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*Review*

# The Biological Assessment and Rehabilitation of the World's Rivers: An Overview

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**Supplementar Material**

**Table S1.** Examples of ecological monitoring networks/programs of rivers and streams implemented in the World (based on the countries considered by this study) by official authorities or "seed programs" by research teams (where no official program is available).

| **Continent/ country** | **Scale** (national/state/regional /catchment/other) | **Law addressing the ecological assessment (if any)** | **Biological elements monitored** |
|---|---|---|---|
| **AFRICA** | | | |
| South Africa | National | National Water Act | Fish, riparian vegetation and invertebrates |
| South Africa, Namibia, Botswana and Lesotho | Catchment - transboundary Orange-Senqu River basin | Orange-Senqu River Commission | Fish, riparian vegetation and invertebrates |
| Lesotho | | Lesotho Highlands Water Project | Invertebrates, fish and riparian vegetation |
| **ASIA** | | | |
| China | | Law of the People's Republic of China on Water and Soil Conservation & Opinions of the State Council on the Implementation of the Strictest Water Resources Management System (2012) | Fish, aquatic mammals, benthic animals, epiphytic algae, phytoplankton, aquatic vascular plants, waterside vegetation, beach vegetation, benthic animals, amphibians, reptiles, wetland birds, Indigenous, rare, endangered and endemic species |
| Japan | National | National Census on the River Environment | Fish, benthic invertebrates, plants, birds |
| South Korea | National | Water Quality and Aquatic Ecosystem Conservation Act – from 2008<br>Ministry of Environment's Water Environment Conservation Act – from 2018 | Diatoms, invertebrates, riparian vegetation |
| Singapore | | Public Utilities Board of the Singapore Government | Invertebrates |
| **EUROPE** | | | |
| European Union (27 MS + UK and Norway) | European/National | European Water Framework Directive & national legislations | Invertebrates, diatoms, macrophytes and fish are regularly monitored each 3 years to determine the ecological status of all water bodies |
| **CENTRAL & SOUTH AMERICA** | | | |
| Equador | National – but only for environmental impact assessment | Ecuadorian normative for Mining Impact assessment | Invertebrates |
| Costa Rica | National | Costa Rica, 2007; Política Nacional de Áreas de Protección de Ríos Quebradas, Arroyos y Nacientes (2020) | Invertebrates |

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| Brazil | National law | CONAMA Resolution No 357 (Brasil 2005) | The law considers biological elements but is not implemented |
| Colombia | | Colombia 2018 | The law considers the use of biological elements but is not implemented |
| **OCEANIA** | | | |
| Australia – Vitoria, Queensland, Australian Capital Territory | State: Victoria (VEFMAP & WetMAP) | None | VEFMAP: fish and riparian vegetation<br>WetMAP: fish, birds, vegetation and frogs |
| Australia | State: Australian Capital Territory (Catchment Health indicator program) | None | Macroinvertebrates, water quality and riparian condition |
| New Zealand | Catchment - Australia's Murray Darling Basin | The Water Act (2007) | Fish communities, groundcover vegetation diversity and stream metabolism, waterbirds and less frequently, frogs and tree condition |
| **NORTH AMERICA** | | | |
| USA | National and some States (California, Iowa, Maryland, Ohio, Oregon) | Clean Water Act | Invertebrates and fish |
| Canada | Province | | Invertebrates; fish to a lesser extent |
| Mexico | Some catchments (i.e., Ayuguila, Armería, Pánuco, Sonora, Balsas and Bravo rivers) | | Invertebrates; fish to a lesser extent |

**Table S2.** Examples of rehabilitation of rivers around the world aiming the improvement of the biological assemblages.

| **Case study/ country** | **Scale** | **Aims /Targets for restoration** | **What triggered the program?** (legislation & problems) | **Pre/Post ecological monitoring** | **Success** | **References** |
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| **AFRICA** | | | | | | |

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| Working for Water Programme/ South Africa | National | Reduction in the density of terrestrial, invasive alien plants on river catchments, by 22% per annum. Improve stream flow and general river ecological condition and function, job creation, livelihoods diversification and environmental education and awareness raising. | National Water Act (Act No. 36 of 1998) National Environmental Management Act (NEMA) Act No. 107 of 1998); Conservation of Agricultural Resources Act | Yes | The programme has been largely successful, improving stream flow, and thus biodiversity and has generated thousands of jobs. | **410** https://www.environment.gov.za/projectsprogrammes/wfw#aims |
| The Tsitsa River Project/South Africa | National Water Act and National Environmental Management Act | Sustainable restoration and improvement of land, water resources and livelihoods diversification. Restore degraded land, reduce siltation and improve livelihoods | National Water Act and National Environmental Management Act /Planned construction of dams on the Tsitsa River, fear of siltation due to degraded land and erosivity | Yes | The project is still on-going; it was successful so far due to the involvement of communities, diverse practitioners and academic knowledge systems. | **411** |
| **ASIA** | | | | | | |
| Taihu Basin/China | 22 major rivers (120 000 | Improve water quality and ecological | The Taihu Basin | Yes, monitoring of blue- | Water quality indicators are steadily | **412** |

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| | km²) and 1 large catchment (233800 ha) | health, enhance connectivity of rivers and lakes. Severe cyanobacteria outbreak. | Management Regulations | green algae and water resources | decreasing, and the water ecology is improving | |
| Yangtze River /China | 11 province and province-level municipalities | Priority protection species and are of the Yangtze River and stop its over development. Species and biological resource protection, protection and restoration of habitat and wetlands | Outline of the Development Plan for Yangtze River Economic Belt, Action plan of the Yangtze River Protection and restoration campaign | Yes, a water quality monitoring, phytoplankton, zooplankton, living algae, fry and fish is gradually carried out | Still ongoing | **413** |
| Itachi River/Japan | 3km in Yokohama city | Flood control and Restoration of highly urbanized river | River Law /Flood control and People's demand for natural river | Yes, monitoring of plants and river geomorphology | Successful; Civil Engineering Design Prize 2016 | **80** |
| Tama River/Japan | Two sites within 1km | Conservation of endangered plant species (Aster Kantonensis) and restoration of gravel river bed | River Law/ Incised river channel and endangered species | Yes, monitoring of plants and river geomorphology | Successful | **80** |
| Kushiro River (Mire)/Japan | 2.4 km meander river restored | Restore in-stream habitat for native fish, invertebrates | River Law and Law for the Promotion of Nature | Yes | Successful, not only the natural landscape of a meandering | **332** |

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| | | floodplain vegetation by increasing flooding frequency and raising the groundwater table; reduce sediment and nutrient loads in the wetland areas restore a river–floodplain landscape | Restoration/ Degradation of Kushiro mire: sediment increments and drying wetland | | river but also its function | |
| Kamisaigo River/Japan | Ca. 1km in urban area | Flood control Restoration of river environment and relation between river and residents | River Law | Yes, monitoring of fish fauna, physical environment, and vegetation | Successful, Civil Engineering Design Prize 2016 | **333** |
| Anyangchen River - Korea | 32km in main stream and 4 tributaries within Anyang city | Improving water environment, ecosystem and flood mitigation in urban streams. Promote harmony between Flood Management and Ecological Environment | Water Environment Conservation Act. Improve the quality of life of urban residents (Yangjaecheon river success story was a catalyst) | Yes, monitoring water quality, geomorphology, flora and fauna, so far | Successful - first award for best practice of river restoration (a typical case of Korea's restoration of urban stream) | **414** |
| Cheonggyecheon River (started in 2001–completed in 2010) -Korea | 5.8km in Seoul city | Improving water environment, ecosystem and safety for | Local government Ordinace, River Act, | Yes, monitoring water quality, air pollution | Successful - removed roads from streams used as motorways | https://www.ser-rrc.org/project/south-korea-restoration-of- |

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| | | flood in urban streams. To promote harmony between Flood Management and Ecological Environment | Water Environment Conservation Act. Improve the quality of life of urban residents | along waterfront, flora and fauna, so far | and restored streams along with the improvement of urban landscapes | the-cheonggyecheon-river-in-downtown-seoul/ |
| Yangjaecheon Stream Restoration (started in 1995 – complete) – Korea | 3.5km in Gangnam district of Seoul City | Improving water environment, ecosystem and setting up rest facilities in urban streams.To restoring stream that citizens have shunned as near stream through a clean and natural appearance | Funding from a private company. Ecological restoration and urban river environmental park project | Yes, monitoring water quality, geomorphology, flora and fauna, landscape | Successful-First river restoration case in Korea (It triggered restoration of rivers nationwide in Korea) | http://www.korea.net/NewsFocus/Travel/view?articleId=142266 |
| **EUROPE** | | | | | | |
| Mondego river/Portugal | River stretch of 65 km | Improve longitudinal connectivity for migratory fish (diadromous); several fish passages were implemented | Endangered and economically important fish species | Yes, annual monitoring to assess the abundance of larvae or juveniles of some species (electric fishing); Biotelemetry to evaluate | Yes. Recovery of habitat for all target fish species; the larvae of sea lamprey (Petromyzon marinus) increased up to 100x when compared with the monitoring data obtained before the | **363** **364** |

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| | | | | the fish passage efficiency; visual census conducted at the fish passage monitoring window to count the anadromous spawners that enter every year to spawn | construction of the fish passages | |
| River Vienne/France | River stretch of 15 km | Improve the connectivity for migratory fish - removal a dam due to its numerous effects on river continuity and its low level of economic benefit / | Absence of migratory fish upstream the dam; poor effect of fish-passes. Long-term management plan for the River Loire) | Yes, monitoring of migratory fish | Re-activation of sediment transport, for anadromous fish, with evidence of recolonization and increasing reproduction reconnection of 35k of river | https://professionnels.ofb.fr/sites/default/files/pdf/rex_r1_vienne_vbatGB.pdf |
| Isar River/Germany | River stretch of 8 km | Improving resilience to flooding events, restoring the natural conditions of the riverine landscape, enhancing the recreational value. Re-widening of | Flood protection standards and need for recreational spaces | The presence of several biological groups was assessed: fish, amphibians, birds, terrestrial invertebrates | Stronger dynamics in river morphology; wide acceptance of the improved recreational space; increased biodiversity | https://www.wwa-m.bayern.de/fluesse_seen/massnahmen/isarplan/doc/isar_river.pdf |

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| | | the channelized river; replacement of cross-river sills by rough ground ramps; construction new gravel beds and new floodplains; upgrade of waste-water treatment plants | | | | |
| Sokołówka River/ Lodz/Poland | Urban river section | Improved storm-water management, increased water retention, and better water quality supporting higher biodiversity and improvement of quality of life/ encourages society healthy lifestyles, attracts business, and become resilient to global climate change | Floods in the city during storms are result of high proportion of impermeable surfaces and channelization/Degradation of the freshwater habitats/Poor water and ecological quality | Yes, assessment of fish assemblages and RNA/DNA ratio in fish tissues. | Yes, in terms of stormwater retention; aesthetic value; environmental quality in the urban space; no clear indications for aquatic biological elements | https://climate-adapt.eea.europa.eu/metadata/case-studies/urban-river-restoration-a-sustainable-strategy-for-storm-water-management-in-lodz-poland/#adapt_options_anchor; http://www.switchurbanwater.eu/outputs/pdfs/W6-2_CLOD_RPT_SWITCH_City_Paper_-_Lodz.pdf |
| Bernesga River/ Duero river basin/Spain | Dam area | Removal of a dam and all mechanisms | Spanish National Strategy of | Yes, assessment of fish and | Yes, the connectivity of the river was | https://damremoval.eu/portfolio/la- |

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| | | associated to gates and all concrete material; reestablishment of natural connectivity, migration of fish and passage for macroinvertebrates and other species | River Restoration; accumulation of sediment above dam and deficit downstream; barrier for fish | macroinvertebrates (before and one-year data after the dam removal) | restored; sediments were naturally transported downstream; macroinvertebrate indices improved downstream | gotera-dam-spain/ |
| **CENTRAL & SOUTH AMERICA** | | | | | | |
| Upper Guayllabamba River Basin | Small tributary stretches: Ortega and Shanshayacu streams | Rehabilitation of urban streams due to garbage accumulation, health hazards and recover of green spaces for neighborhoods/Riparian clean up, riparian vegetation recovery, bank stabilization | Unsafe conditions of stream riparian areas, and awareness from neighbors. | No | Only visual riparian recovery | **338** |
| La Vieja River Basin, Colombia | Basin wide management, with protection of riparian corridors. | Restore riparian and stream quality from the effect of extensive cattle | A basin scale project to switch extensive agriculture to silvopastoral systems | Riparian, physical habitat, macroinvertebrate community, water quality | Yes | **339** |
| Nutrias stream, Argenitna | Reach scale | Recover from intensive/extensive cattle | A research program to address | Riparian, habitat, bank and | Yes | **415** |

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| | | | passive restoration intervention in Pampean Streams | fish communit y | | |
| Pichis River, Perú | River basin | Riparian restoration for fish community recovery | Decreases in fisheries and disappearan ce of target species | Yes | Yes, fish re-appearance due to riparian forest recovery | **341** |
| Urban streams of Belo Horizonte city, catchment of Rio das Velhas | Streams | Improve water quality, aesthetic value, human health | Water Master Plan (Belo Horizonte 1999, 2012)/ Pollution and degradation of the urban streams causing risks to human health and contributing to poor living conditions in the surrounding s | Yes, 10 years of follow-up monitoring (Recurb project) | Improvement of water quality, species richness, composition and assemblage structure of benthic invertebrate communities, and appearance of new sensitive taxa | **121,370,368** |
| **OCEANIA** | | | | | | |
| MDB Basin Plan/Australia | River basin (>1 M km2) | To bring the basin back to a healthier and sustainable level, while continuing to support farming and other industries for | Multiple large-scale condition assessment programs showing that the basins rivers were in poor ecological | Yes (LTIM & MER) | Some site specific successes: supporting waterbird breeding, increasing productivity, supporting fish breeding. | **332,313, 314 416,321**, **417** |

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| | | the benefit of the Australian community/ Improvement of riparian vegetation, fish community, bird habitat, river banks, flow | condition and drought. | | | |
| Murrumbidgee River Restoration Program/Australia | River basin (>80,000 km2) | Improve water quality | NHT/Poor water quality | No (ad-hoc) | Unknown | **418** |
| Victorian environmental flows program/ Australia/ | River basin (size) | Improve ecological condition | Flora and fauna bulk entitlement | Yes | Somewhat | **419,420,421** |
| Macquarie Perch Action Plan (for Cotter River and other ACT rivers)/Australia | Several catchments in ACT region | Enhance the long-term viability of populations | Nature Conservation Act 2014/Endangered species status | Yes | Yes, although their status is still endangered | **398** |
| ACT Water Strategy (for all ACT waterways)/Australia | Several catchments in ACT region | Maintain or improve the quality of water across all ACT managed sub-catchments Healthy catchments and waterbodies | Water Resources Act 2007, Environment protection Act 1997 & others/ Reform programs in biodiversity conservation and water quality and quantity management occurring | Yes | Examples of both success and failure | **399,422** |

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| | | | Australia-wide | | | |
| Northern basin connectivity/Australia | Multiple catchments including Border Rivers, Gwydir, Macquarie and Barwon-Darling | To improve connectivity between catchments and reduce the number of cease to flow days in the Barwon-Darling/Fish condition and local movement | Commonwealth and state laws/Disturbance (drought combined with legislative changes that impacted on small and medium in channel flows) | Yes | Leading to changes in water sharing arrangements. It could take decades to see the ecological benefits. | **319** |
| Project River Recovery (Waitaki River)/New Zealand | 1 large catchment (35,000 ha) | Enhance habitat for Nationally threatened riverine birds/Riparian willow removal | Compensation for hydro development/Threatened species | Yes. Bird reproduction, predator & weed control monitoring | Increased bird habitat, some improvement in bird numbers | **423** |
| Zealandia (Karori Sanctuary)/New Zealand | 1 urban catchment | Predator control | Sanctuary for threatened species | Fish monitoring | Invasive fish species removed | https://www.visitzealandia.com/Portals/0/Resources/20200128%20Sanctuary%20to%20Sea%20Strategy_Final%20Version.pdf?ver=2020-02-17-092719-310&timestamp=1581884864923 |
| Upper Silverstream Creek/New Zealand | 1 km of small, 1st order stream | Improve water quality and ecological health/Riparian planting, | Landowner initiative | Yes, water quality, benthic invertebrates, | Some improvement in ecological health | https://www.canterbury.ac.nz/science/schools-and-departments/ |

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|---|---|---|---|---|---|---|
| | | sediment & macrophyte control | | macrophytes, decomposition, fish | | biological-sciences/research/ferg/carex/ |
| **NORTH AMERICA** | | | | | | |
| Willamette Basin/USA | River basin | Improve water quality, fish assemblages Salmon | Clean Water Act (CWA)/ Water pollution | Yes | Somewhat | **424** |
| Scioto River Mature/USA | Mainstem | Improve Water quality, fish & macroinvertebrate assemblages | CWA/Water polllution | Yes, | Mostly | **378** |
| Kissimmee River/USA | Mainstem | Naturalize/reconfigure the channel; improve water quality, channel complexity, waterfowl | Endangered Species Act (ESA) /Ecological degradation | Yes | Somewhat | **425** |
| Elwha River/USA | Mainstem | Promote Salmon passage/dam removal, improve fish assemblages | Endangered Species Act (ESA)/Migration barriers | Yes | Mostly | **426** |
| Bow River/Canada | mainstem | Sport Fishery/Tertiary sewage treatment and P removal | Excessive macrophyte growth | Yes | Yes | **427** |
| Sackville River/Canada | Mainstem and tributaries | Habitat and passage | Atlantic Salmon Fishery/Habitat loss and barriers | No | | **428** |

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| Ayuquila River Complete Mexico | Mainstem (partial) | Improve water quality | NOM-001-SEMARNAT-1996/ Water pollution/ Fish mortality | Yes | Yes, previously and ongoing | **293** |
| Rio Magdalena Early Mexico | Basin | Water quality Improvement and conservation | Water pollution | No | No information yet | **429,430** |
| Teuchitlan Stream Early (Ongoing) Mexico | Basin | Endangered species reintroduction /Water quality, habitat | Species loss | Yes | Yes, previously and ongoing | **431** |

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