likely contaminant risks, at levels low enough to demonstrate that they are below the levels which can affect parts of the aquatic ecosystem.

The significant gaps in biological understanding of the impacts of complex cocktails of chemicals and stressors further limit clear articulation of precise risks to fisheries and wider aquatic ecosystem productivity. The use of bioassays to assess effluent water and invertebrate monitoring in sediments adjacent discharge points can assist, as is currently utilized in Canada.

This lack of consideration of cumulative impacts 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 systems appear 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. A recent independent review[17] of Australia's *Environment Protection and Biodiversity Conservation Act* found that "Good outcomes for the environment, including heritage, cannot be achieved under the current laws" and noted that, "..cumulative impacts on the environment are not systematically considered." (132)

LACK OF FINANCE TO PREVENT WATER POLLUTION

Within all case study sites financial resource allocation was identified as a limitation to improving the control of water pollution. This appears to reflect the socio-political landscape where environmental protection and restoration is a lower priority than other local development initiatives such as roads, hospitals, and sporting facilities.

When government budgets become tight, support for environmental restoration is among the first area to be cut. Conversely, new industrial or agricultural developments are typically fast tracked.

Such short-term thinking fosters the "death by a thousand cuts" syndrome which slowly but surely depletes fishery productivity and resilience.

INADEQUATE DETECTION TECHNOLOGIES

It is common for new pesticides or industrial chemicals to enter the market prior to commercial laboratory analytical methods being established that can detect them in the environment at concentrations relevant to their most sensitive effect endpoints, such as endocrine disruption or immunotoxicity. This creates a significant cost and time constraint to monitor their presence in rivers and to be able to consider their impacts.

ON RICHMOND RIVER, Australia the monitoring programs for drinking water which is extracted from the river test for a range of pesticides in the source water. Only approximately 6% of the pesticides known to be in use over the catchment area are included in the current testing protocol (133).

17 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

FISHERY HABITAT AND WATER QUALITY NOT VALUED

The lack of robust accounting for the value of aquatic habitat, including water quality was apparent in all case study locations. While ecosystem services and natural capital are conceptually acknowledged, they are not presently controlling or limiting the impact of urban, agricultural, or industrial development on the health of aquatic ecosystems. Hence, loss of these aquatic habitats and ecosystem services is occurring quietly. The declines in fishery catch (Figure 6, Figure 7, Figure 8) across all three case study areas are perhaps the clearest signal of the consequence of this accounting failure.

IN 1914, instability created from the construction of the railway in the upper Fraser River, known as Hell's Gate, contributed to a landslide which led to the functional blockage of the passage of sockeye salmon as it caused an extended stretch of the river to have a higher velocity that fish were largely unable to swim through to reach their upriver spawning grounds.

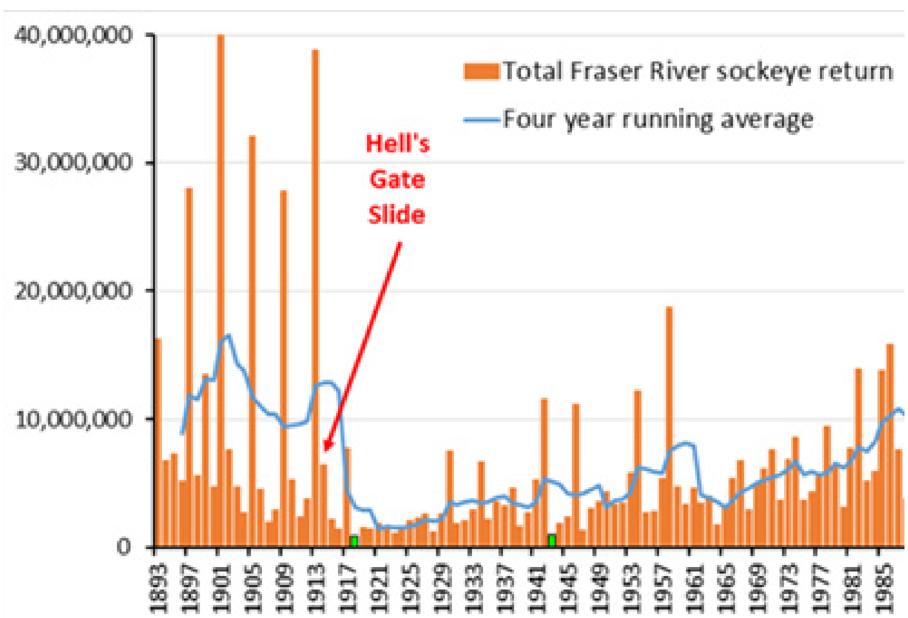

Figure 5 Fraser River sockeye salmon return after Hell's Gate landslide in 1914.
Source: https://www.psc.org/about-us/history-purpose/our-history/

It was not until 1945 that engineering works started to construct a fishway to facilitate access for the salmon to resume moving upriver in large numbers, albeit not returning to historic levels. The priority of commerce offered by the railway had been valued over the critical features of the habitat required to support salmon's abundance.

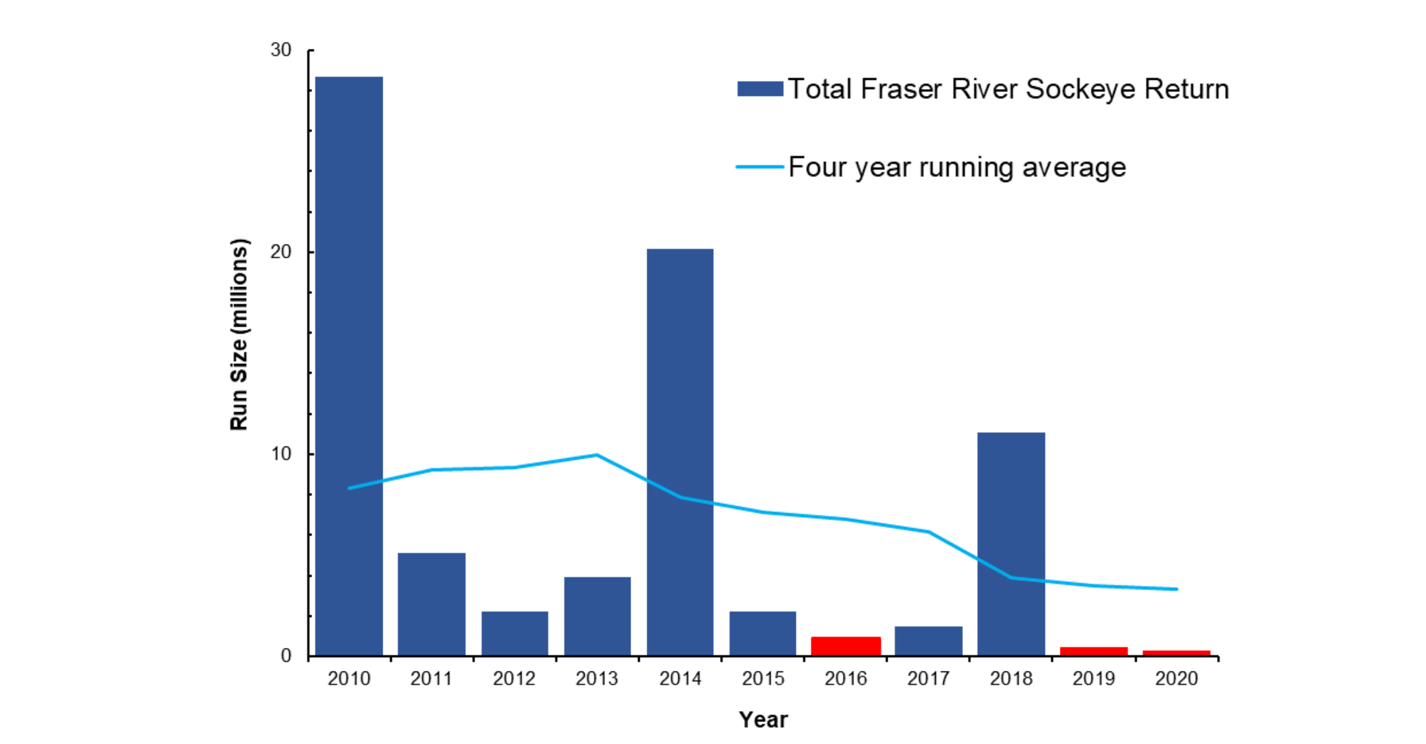

Figure 6 Returns of Fraser River Sockeye Salmon 2010-2020 Source: psc.org/about-us/history-purpose/our-history

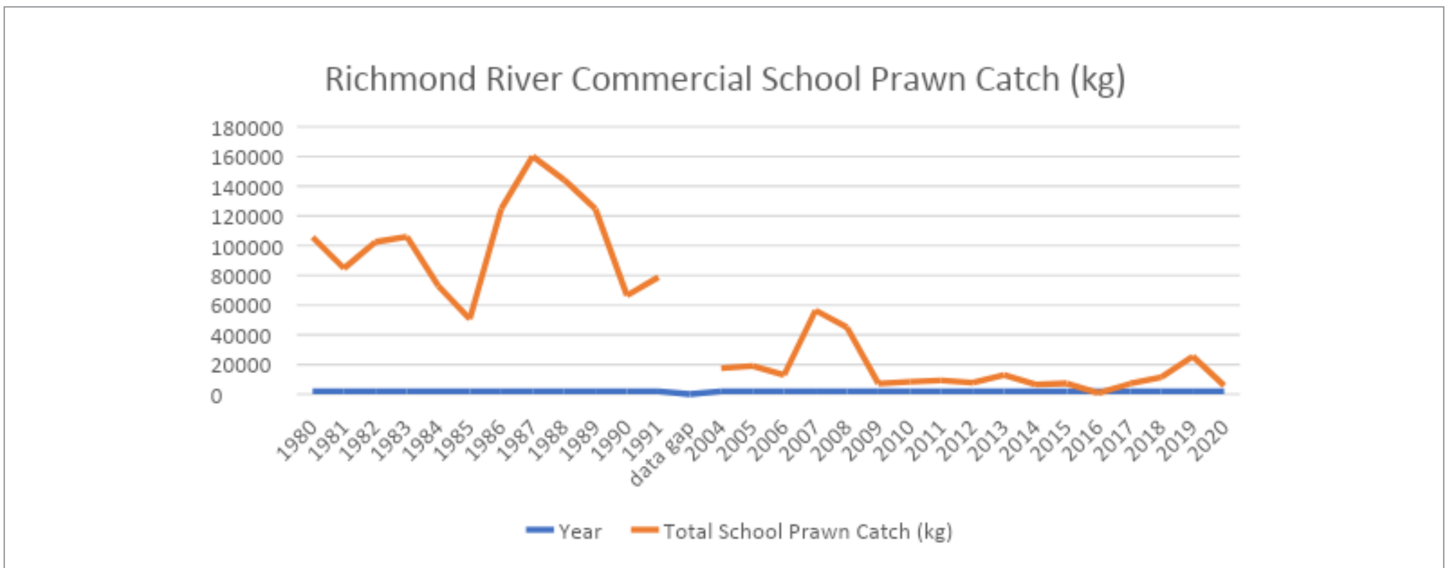

Figure 7 Richmond River, Australia declines in School Prawn (Shrimp) commercial catch 1980-2020

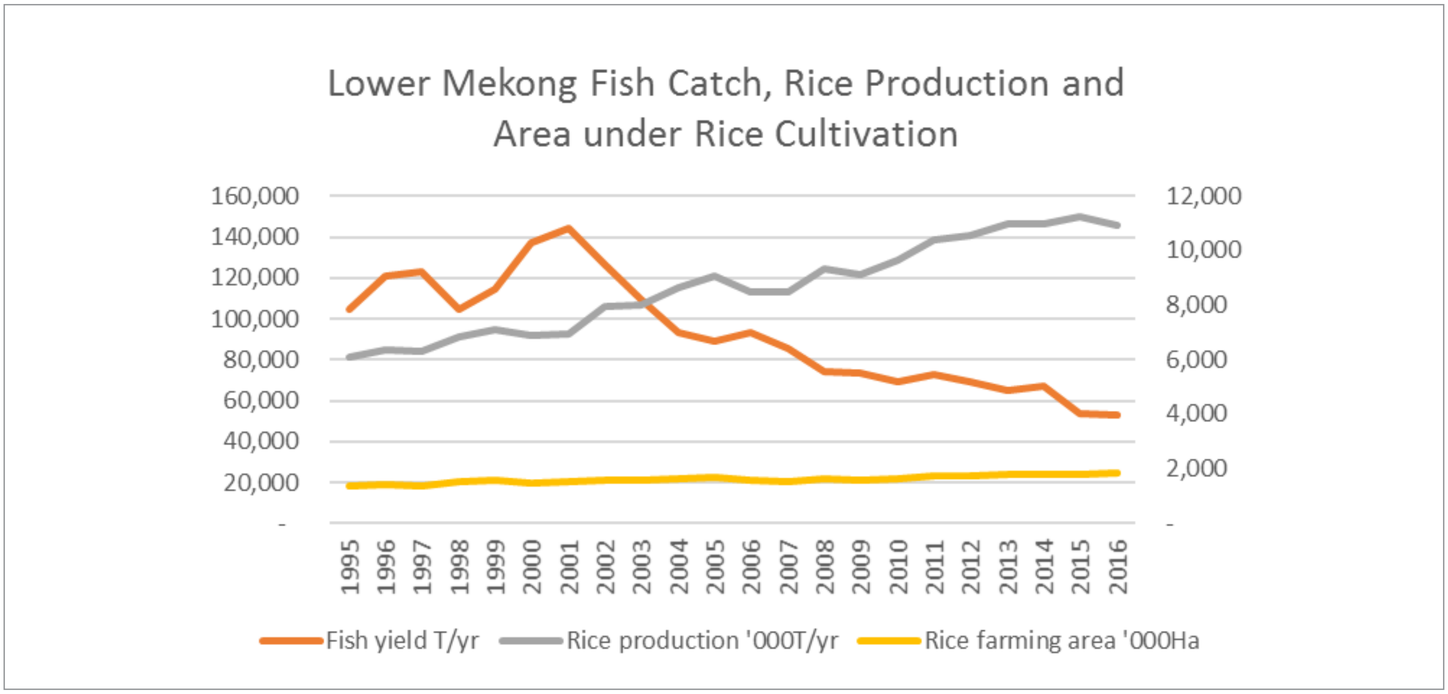

Figure 8 Trends in annual fish yield, rice farming area and rice production over a 20-year period in the Mekong Delta of Vietnam. Data from inland provinces only. Source: K Hortle

RECOMMENDATIONS

The following big picture recommendations are drawn from the case studies. More detailed recommendations can be found in the individual case studies.

The detection of a range of industrial, household, agricultural, pharmaceutical and personal care chemicals in waterways highlights a foundational regulatory oversight. Corrective action for this oversight to eliminate chemical pollution impacts on fisheries could be achieved through using the *Precautionary Principle* as a guide and to legislate, and fully implement the following four pillars of sound chemical regulation:

1. **Right to Know:** the community has a right to know what is, or has been used and released, and the level of contamination of public resources such as water and air.
2. **No data / No market:** when there is no chemical information, e.g., a human and environmental toxicity profile, or an absence of suitably validated and sensitive analytical techniques, there should be no right to use or release the chemical product into the market or environment.
3. **Substitution and Elimination:** if there is a safer, better way of achieving outcomes, then this should be mandatorily substituted for risks otherwise faced.
4. **Polluter pays:** Where pollution is emitted the polluter must pay for the impacts caused. The scale of payment must incentivize the elimination of the release of the pollutant.

GLOBAL DRIVERS OF EXPANDED POLLUTION RISK TO FISHERIES	RECOMMENDATIONS
Exceeding planetary boundaries	• Support First Nations/Indigenous people to lead landscape restoration incorporating their cultural knowledge • Shift pollution control to prevention rather than focusing on treatment of problems once they have occurred or on mitigating risks after they have been unleashed. This must go all the way back to the design of chemicals and plastics. They must be non-toxic throughout their whole lifecycle and have data to demonstrate this prior to entry onto the market.
Fossil fuel dependent food production	• Landscape restoration requires installation of the circular economy, to restrain the expansion of the linear economy outputs derived from ongoing fossil fuel extraction including combustion fuels, petrochemicals and plastics. • Shift to agricultural production systems that are not dependent upon fossil fuel derived pesticide and fertilizer inputs such as organic and regenerative agriculture.
Privatized profits socialized costs	• Promote polluter pays model to ensure that all forms of aquatic pollution can be traced to their source and that their deleterious impacts on aquatic habitat, water quality and fisheries productivity are fully valued
Corrupted science	• Sovereign Governments should have a scientific integrity body responsible for ensuring that political decisions are made on complete and robust scientific data
Competing priorities	• Re-learn and promote a fundamental shift in societal values towards those of First Nations/Indigenous people where community is valued over the individual and the environment is placed before profit. • Recognition in law that nature has intrinsic rights
Diffuse source pollution	• Support proposed UN treaty to control plastic production provided it includes controlling additives in plastics in addition to plastic itself[18] • Promote regenerative aquaculture of shellfish and seaweed to recreate habitat
Point source pollution	• Develop cheaper monitoring technologies such that the full range of contaminants can be mandatorily monitored to inform regulatory action to prevent entry of the pollutant to the environment aligning with zero-waste[19] philosophy
Cumulative impacts under-assessed	• Implement UNEP decade of restoration actions
Lack of finance to prevent water pollution	• Create economic incentives of greater magnitude than agricultural returns for restoration and maintenance of riparian vegetation on all water courses and reinstatement of natural hydrological function to wetland areas.
Inadequate detection technologies	• Invest in further development of cheap environmental sensor technology and big data analytics to improve monitoring data to support decision making for targeted pollution control
Fishery habitat and water quality not valued	• A fundamental shift is required to focus on delivering fishery management that restores and sustains the abundance, biodiversity, and health of the bottom of the aquatic food web, whilst reframing the role that traditional stock assessment plays. • Shift fishery management to incorporate aquatic ecosystem, catchment health status and pollutant loadings. This can help guide efforts to correct pollution at the source and support recovery of pollution sensitive fishery habitats.

18 https://ellenmacarthurfoundation.org/towards-a-un-treaty-on-plastic-pollution

19 https://zerowasteeurope.eu/

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