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Agriculture Water Environment

Sustainable management and protection of vulnerable African water resources through holistic environmental flow framework determination and implementation

O'Brien, G.C., Wade, M., Dickens, C and Wepener, V

22nd Savanna Science Network Meeting, Skukuza



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Environmental
Reviews

Accelerating environmental flow implementation to bend the curve of global freshwater biodiversity loss

Angela H. Arthington, David Tickner, Michael E. McClain, Mike C. Acreman, Elizabeth P. Anderson, Suresh Babu, Chris Dickens, Avril Horne, Nitin Kaushal, Wendy Monk, Gordon O'Brien, Julian D. Olden, Jeffrey Opperman, Afua Owusu, LeRoy Poff, Brian Richter, Sergio A. Salinas-Rodríguez, Beauty Shamboko Mbale, Rebecca E. Tharme and Sarah M. Yarnell

<https://cdnsiencepub.com/doi/full/10.1139/er-2022-0126>



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Environmental
Reviews

Measures to safeguard and restore river connectivity

Michele Thieme, Kim Birnie-Gauvin, Jeffrey J. Opperman, Paul A. Franklin, Holly Richter, Lee Baumgartner
Nathan Ning, An Vi Vu, Kerry Brink, Michael Sakala, Gordon C. O'Brien
Robin Petersen, Pakkasem Tongchai and Steven J. Cooke

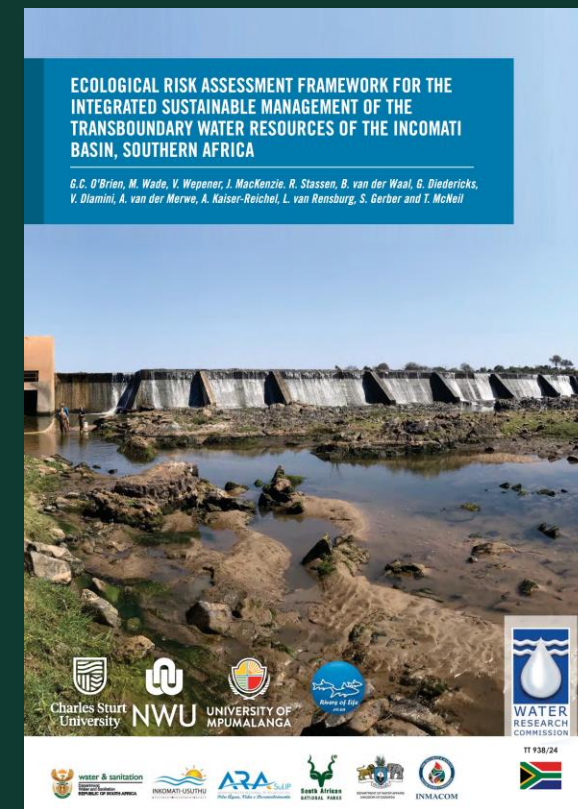
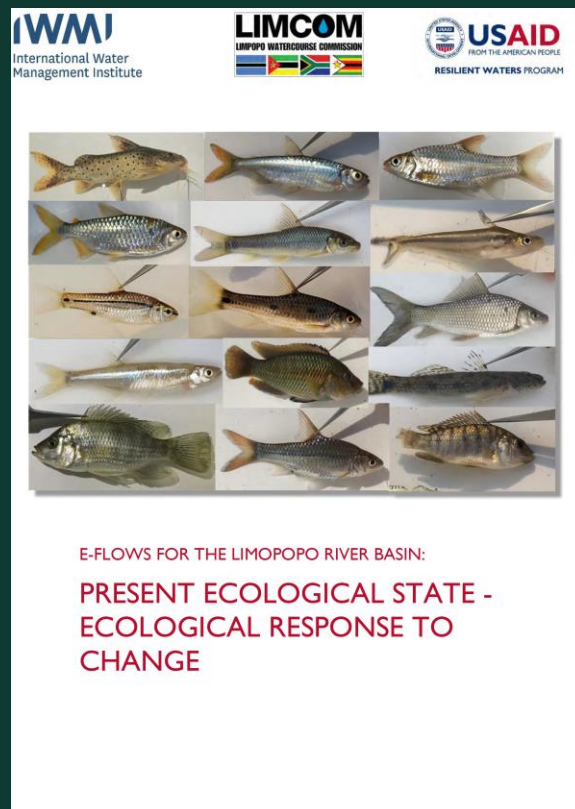
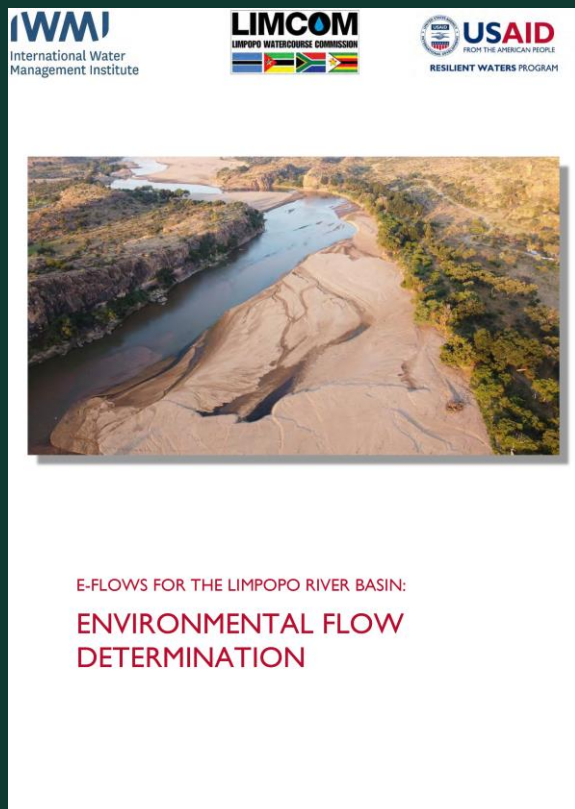
<https://cdnsiencepub.com/doi/full/10.1139/er-2023-0019>



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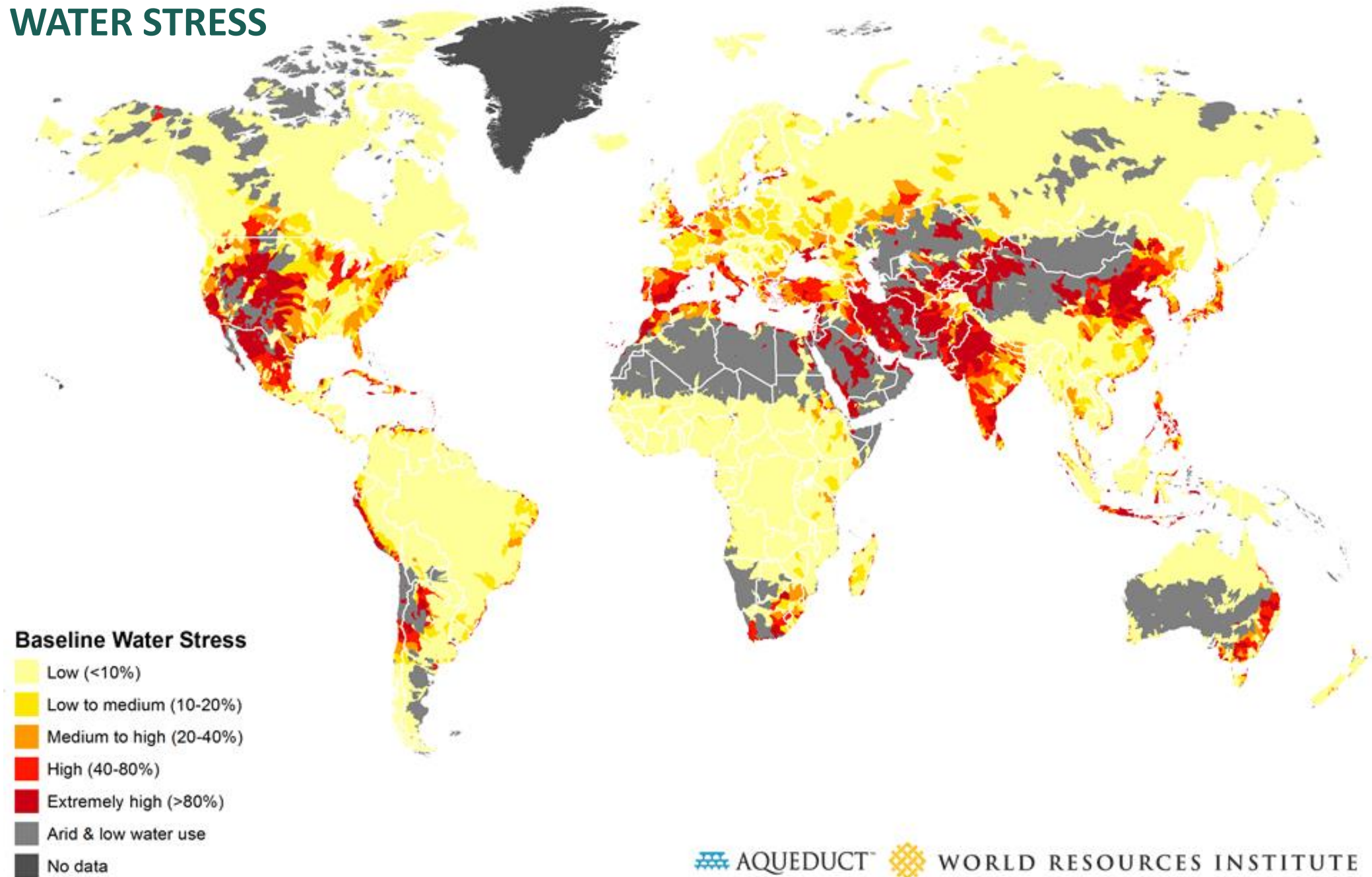


O'Brien, G.; Dickens, Chris; Wade, M.; Stassen, R.; Diedericks, G.; MacKenzie, J.; Kaiser, A.; van der Waal, B.; Wepener, V.; Villholth, Karen; Ebrahim, Girma; Dlamini, V.; Magombeyi, Manuel. 2022. **E-flows for the Limpopo River Basin: environmental flow determination**. Project report prepared by the International Water Management Institute (IWM) for the United States Agency for International Development (USAID). Colombo, Sri Lanka: International Water Management Institute (IWM); Washington, DC, USA: USAID. 209p. (E-flows for the Limpopo River Basin: Report 7) [doi: <https://doi.org/10.5337/2022.222>]

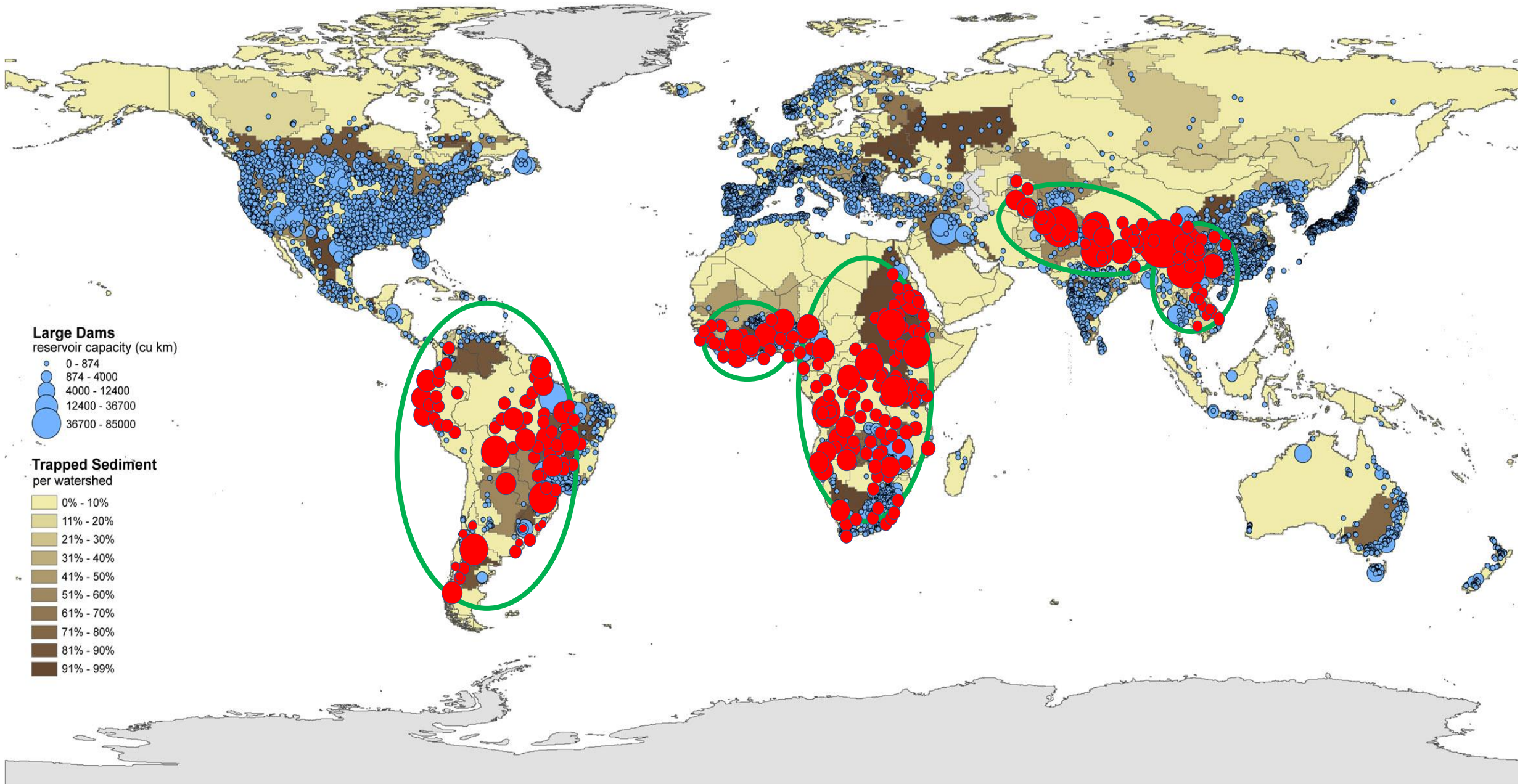
O'Brien, G.; Dickens, Chris; Diedericks, G.; Kaiser, A.; Barendse, C.; Pearson, H.; LeRoux, H.; MacKenzie, J.; Gerber, S.; Petersen, R.; Dlamini, V. 2022. **E-flows for the Limpopo River Basin: present ecological state - ecological response to change**. Project report prepared by the International Water Management Institute (IWM) for the United States Agency for International Development (USAID). Colombo, Sri Lanka: International Water Management Institute (IWM); Washington, DC, USA: USAID. 223p. (E-flows for the Limpopo River Basin: Report 6) [doi: <https://doi.org/10.5337/2022.221>]

O'Brien, G.C., Wade M., Wepener V., MacKenzie J., Stassen R., van der Waal B., Diedericks G., Dlamini V., van Der Merwe A., Kaiser-Reichel A., Van Rensburg L., Gerber S. and McNeil T. 2024. **Ecological Risk framework for the integrated sustainable management of the transboundary water resources of the Incomati Basin, southern Africa**. Water Research Commission Report TT938/24. ISBN: 9780639206332. Water Research Commission. Pretoria. <https://www.wrc.org.za/wp-content/uploads/mdocs/TT%20938%20web.pdf>

GLOBAL WATER STRESS



Dam projects in developing parts of the world



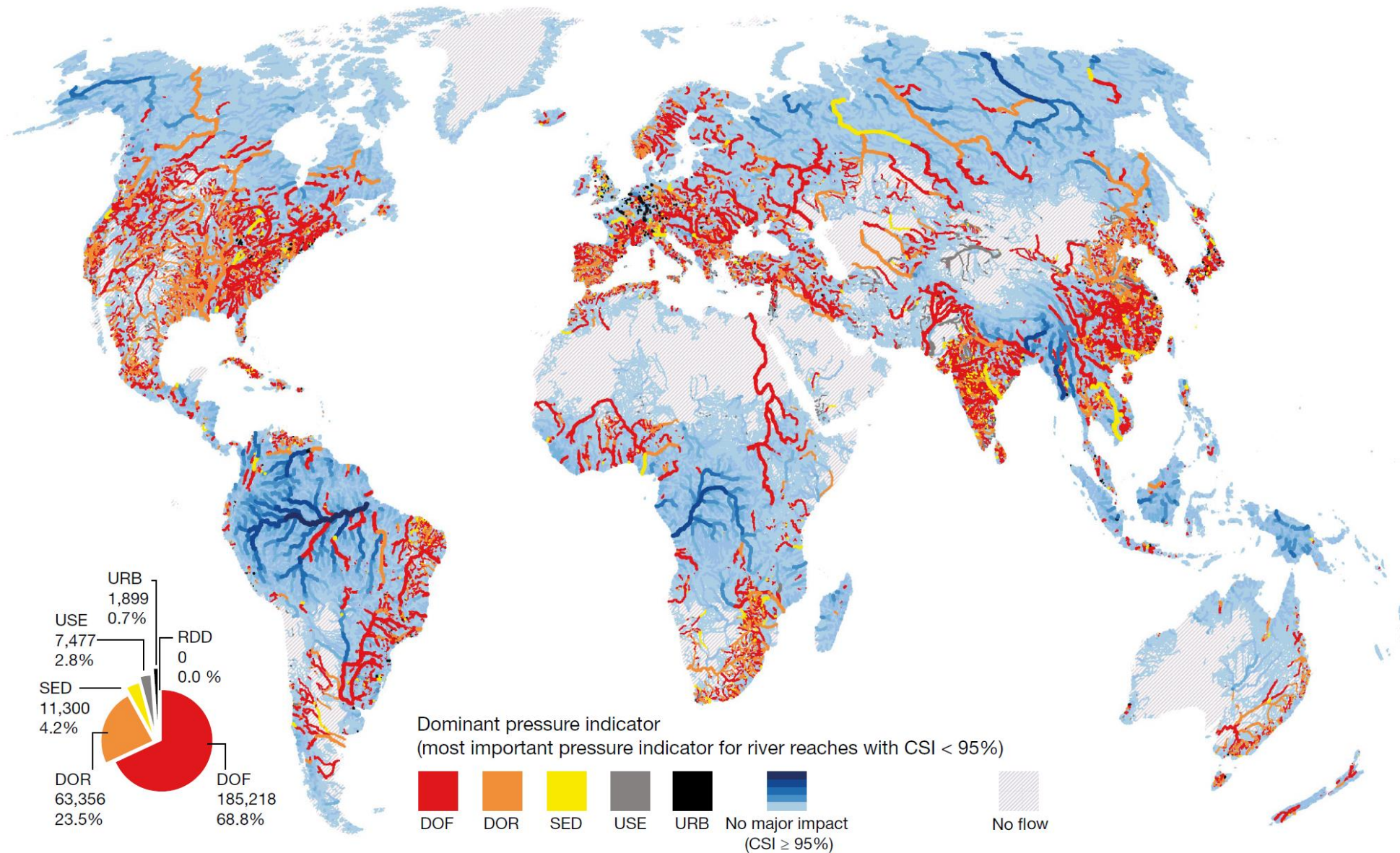


Fig. 2 | Dominant pressure indicator for global river reaches below the CSI threshold of 95%. The dominant pressure indicator—the most important pressure indicator for river reaches with CSI < 95%—contributed the most to the final CSI value after applying the weighting scheme. Pressure indicators include the DOF (degree of fragmentation),

DOR (degree of regulation), SED (sediment trapping), USE (consumptive water use) and URB (urban areas). The RDD (road density) does not occur as a dominant pressure indicator on the map. The inset shows the number and proportion of river reaches per dominant pressure indicator at the global scale.

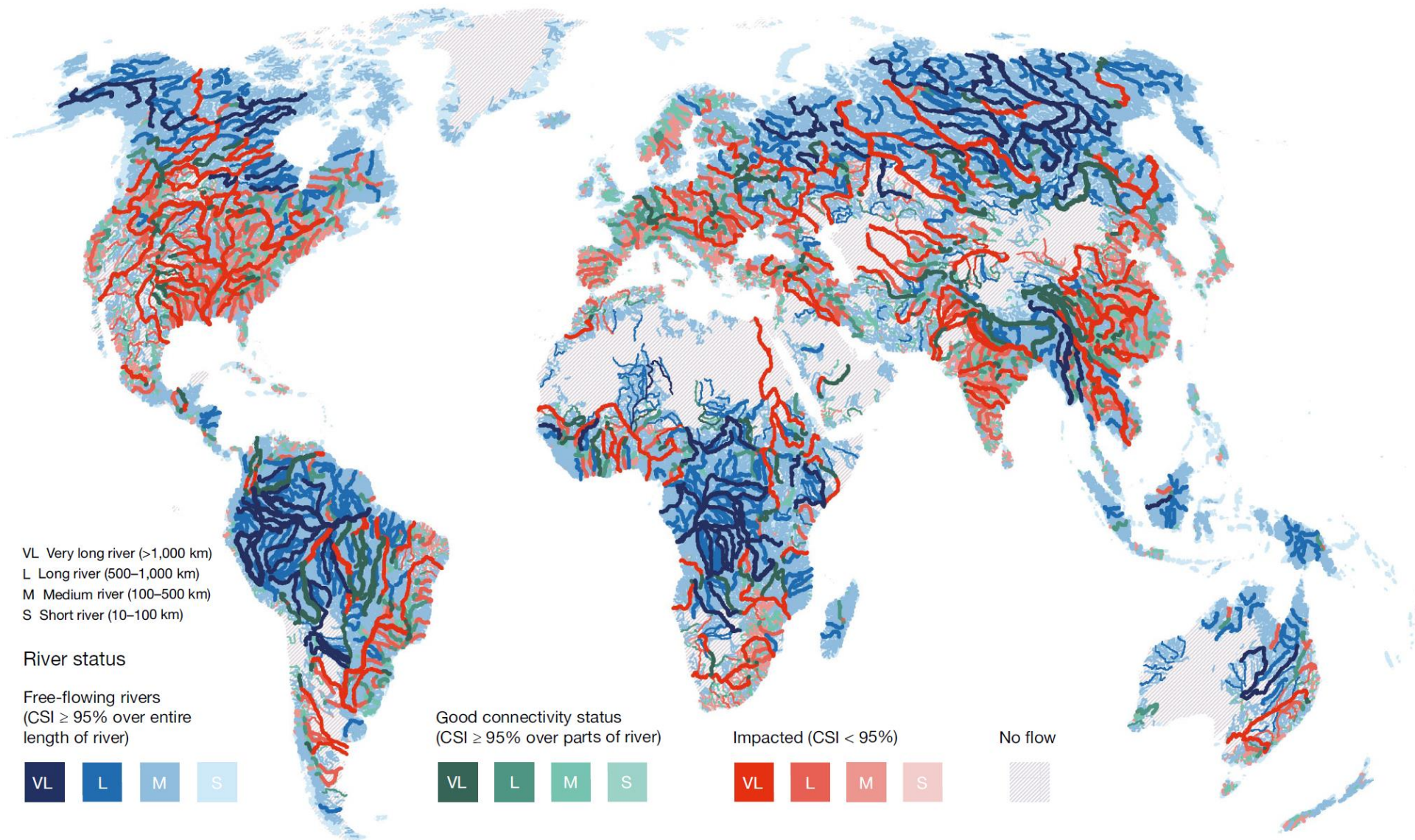
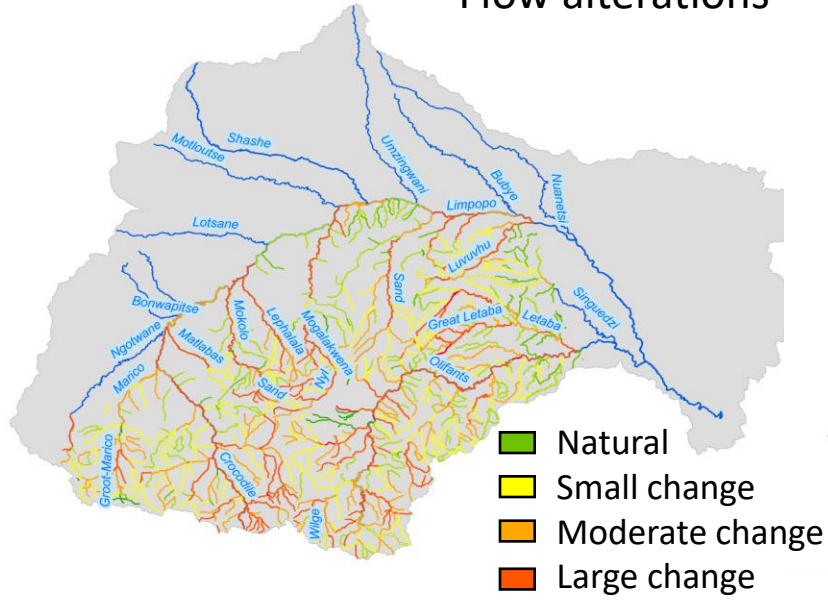


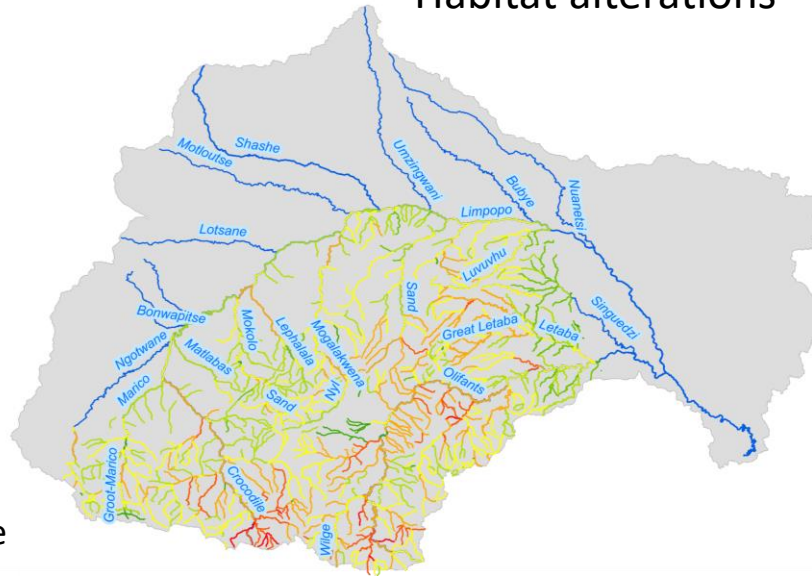
Fig. 3 | Map of the world's free-flowing rivers. This map shows the global distribution of FFRs, contiguous river stretches with good connectivity status and impacted rivers with reduced connectivity. Rivers that are not free-flowing over their entire length (that is, partially below the CSI threshold) are divided into stretches with good connectivity status

(that is, the connectivity status remains above the threshold throughout the stretch; green colours) and stretches where the connectivity status is below the CSI threshold (red colours). A list of FFRs longer than 500 km is given in Supplementary Table 1.

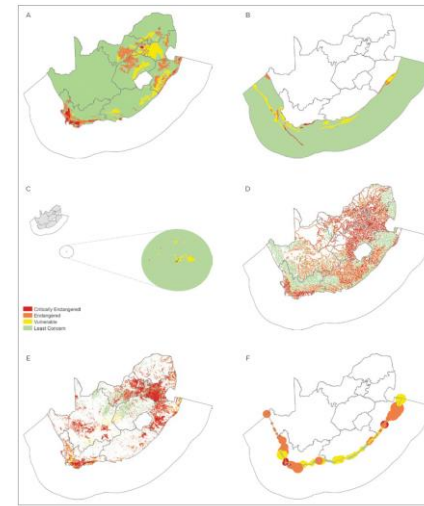
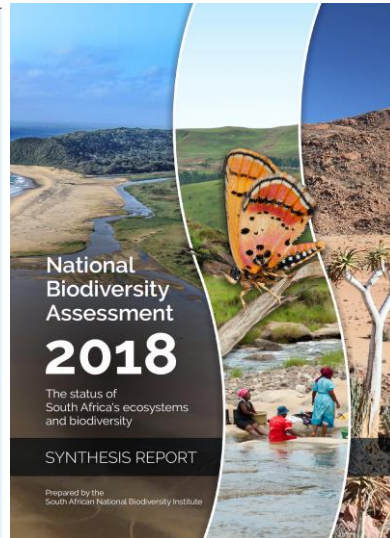
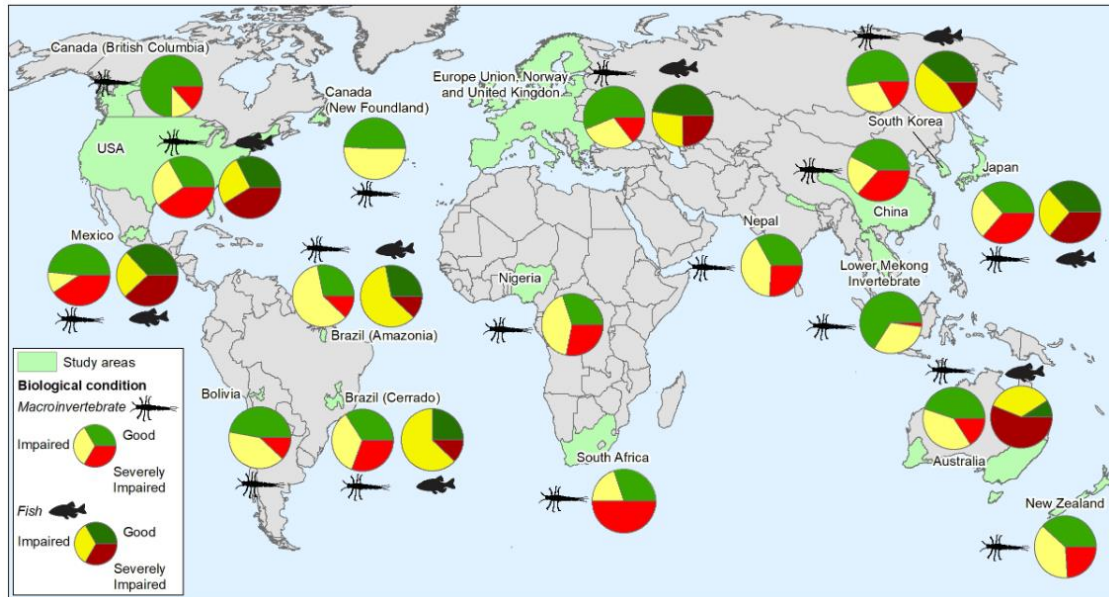
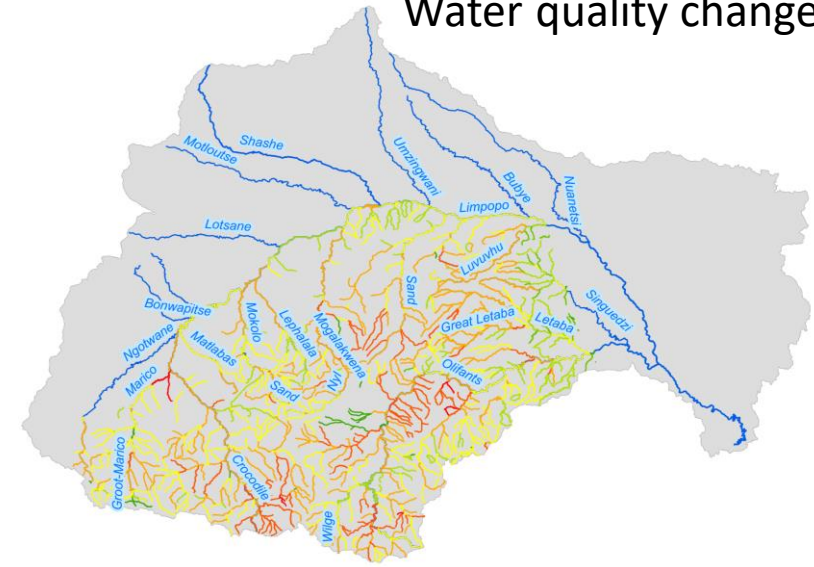
Flow alterations



Habitat alterations



Water quality change



ECOSYSTEMS

64%
of 222 river ecosystem types
Threatened

13%
of 222 river ecosystem types
Well Protected

42%
of 222 river ecosystem types
Not Protected

79%
of 135 inland wetland ecosystem types
Threatened

6%
of 135 inland wetland ecosystem types
Well Protected

61%
of 135 inland wetland ecosystem types
Not Protected

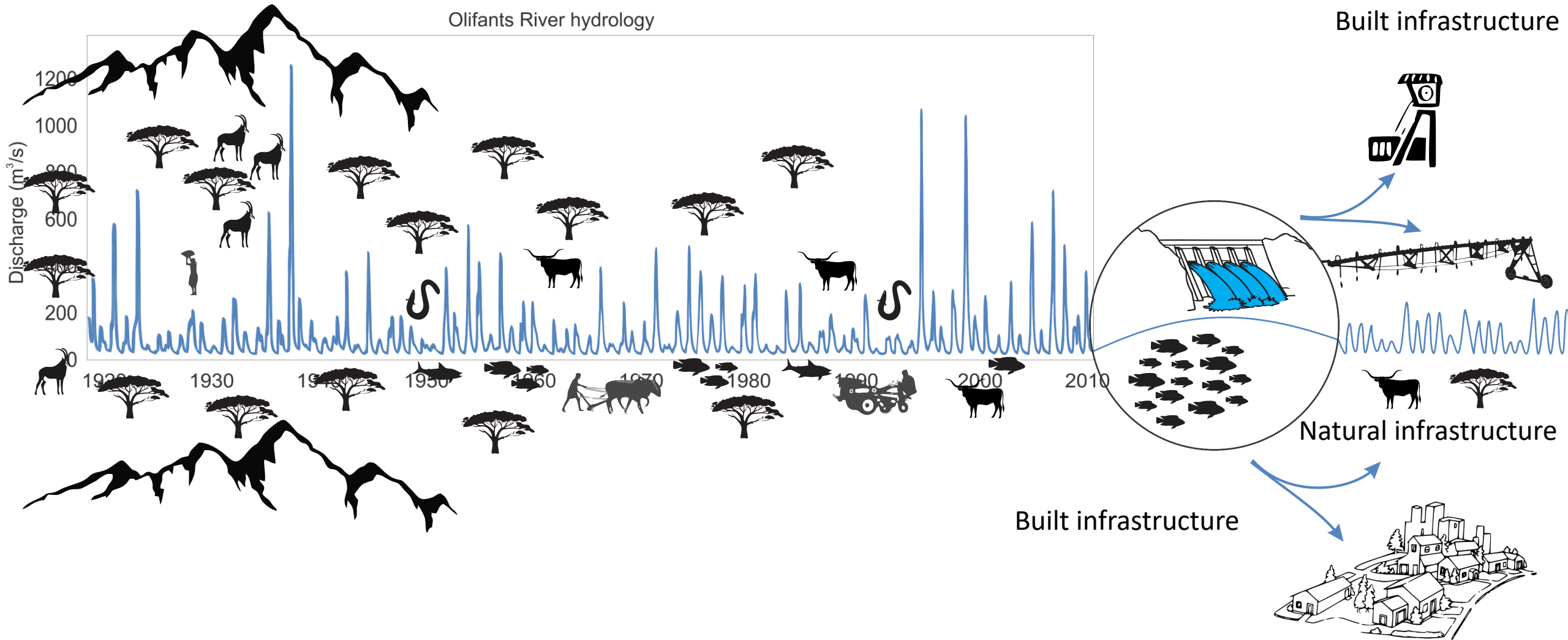
SPECIES

17%
of 658 taxa assessed
Threatened

68%
of 501 taxa assessed
Well Protected

18%
of freshwater fishes
Well Protected

Figure 29. Spatial distribution of threatened ecosystems for each nation: (A) terrestrial, (B) marine, (C) sub-Antarctic territory including the Falkland Islands and surrounding seas, (D) river, (E) inland wetland, (F) estuarine (since the actual estuaries are not visible at the map scale used, circles, scaled to the extent of each estuary, are used).



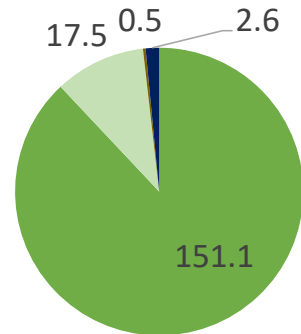


Average annual economic benefits and costs before and after dam construction

Pre-dam

Total monetary value of services:
USD 172 million

Average annual flood damage:
USD 19.6million

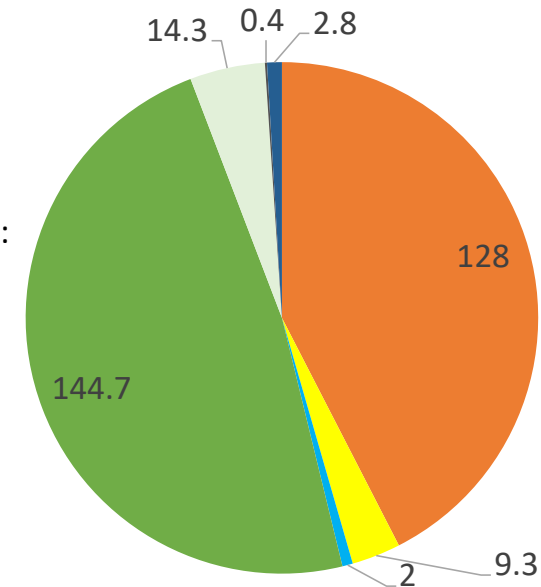


- Livestock
- Flood recession agriculture
- Floodplain fisheries
- Marine fisheries/shrimp

Post-dam

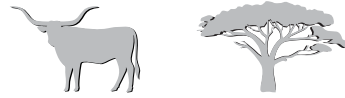
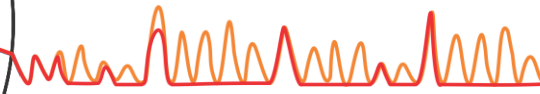
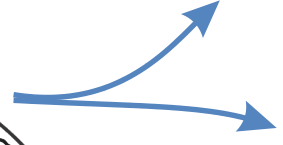
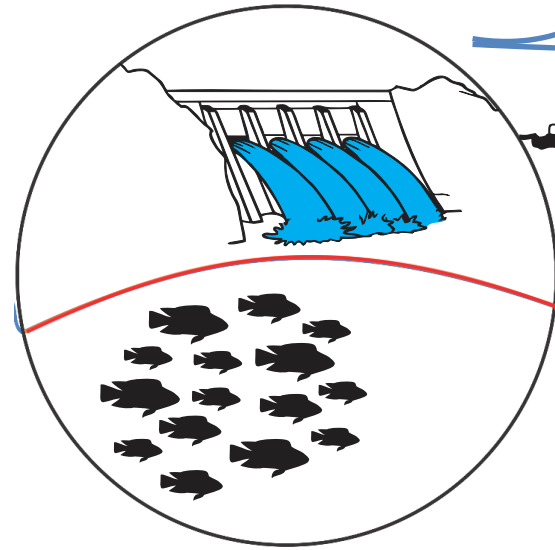
Total monetary value of services:
USD 302 million

Average annual flood damage:
USD 3.4 million



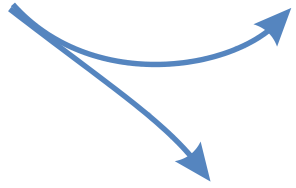
- Electricity
- Irrigation
- Reservoir Fisheries
- Livestock
- Flood recession agriculture
- Floodplain fisheries
- Marine fisheries/shrimp

Built infrastructure



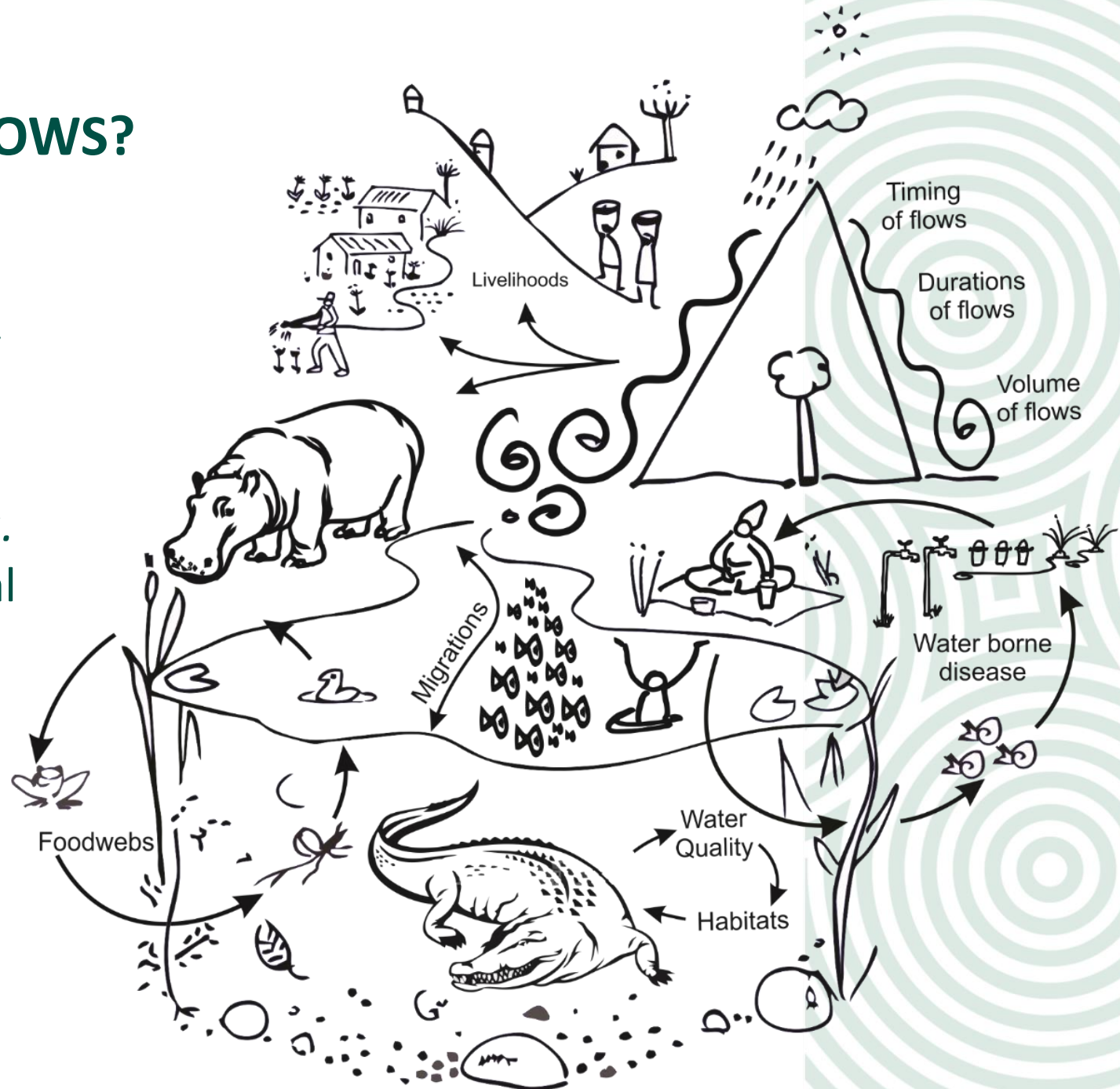
Natural infrastructure

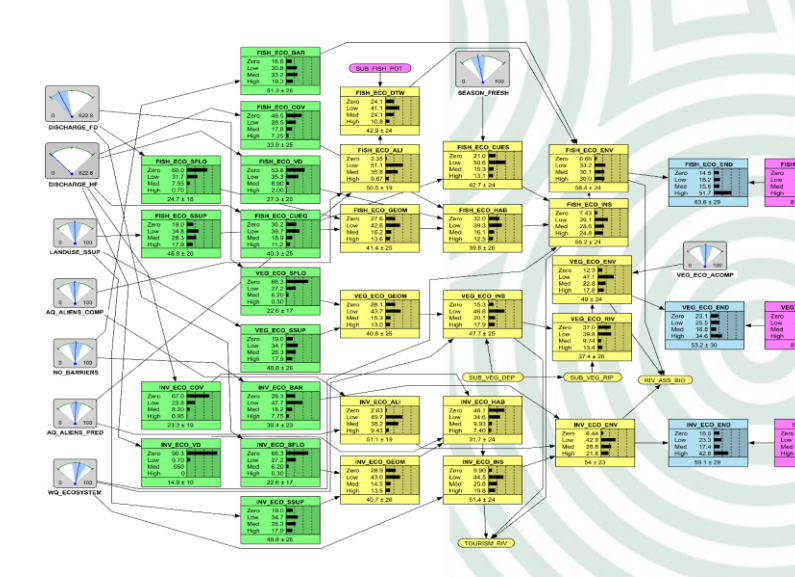
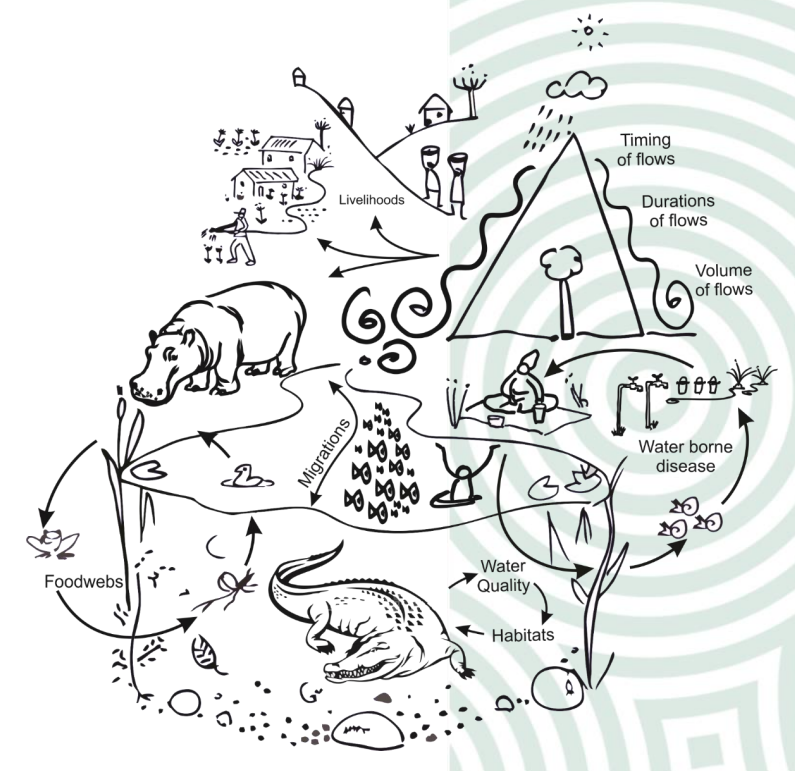
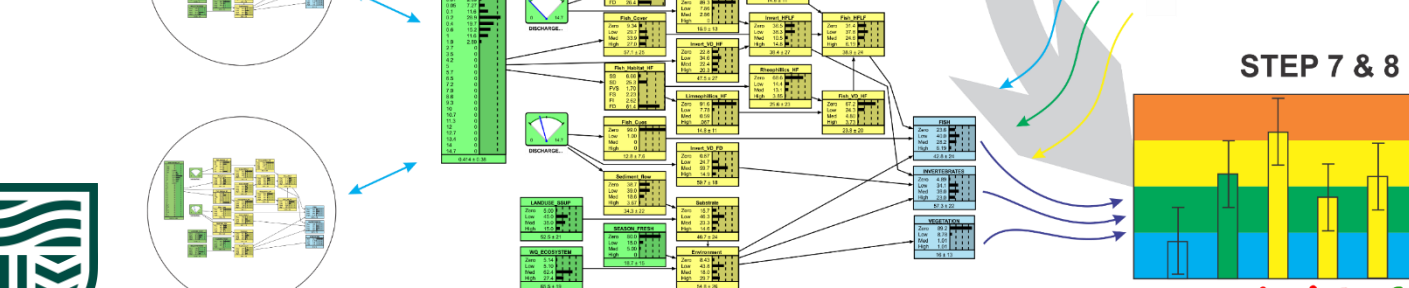
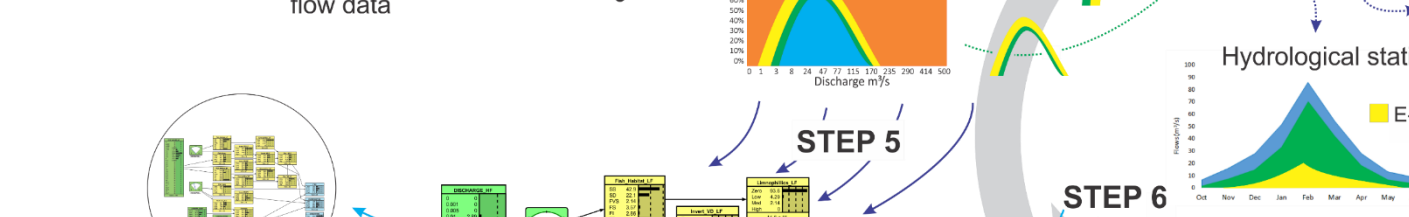
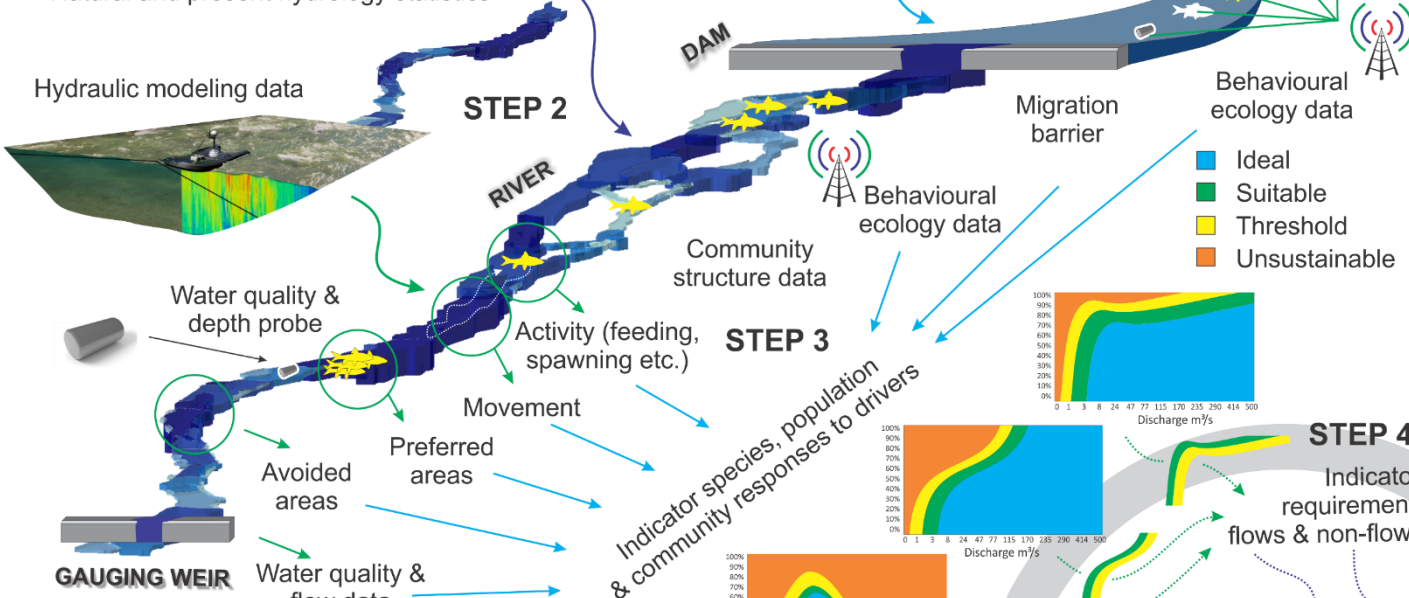
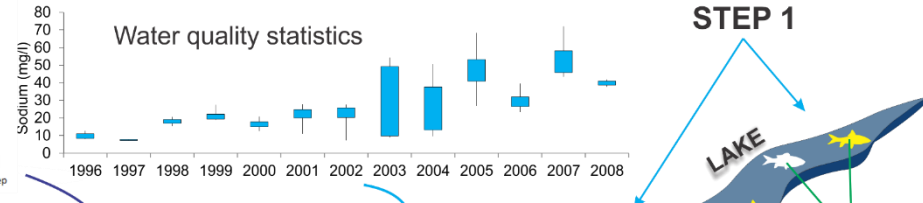
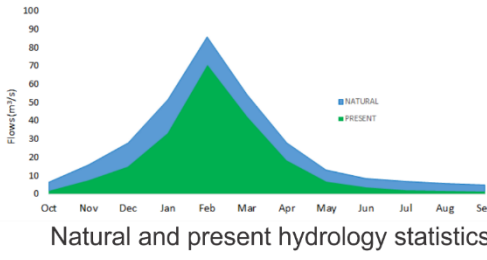
Built infrastructure



WHAT ARE ENVIRONMENTAL FLOWS?

Environmental flows describe the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, livelihoods, and wellbeing.
Brisbane declaration of environmental flows (Arthington et al., 2018)





Upstream - downstream linked Bayesian Networks representing risk of multiple stressors to endpoints

XX✓



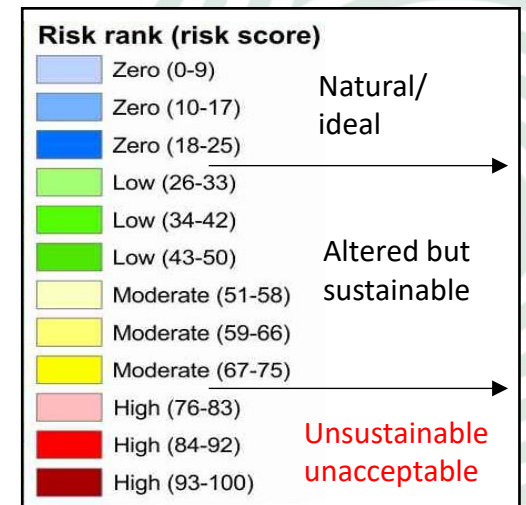
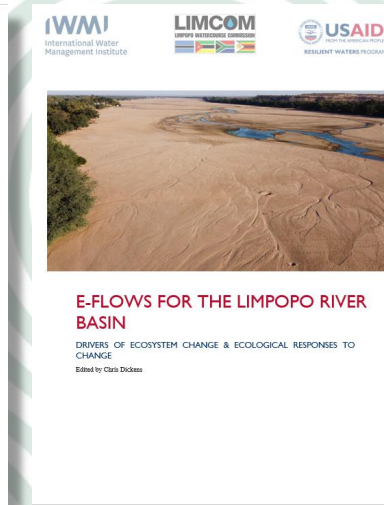
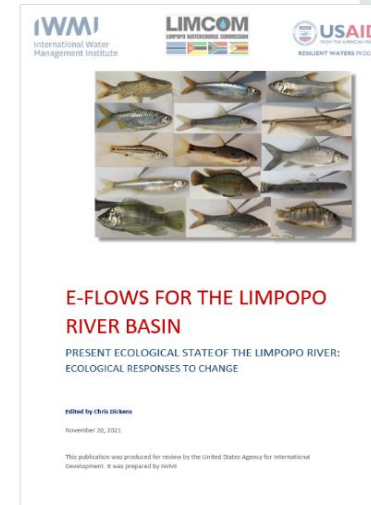
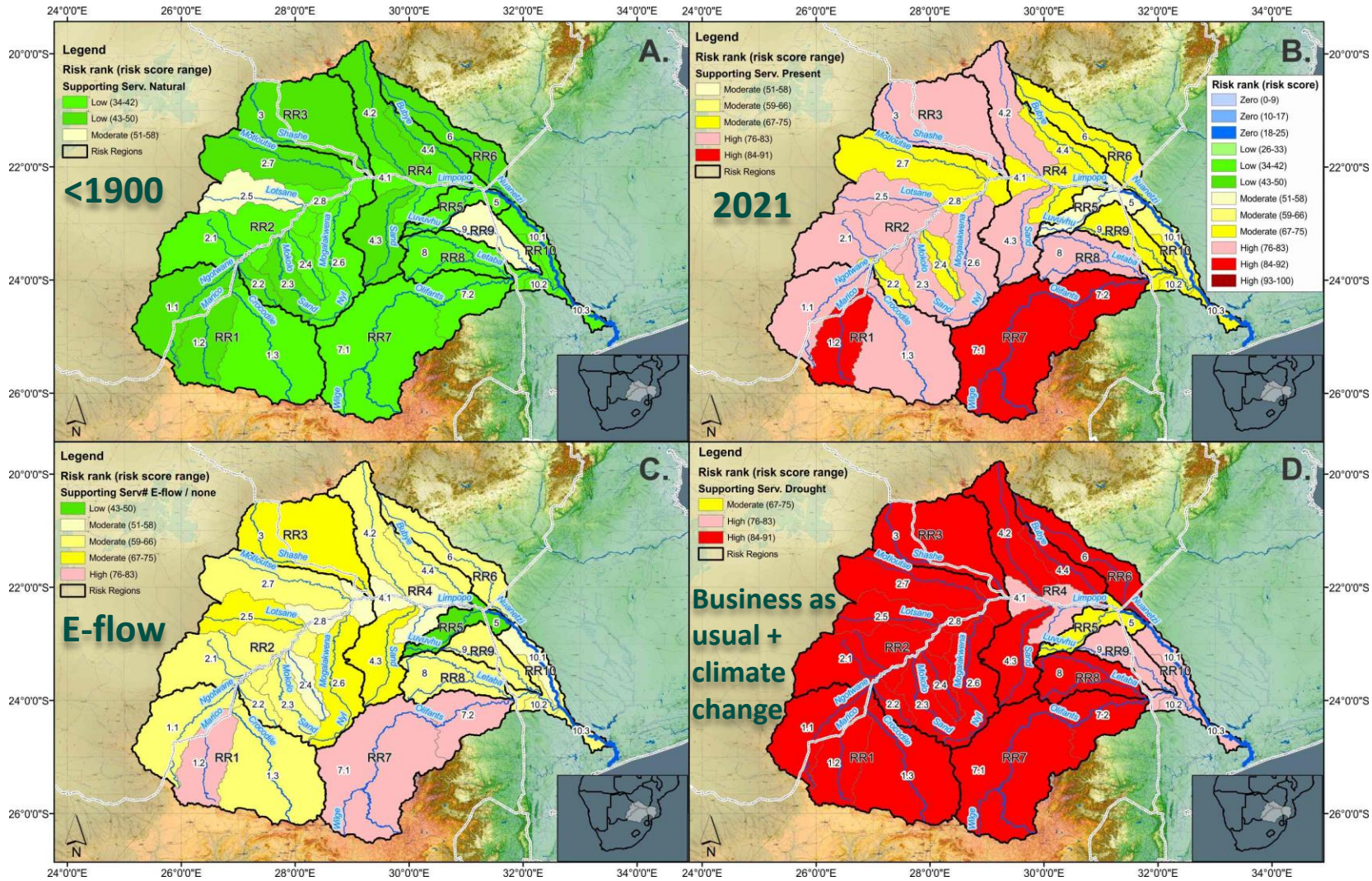
Rivers	E-flow site	nMAR (10 ⁶ m ³)	%Drought	%Baseflows	%Floods	%Total
Crocodile River	CROC-A24J-ROOIB	596	9.48	25.73	9.37	35.09
Limpopo River	LIMP-A41D-SPANW	591	6.31	24.67	12.4	37.07
Matlabas River	MATL-A41D-WDRAAI	40	1.04	10.64	39.23	49.86
Lephalale River	LEPH-A50H-SEEKO	142	8.79	18.09	21.02	39.11
Limpopo River	LIMP-A36C-LIMPK	801	3.03	23.15	11.35	34.51
Mogalakwena River	MOGA-A36D-LIMPK	243	13.98	19.24	17.82	37.06
Shashe River	SHAS-Y20B-TULIB	687	0	5.33	11.96	17.29
Limpopo River	LIMP-A71L-MAPUN	1684	2.6	16.15	8.12*	24.27 [#]
				>2000 m ³ /s (3-5year flood for >7 days).		
Umzingwani River	UMZI-Y20C-BEITB	438	0	4.74	15.5	20.23
Sand River	SAND-A71K-R508B	74	0	9.02	23.41	32.43
Luvuvhu River	LUVU-A91K-OUTPO	560	12.29	24.1	15.97	40.06
Mwenedzi River	MWEN-Y20H-MALAP	412				
Limpopo River	LIMP-Y30D-PAFUR	2792	1.16	10.46	1.63*	12.08 [#]
				>2000 m ³ /s (3-5year flood for >7 days).		
Shingwedzi River	SHIN-B90H-POACH	87	0.93	15.57	16.34	31.91
Groot Letaba River	GLET-B81J-LRANC	441	***	***	***	42.53**
Olifants River	OLIF-B73H-BALUL	1918	10.01	17.72	3.34	21.06
Elefantes River	ELEP-Y30C-SINGU	2552	5.52	15.65	3.56*	19.21 [#]
				>500 m ³ /s (3-5year flood for >5 days).		
Limpopo River	LIMP-Y30F-CHOKW	5572	2.57	10.69	5.08*	15.77 [#]
				>1600 m ³ /s (3-5year flood for >7 days).		

Note (*) E-flow models only provide annual floods but for these sites in the Limpopo River main stem important multi-year or 1:3 or 1:5 year floods are included.

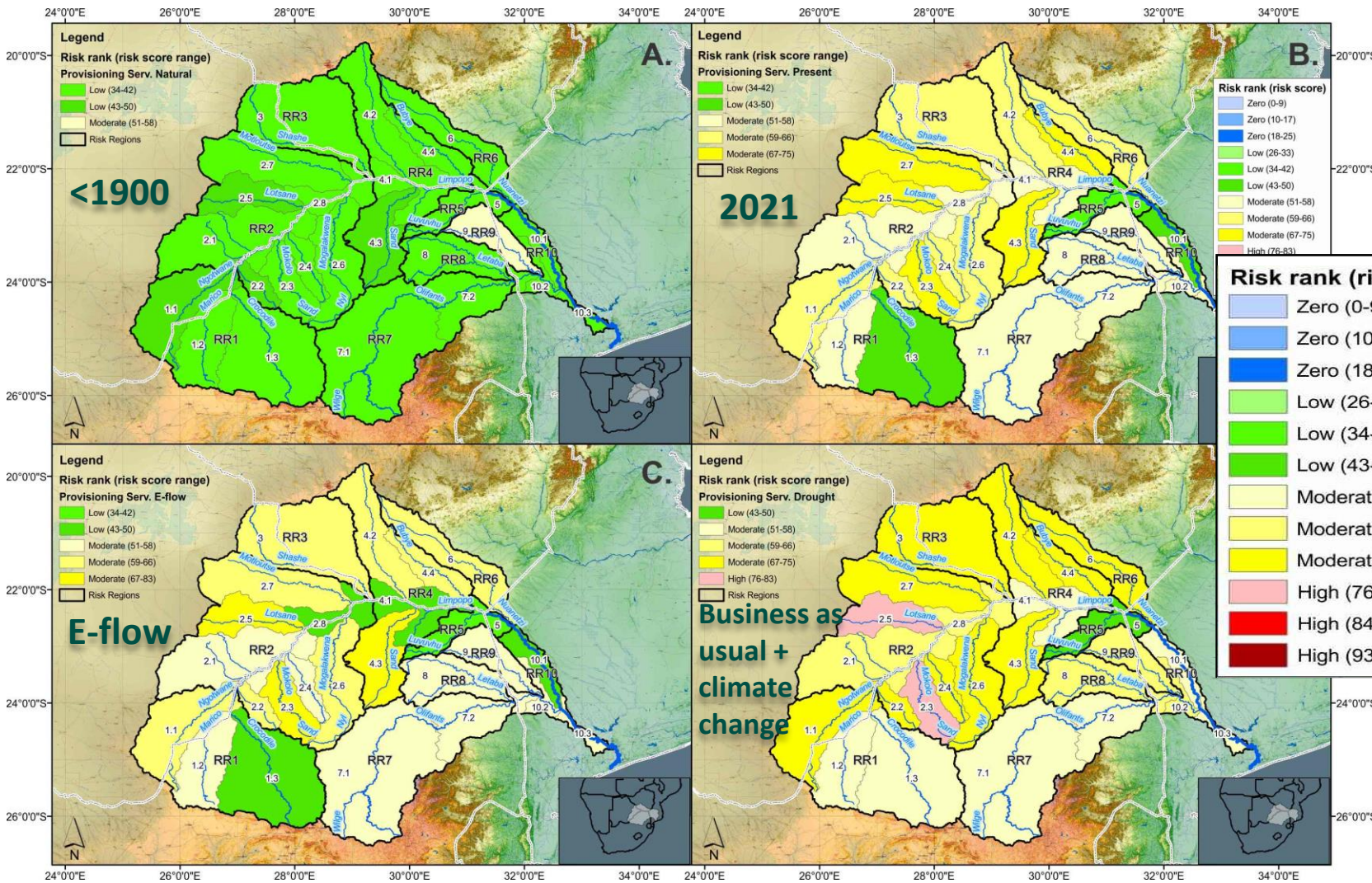
(**) data from Department of Water and Sanitation reserve study limited to total MAR% consider appendix (Table 7 29) for more detail.

(***) no data available

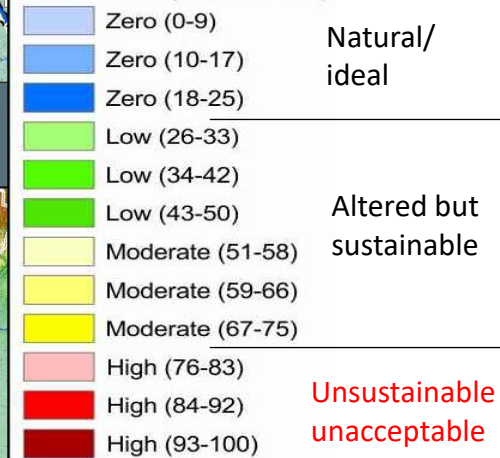
Risk of multiple stressors to the supporting services (ecosystem attributes) of the Limpopo Basin.



Risk of multiple stressors to the provisioning services of the Limpopo Basin.



Risk rank (risk score)



E-FLOWS FOR THE LIMPOPO RIVER BASIN

DRIVERS OF ECOSYSTEM CHANGE & ECOLOGICAL RESPONSES TO CHANGE
 Edited by Chris Dickens

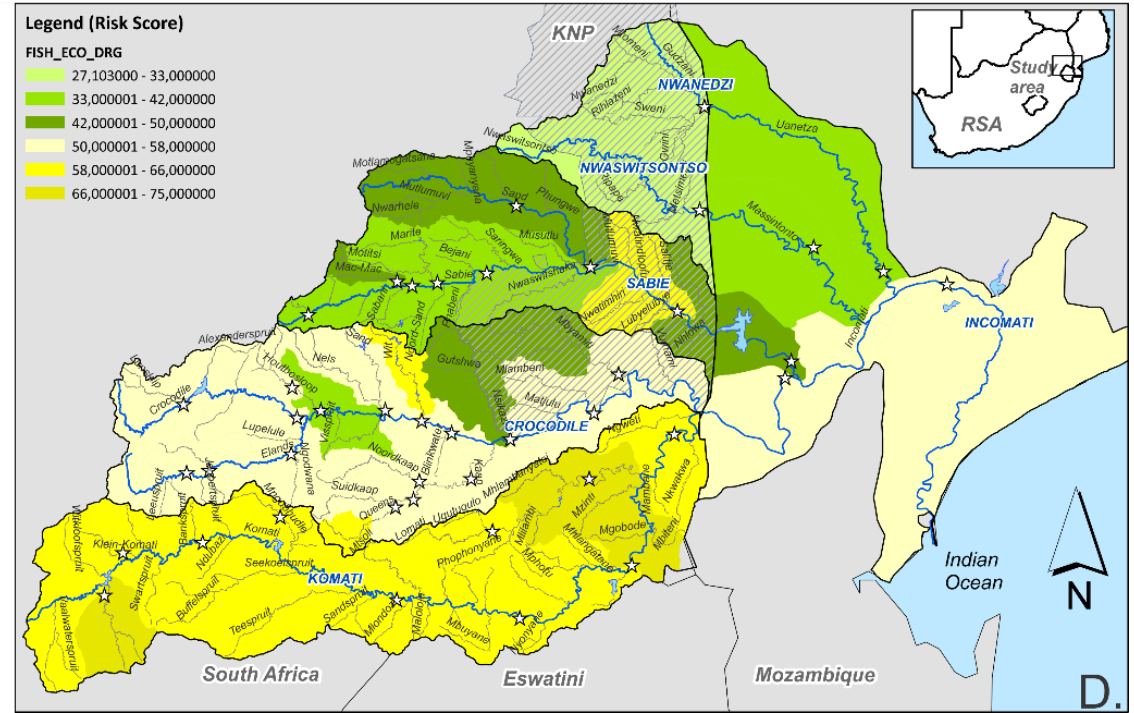
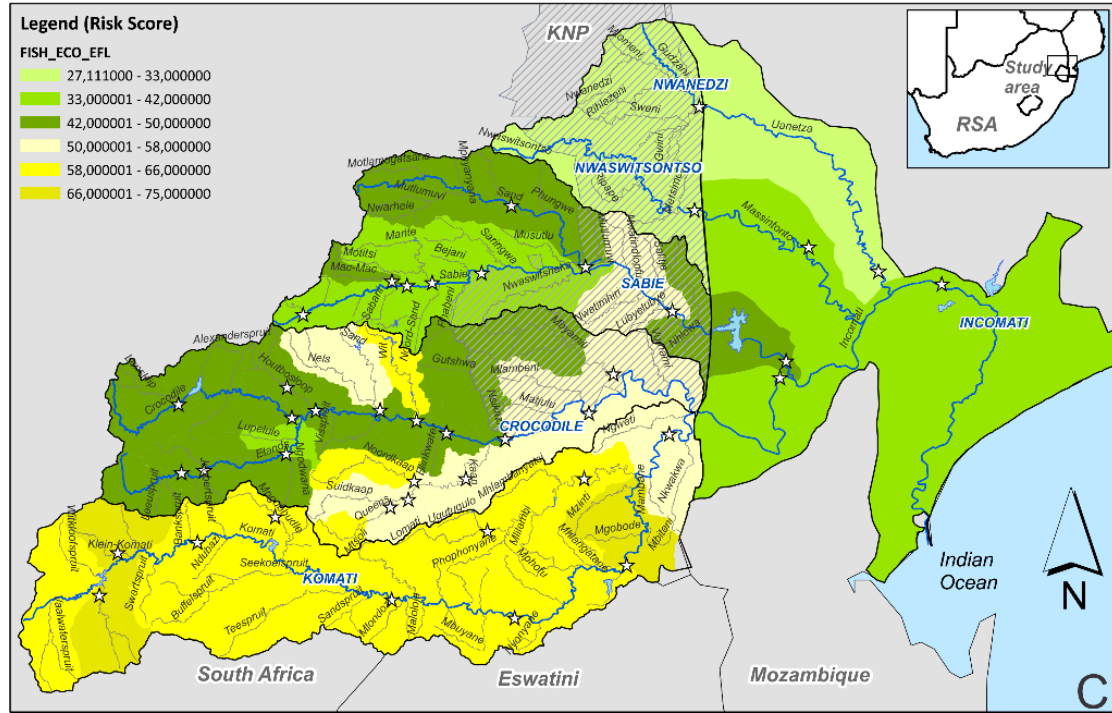
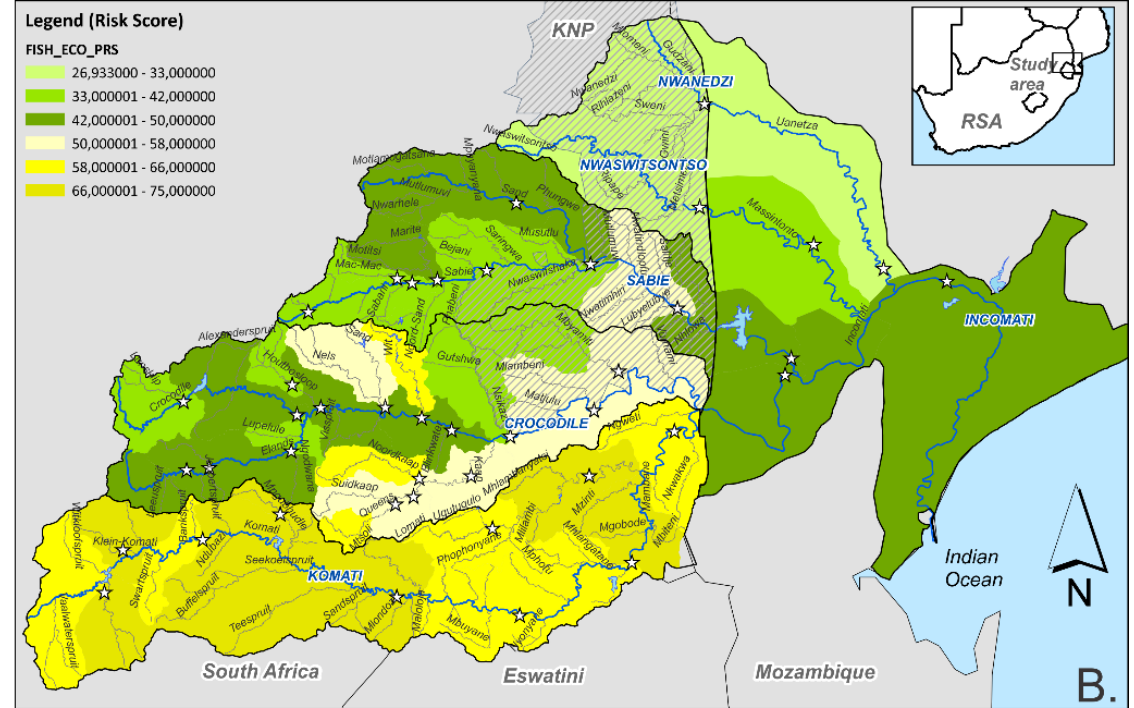
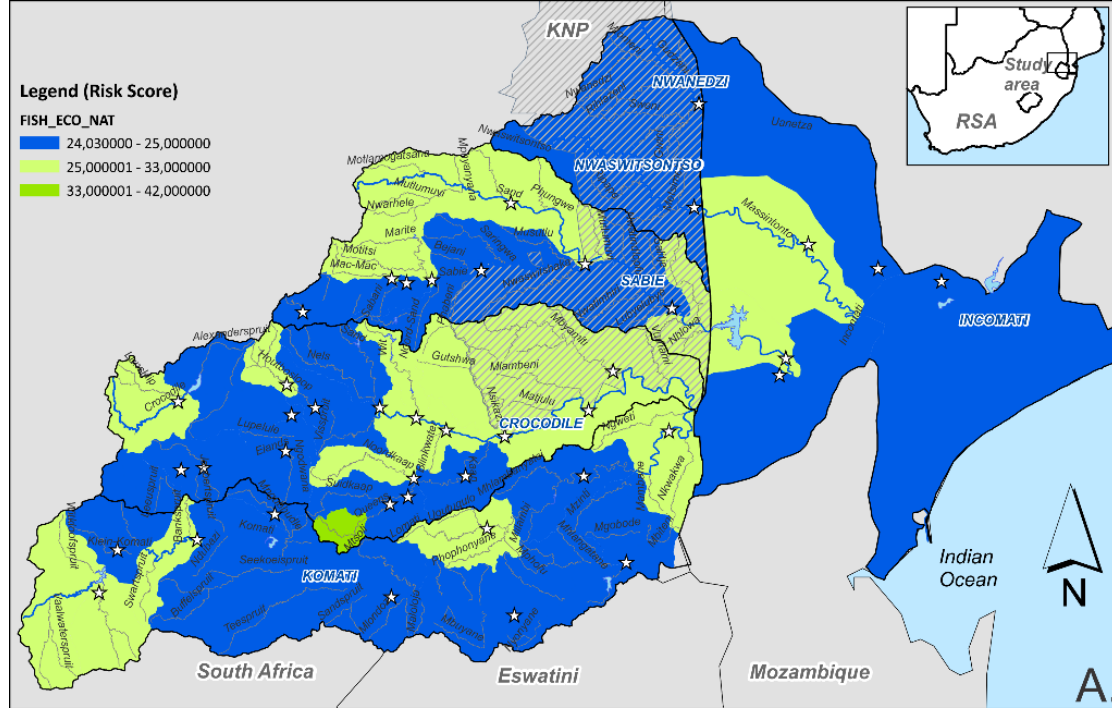


E-FLOWS FOR THE LIMPOPO RIVER BASIN

PRESENT ECOLOGICAL STATE OF THE LIMPOPO RIVER:
 ECOLOGICAL RESPONSES TO CHANGE

edited by Chris Dickens
 November 20, 2021

This publication was produced for review by the United States Agency for International Development. It was prepared by IWMI.



**Are we implementing our
ecological reserves?**

**And are they contributing to
aquatic biodiversity conservation?**

We can do more...

ORIGIN OF THE HIGH REGIONAL AQUATIC BIODIVERSITY OF THE LIMPOPO RIVER BASIN

J. Stankiewicz, M.J. de Wit / Journal of African Earth Sciences 44 (2006) 75–84

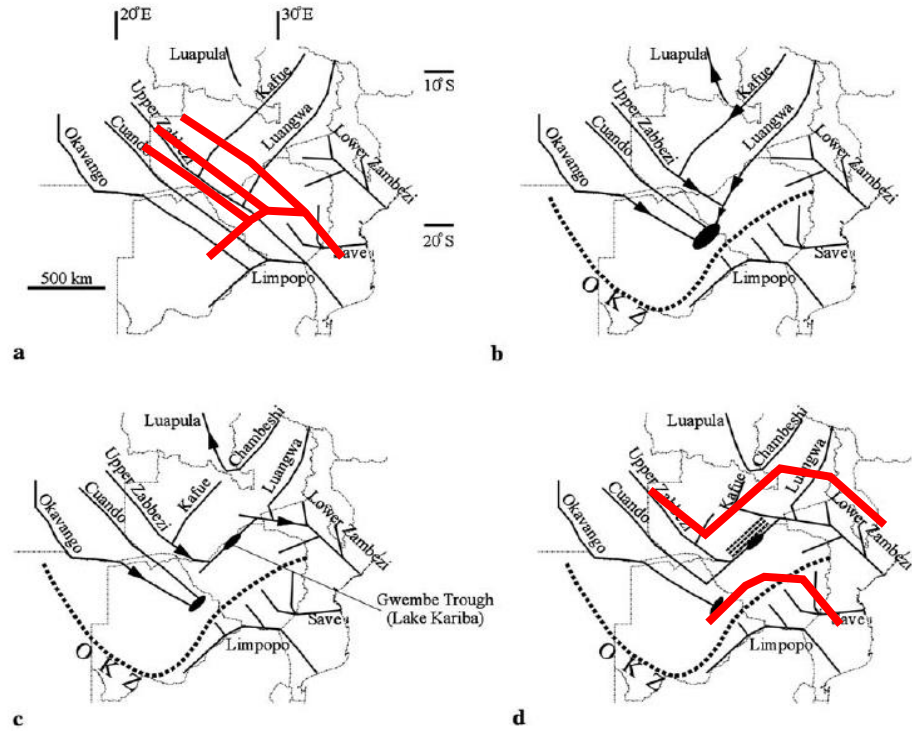
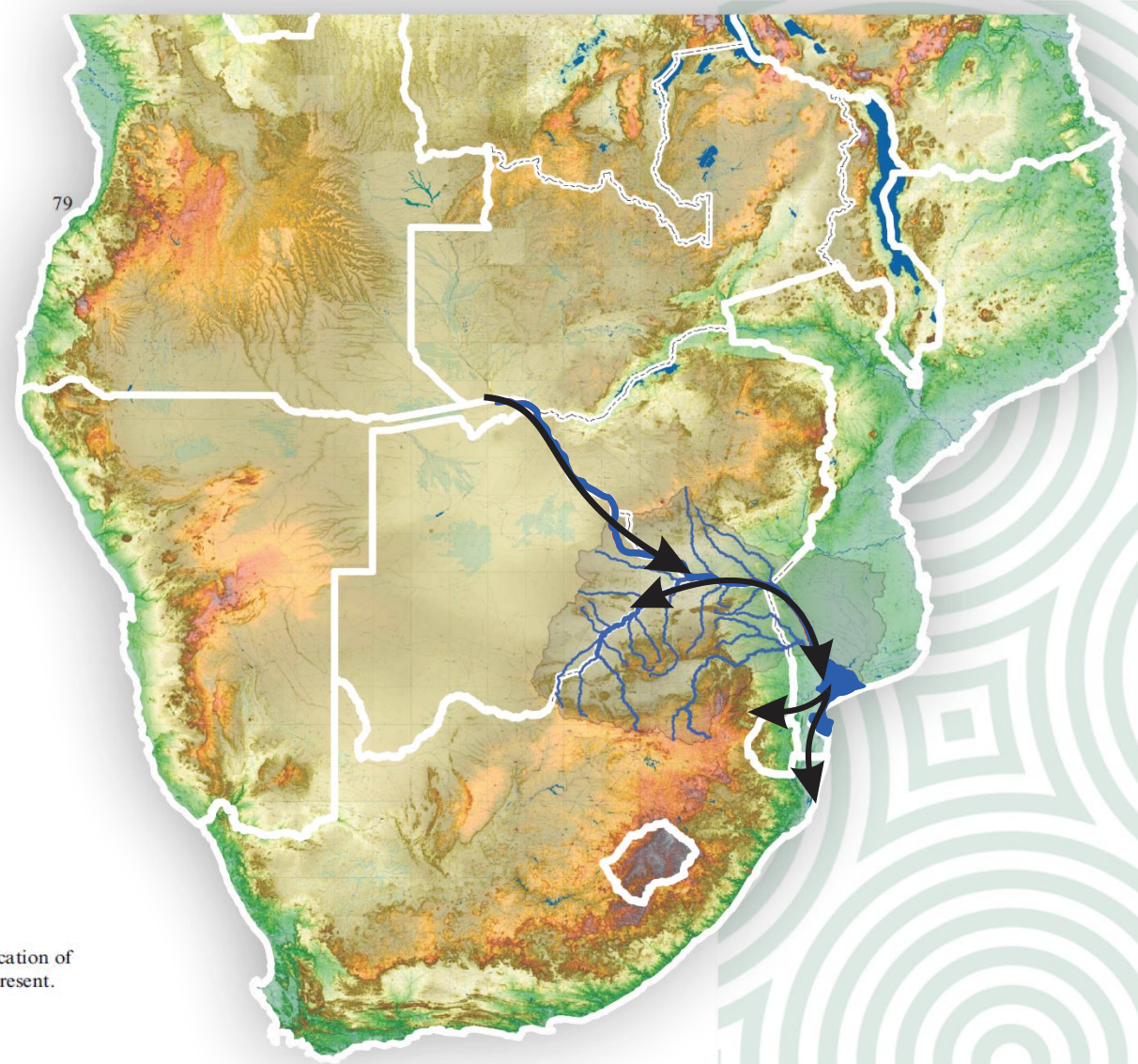


Fig. 4. Drainage evolution model of the Zambezi–Okavango–Limpopo south of the Congo Basin (modified from Moore and Larkin, 2001). Location of sections in Fig. 7 is marked as dashed bold lines in (d). (a) Cretaceous (>65 Ma), (b) Paleocene (34–65 Ma), (c) Pleistocene (~1 Ma) and (d) present.





POPULATION LOSS



RED LIST
< ENDANGERED >
EN



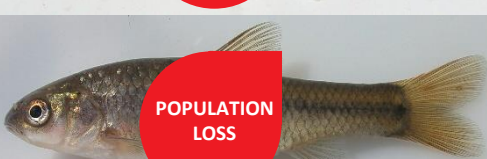
THREATENED OR PROTECTED
TOPS



POPULATION LOSS



POPULATION LOSS



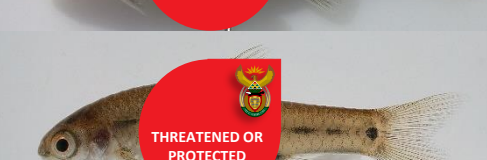
POPULATION LOSS



RED LIST
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POPULATION LOSS



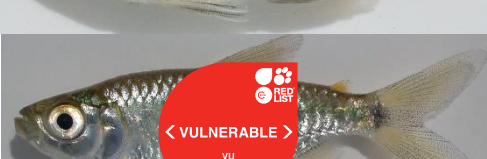
THREATENED OR PROTECTED
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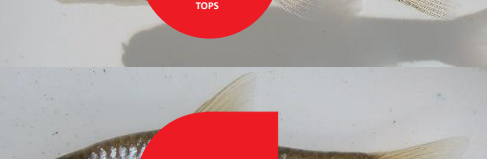
RED LIST
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POPULATION LOSS



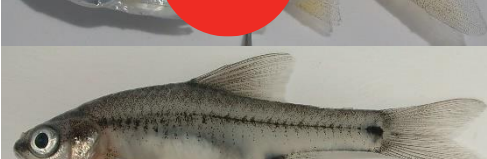
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POPULATION LOSS



POPULATION LOSS



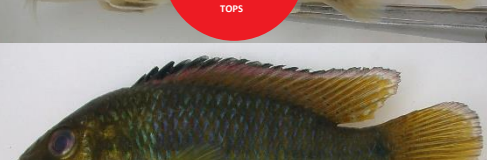
THREATENED OR PROTECTED
TOPS



RED LIST
< CRITICALLY ENDANGERED >
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POPULATION LOSS



POPULATION LOSS



POPULATION LOSS

Regional river connectivity and fish migrations – key requirement of health ecosystems.



African tigerfish
Hydrocynus vittatus



Red-eye labeo
Labeo cylindricus



Incomati suckermouth
Chiloglanis bifurcus

Free-flowing river status
Free-flowing rivers (CSI > 95%)
VL L M S

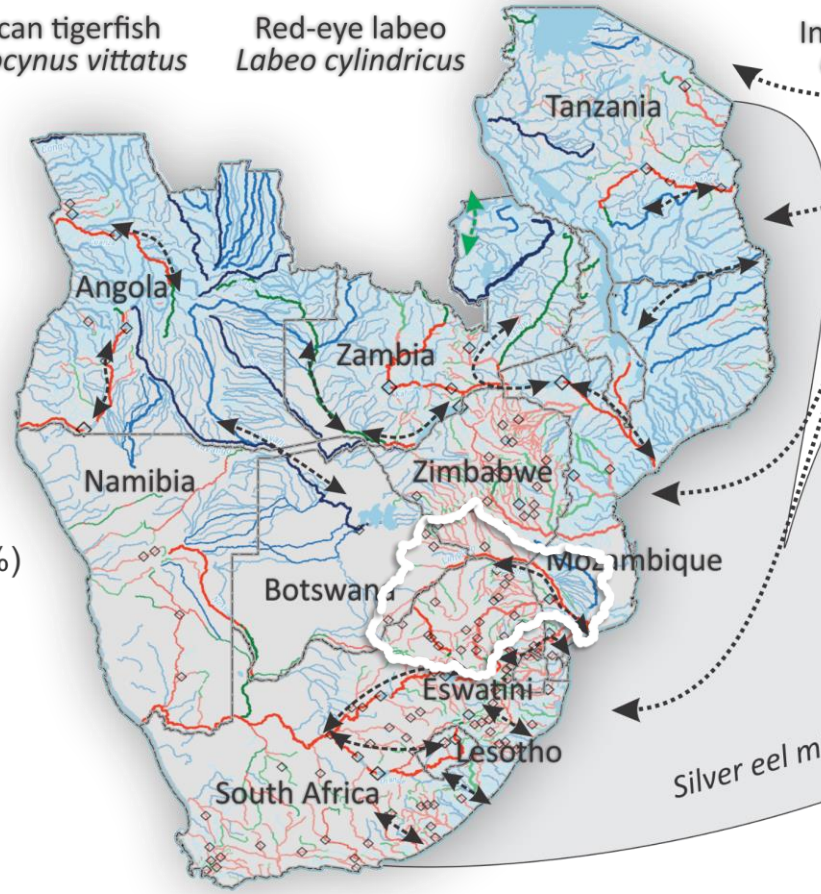
Good connectivity (CSI > 95%)
VL L M S

Connectivity below threshold (CSI < 95%)
VL L M S

VL: Very Long length (>1000km)
L: Long length (500 - 1000km)
M: Medium length (100 - 500km)
S: Short length (>500km)

◇ Large dams

↔ Potadromous fish migration routes



Glass eel drift/migration route
Eel spawning area

Silver eel migration route



Longfin eel
Anguilla mossambica

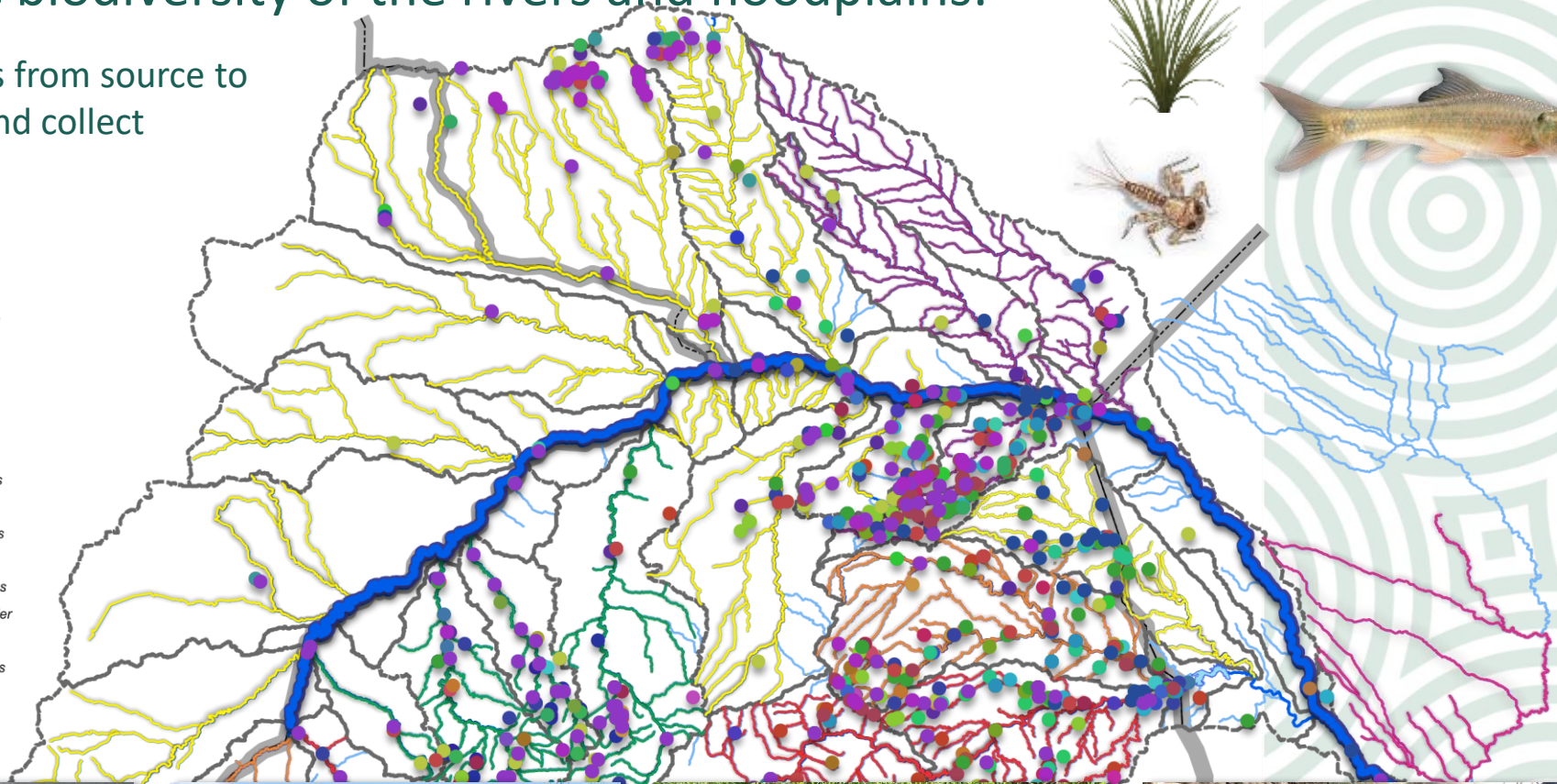
LIMPOPO RIVER FISH BIODIVERSITY – NATURAL DISTRIBUTIONS

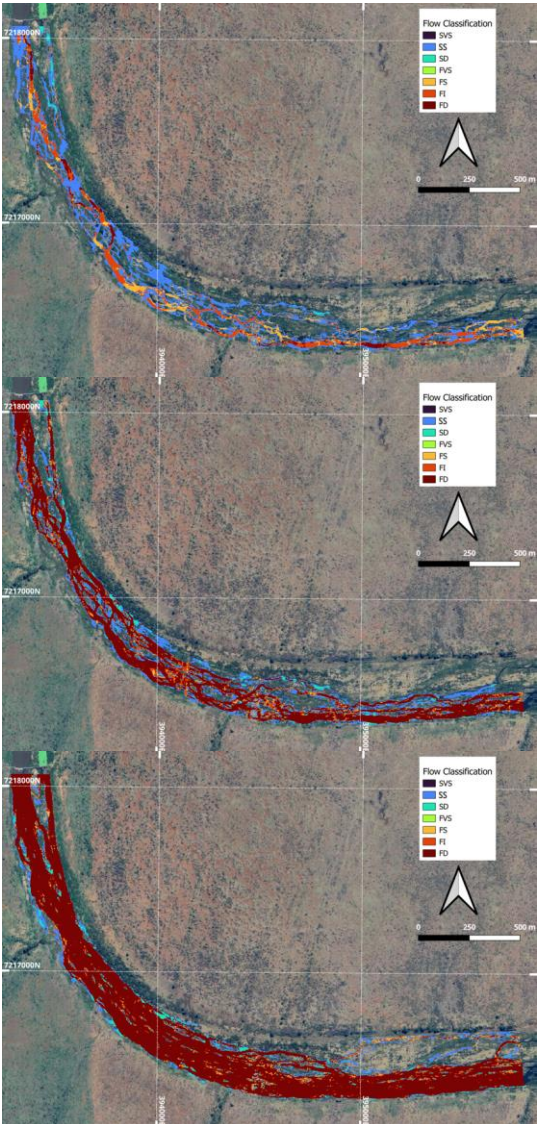
Characterise the aquatic biodiversity of the rivers and floodplains:

- Extensive sampling of rivers from source to sea to assess biodiversity and collect voucher data for eDNA.

LIMPOPO RIVER FISHES

● <i>Amphilius natalensis</i>	● <i>Enteromius trimaculatus</i>	● <i>Labeo rosae</i>
● <i>Amphilius uranoscopus</i>	● <i>Enteromius unitaeniatus</i>	● <i>Labeo ruddi</i>
● <i>Anguilla bengalensis labiata</i>	● <i>Enteromius viviparus</i>	● <i>Labeo umbratus</i>
● <i>Anguilla mossambica</i>	● <i>Brycinus imberi</i>	● <i>Labeobarbus marequensis</i>
● <i>Aplocheilichthys johnstoni</i>	● <i>Chetia flaviventris</i>	● <i>Labeobarbus polylepis</i>
● <i>Aplocheilichthys katangae</i>	● <i>Chiloglanis paratus</i>	● <i>Marcusenius pongolensis</i>
● <i>Awaous aeneofuscus</i>	● <i>Chiloglanis pretoriae</i>	● <i>Mesobola brevianalis</i>
● <i>Enteromius afrohamiltoni</i>	● <i>Chiloglanis swierstrai</i>	● <i>Micralestes acutidens</i>
● <i>Enteromius annectens</i>	● <i>Clarias gariepinus</i>	● <i>Nothobranchius furzeri</i>
● <i>Enteromius anoplus</i>	● <i>Clarias ngamensis</i>	● <i>Nothobranchius orthonotus</i>
● <i>Enteromius lineomaculatus</i>	● <i>Clarias theodorae</i>	● <i>Opsaridium peringueyi</i>
● <i>Enteromius motebensis</i>	● <i>Ctenopoma multispine</i>	● <i>Oreochromis mossambicus</i>
● <i>Enteromius paludinosus</i>	● <i>Glossogobius callidus</i>	● <i>Petrocephalus wesselsi</i>
● <i>Enteromius radiatus</i>	● <i>Glossogobius giuris</i>	● <i>Pharyngochromis acuticeps</i>
● <i>Enteromius rapax</i>	● <i>Hydrocynus vittatus</i>	● <i>Pseudocrenilabrus philander</i>
● <i>Enteromius sp. 'Ohrigstad'</i>	● <i>Kneria sp. 'South Africa'</i>	● <i>Schilbe intermedius</i>
● <i>Enteromius sp. 'Waterberg'</i>	● <i>Labeo altivelis</i>	● <i>Serranochromis meridianus</i>
● <i>Enteromius sp. 'neefi cf. SA'</i>	● <i>Labeo congoro</i>	● <i>Synodontis zambezensis</i>
● <i>Enteromius treurenensis</i>	● <i>Labeo cylindricus</i>	● <i>Tilapia rendalli</i>
● <i>Enteromius toppini</i>	● <i>Labeo molybdinus</i>	● <i>Tilapia sparrmanii</i>



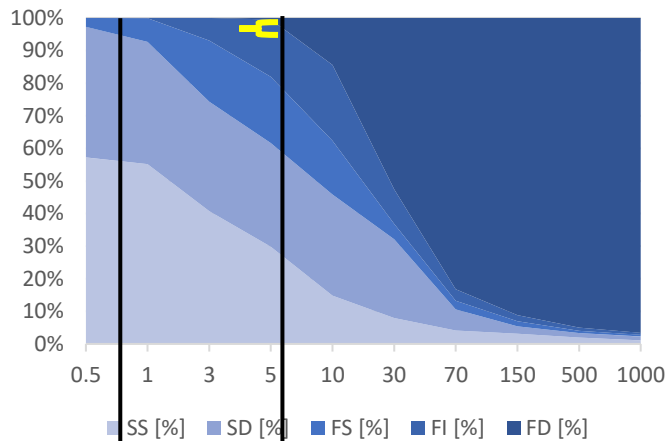
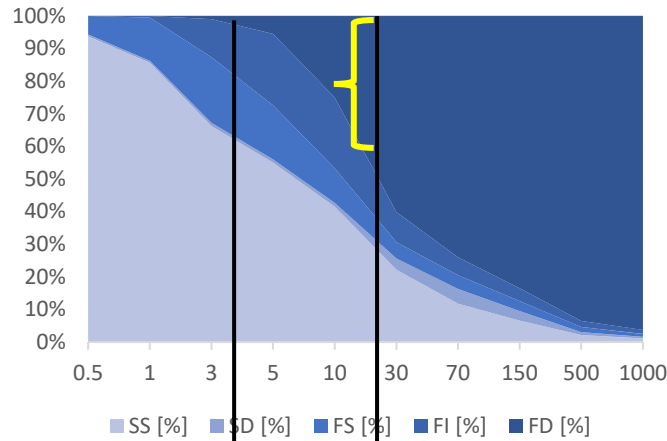


50% FD

1% FD

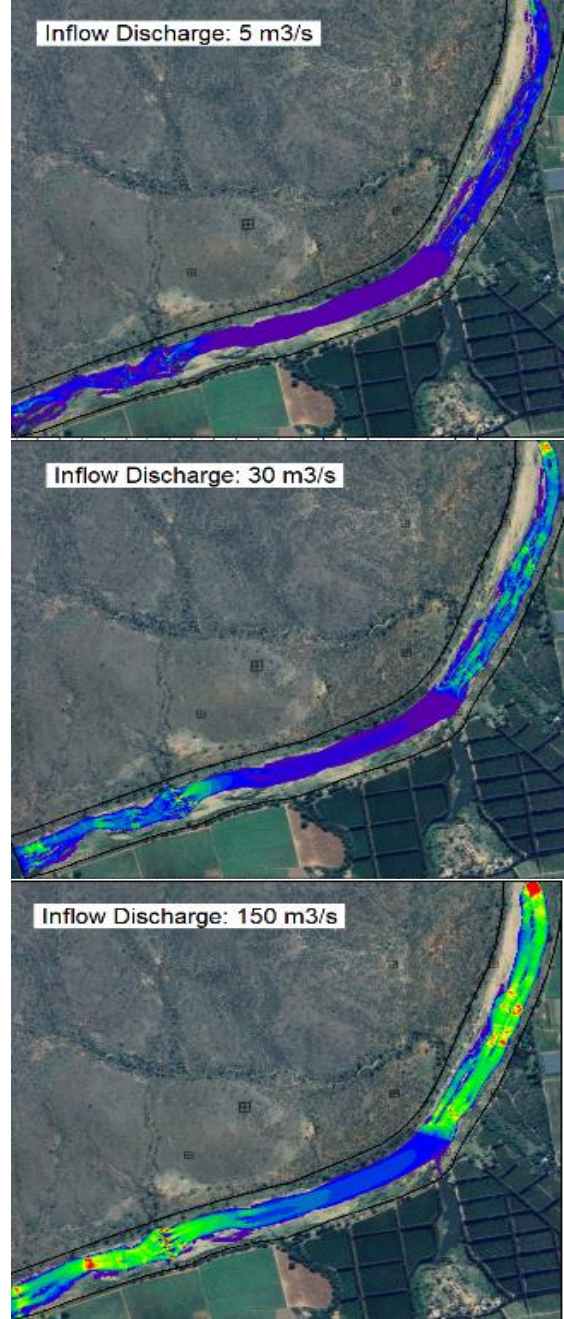
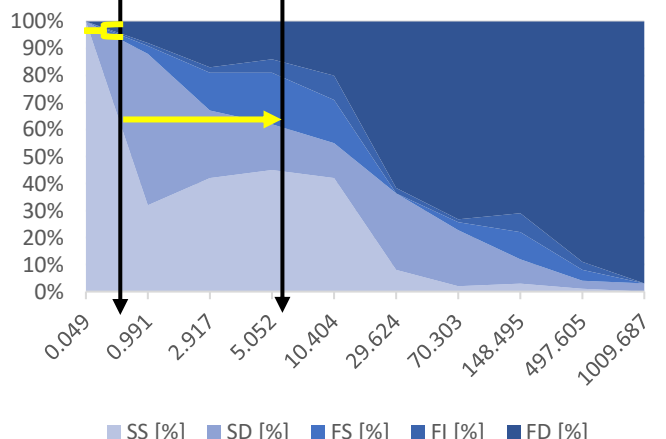
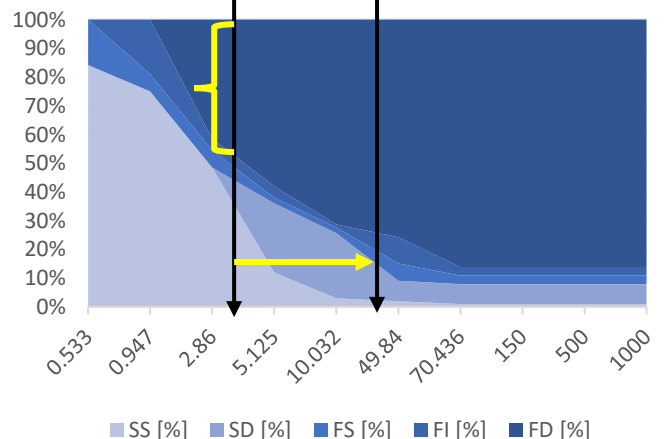
Sabie River 2D model

Crocodile River 2D model



Sabie River 1D model

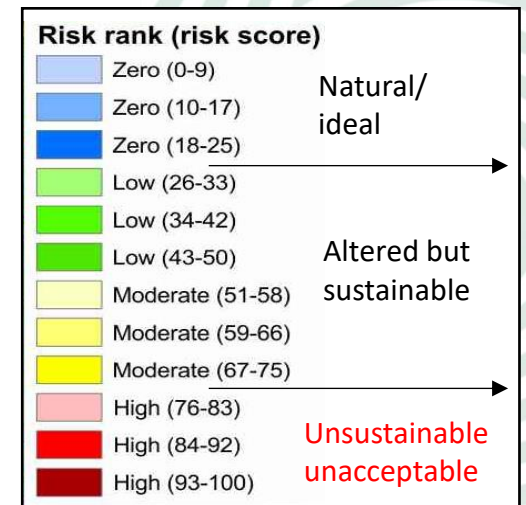
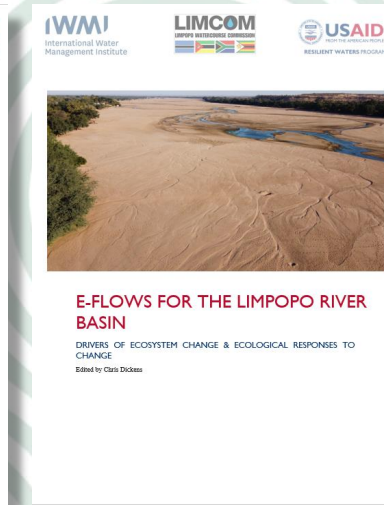
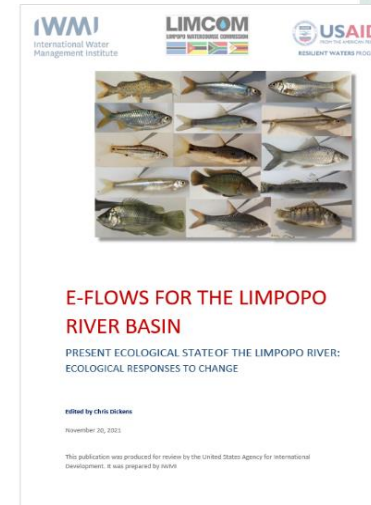
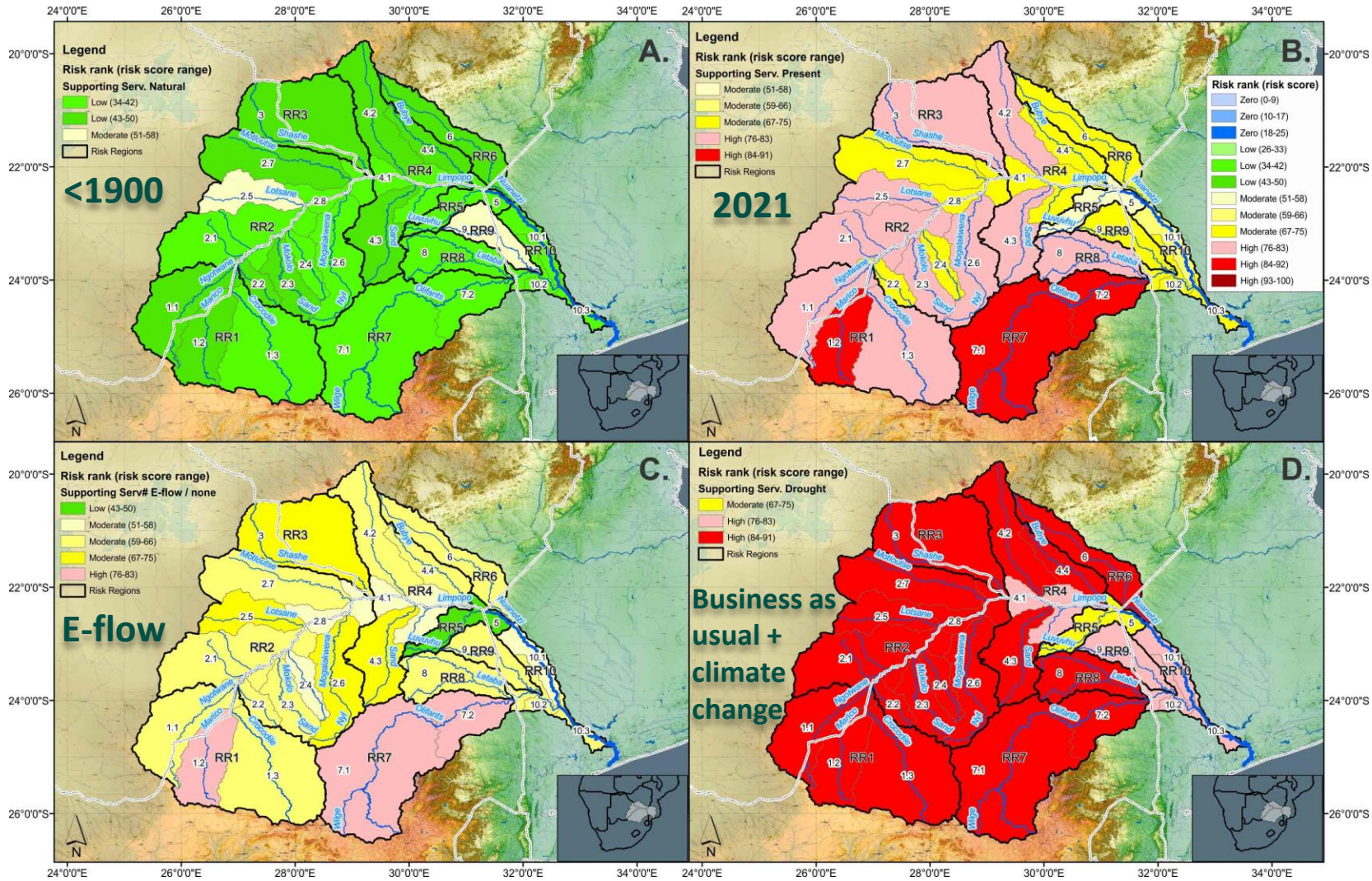
Crocodile River 1D Model



High social value – dependence on water resources.



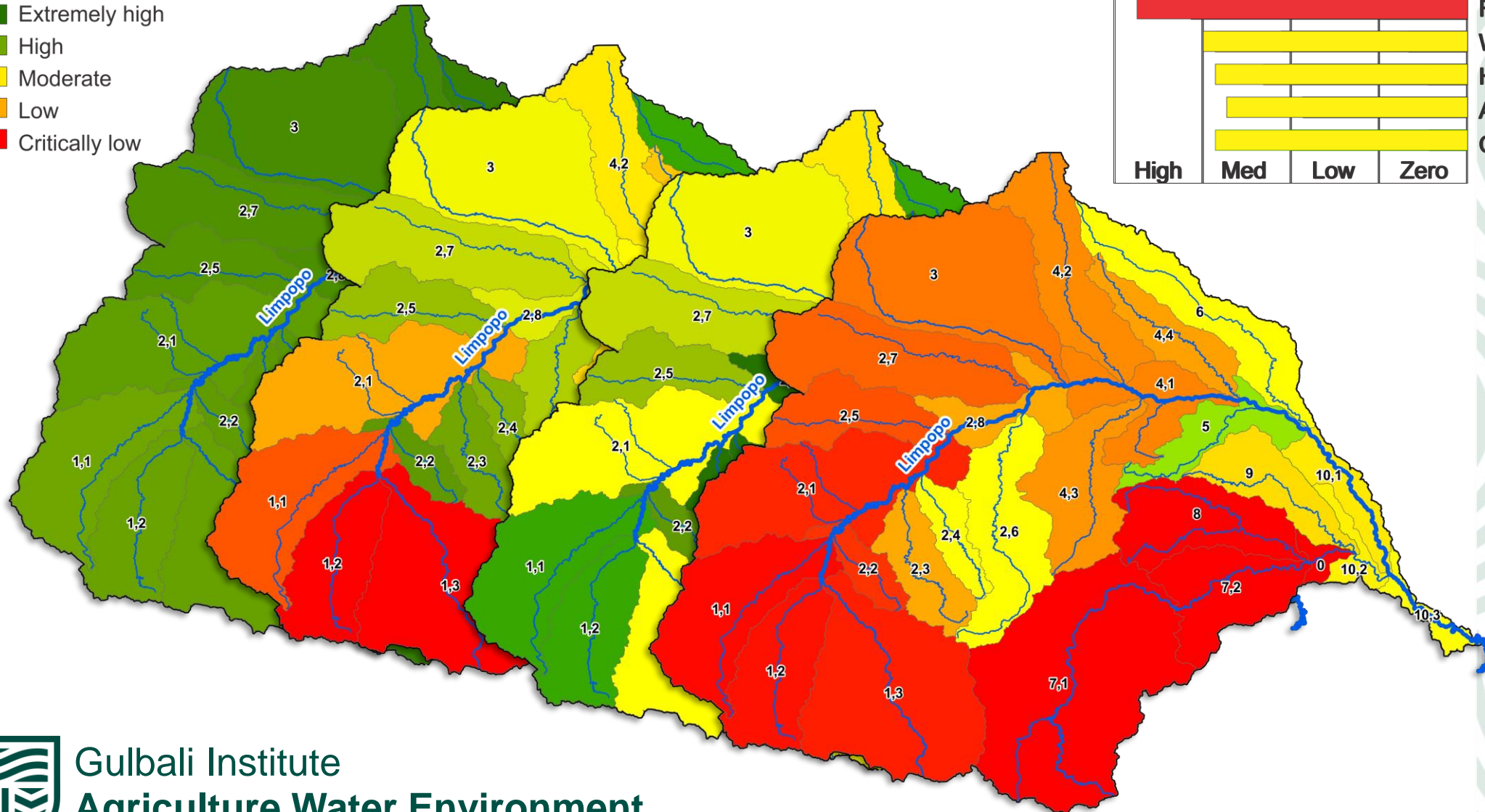
Risk of multiple stressors to the supporting services (ecosystem attributes) of the Limpopo Basin.



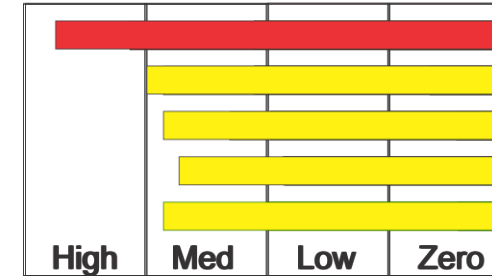
LIMPOPO RIVER – THREATS TO BIODIVERSITY

LEVELS OF BIODIVERSITY

- Extremely high
- High
- Moderate
- Low
- Critically low



STRESSORS



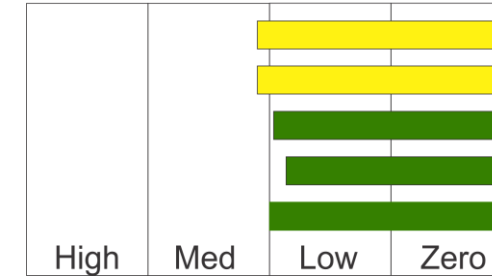
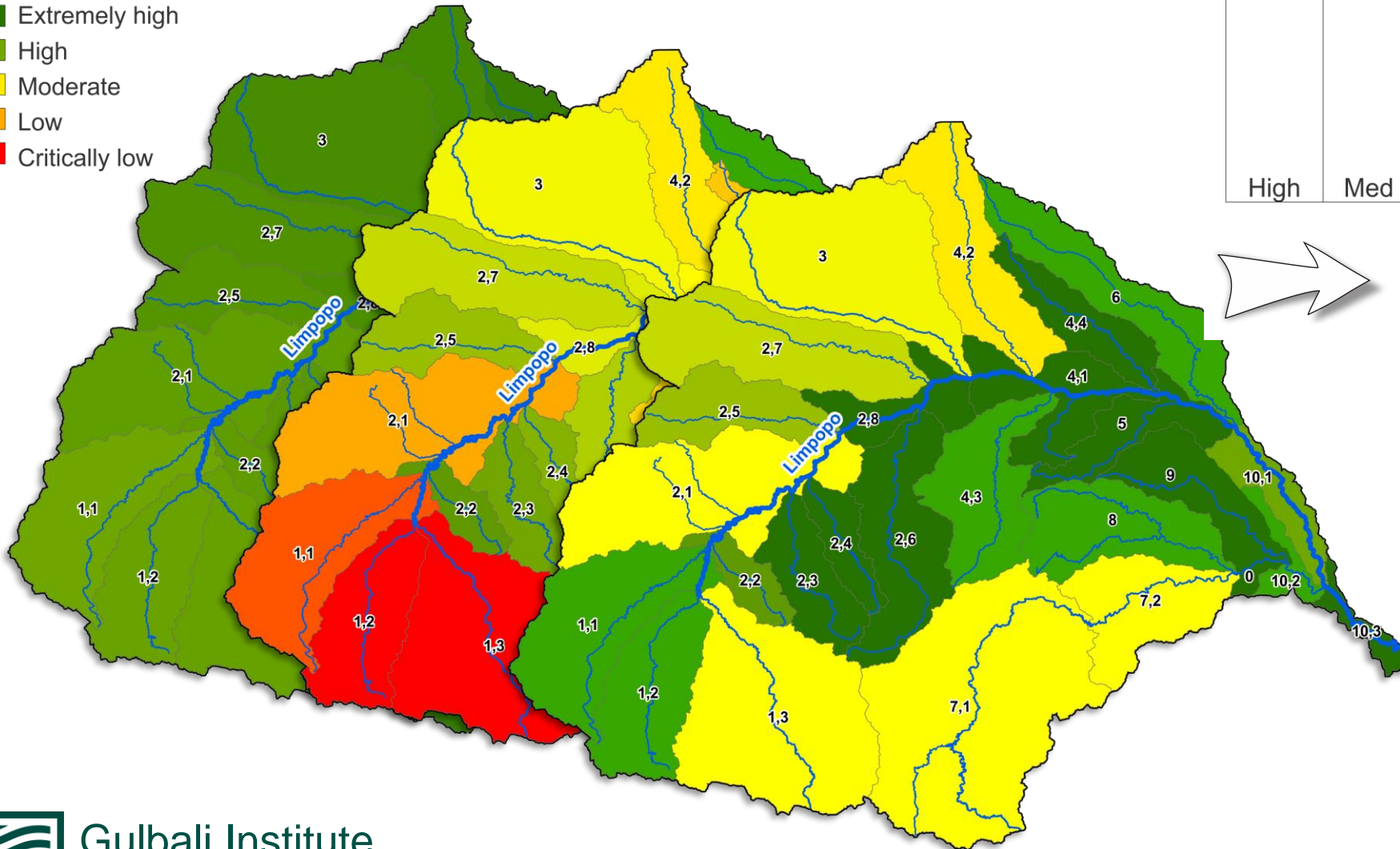
- Flow alterations
- Water quality alterations
- Habitat loss and barriers/dams
- Alien competition/predation
- Climate change



LIMPOPO RIVER – THREATS TO BIODIVERSITY

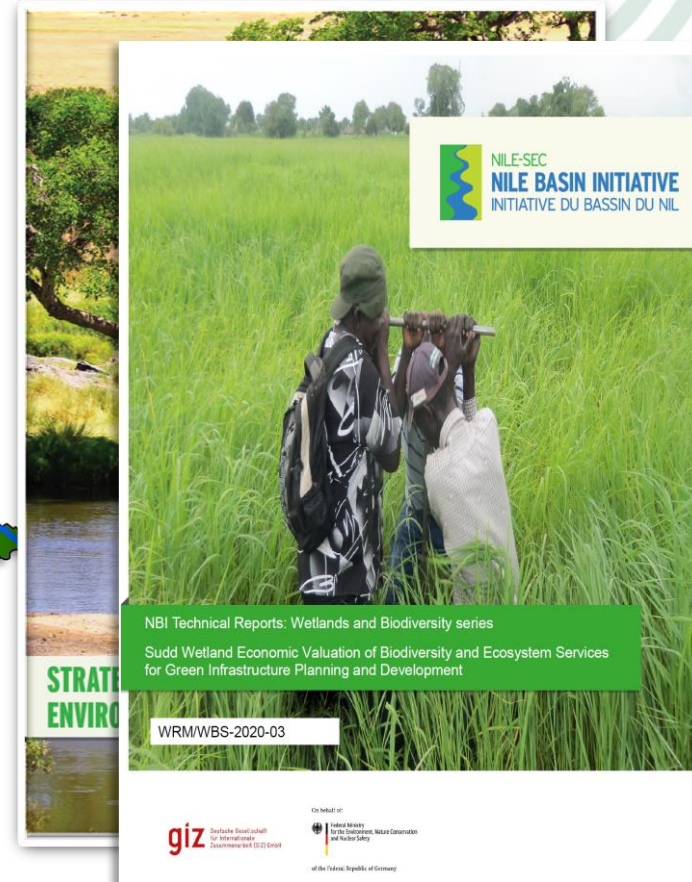
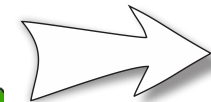
LEVELS OF BIODIVERSITY

- Extremely high
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STRESSORS

- Flow alterations
- Water quality alterations
- Habitat loss and barriers/dams
- Alien competition/predation
- Climate change





Charles Sturt
University

Gulbali Institute
Agriculture Water Environment

Sustainable management and protection of vulnerable African water resources through holistic environmental flow framework determination and implementation

O'Brien, G.C., Wade, M., Dickens, C and Wepener, V

22nd Savanna Science Network Meeting, Skukuza

TOP-DOWN WATER RESOURCE USE MANAGEMENT IN THE LIMPOPO BASIN

SADC sustainable water resource use legislation dominates water resource management

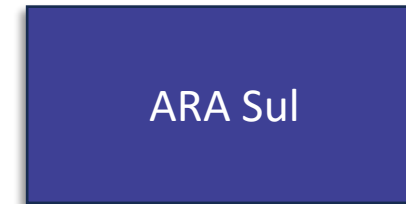
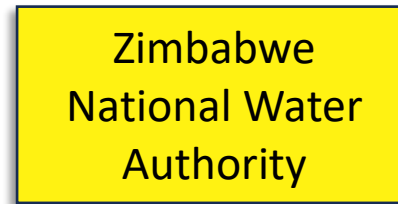


BOTSWANA

SOUTH AFRICA

ZIMBABWE

MOZAMBIQUE



USE MANAGEMENT
SUSTAINABILITY?



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BOTTOM UP CONSERVATION IN THE LIMPOPO BASIN

SADC Wildlife & conservation focus on EIAs & protected areas relies on water legislation



BOTSWANA

SOUTH AFRICA

ZIMBABWE

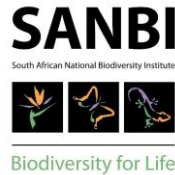
MOZAMBIQUE

Dept. Of Wildlife
& National Parks

Environmental Affairs

Parks and Wildlife
Management

Coordination of
Environmental Affairs



Biodiversity &
Ecosystems

EIAs

Conservation
plans

Protected areas

Authorisations



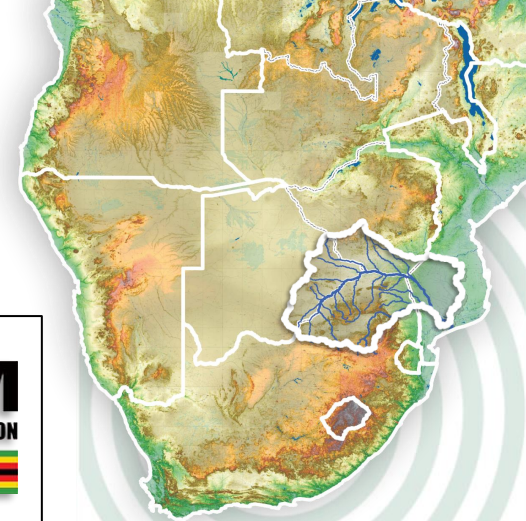
CONSERVATION ORG.
SUSTAINABILITY?



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WATER RESOURCE SUSTAINABILITY PLAN FOR THE LIMPOPO

BOTSWANA SOUTH AFRICA ZIMBABWE MOZAMBIQUE



LIMCOM
LIMPOPO WATERCOURSE COMMISSION

Policy
Agreements
Best practice
Structures

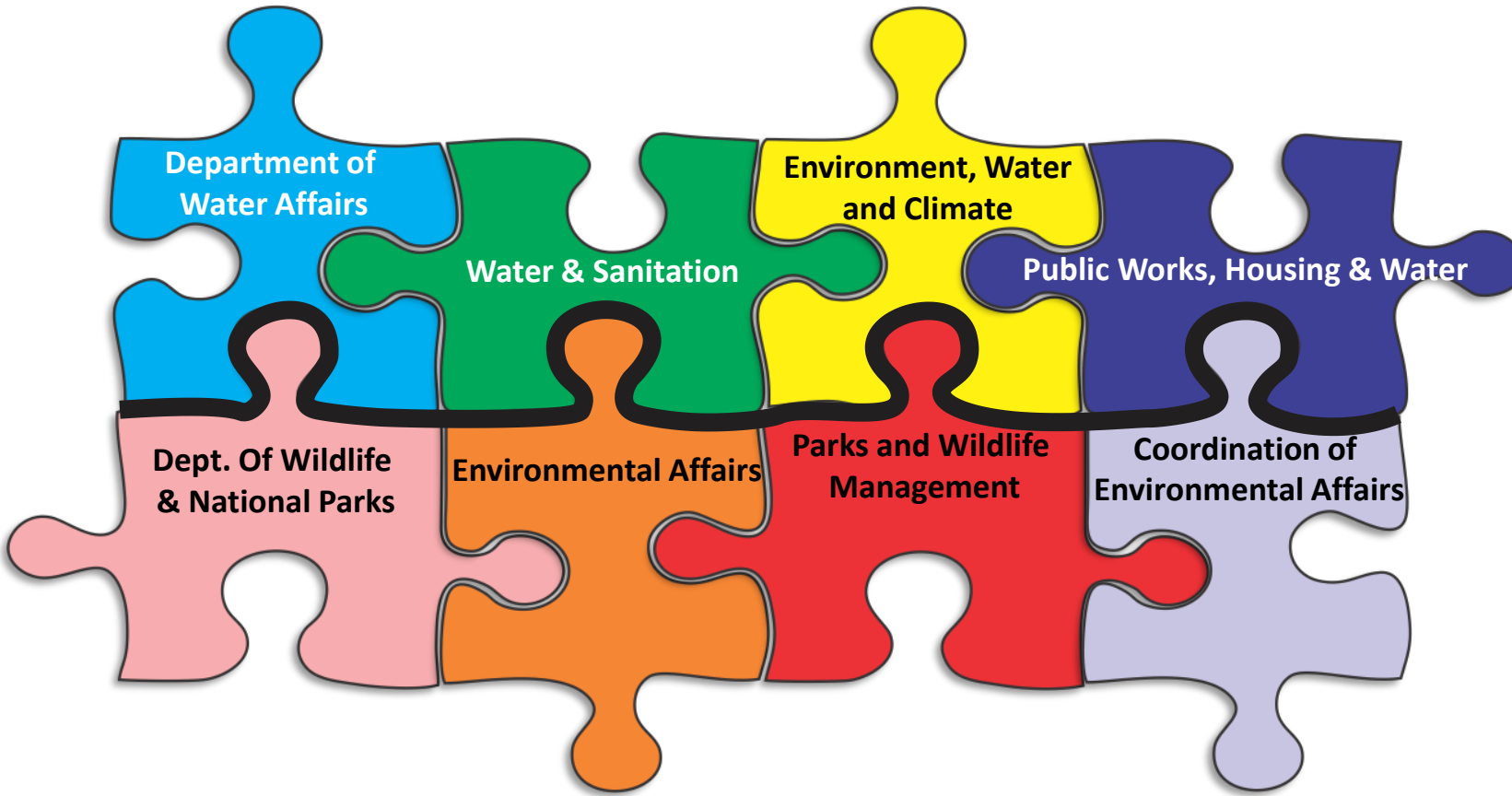
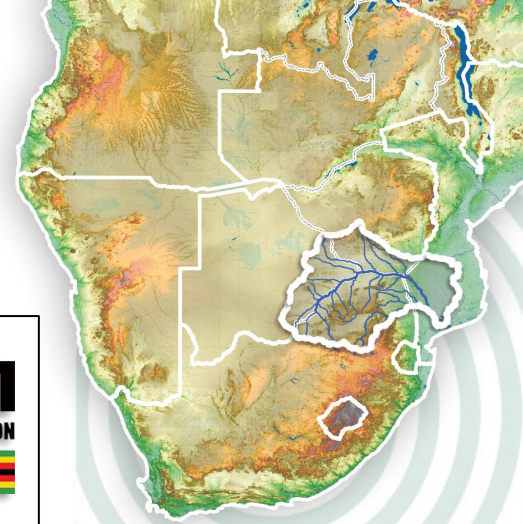


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WATER RESOURCE SUSTAINABILITY PLAN FOR THE LIMPOPO

BOTSWANA SOUTH AFRICA ZIMBABWE MOZAMBIQUE



LIMCOM
LIMPOPO WATERCOURSE COMMISSION

Policy
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USE MANAGEMENT
CONSERVATION ORG.
SUSTAINABILITY



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