E-FLOWS FOR THE LIMPOPO RIVER BASIN:

RISK OF ALTERED FLOWS TO THE ECOSYSTEM SERVICES

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(Submitted in fulfilment of Milestone 10: Draft E-flows Synthesis Report)

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Limpopo River Commission, Mozambique

Rivers of Life located in the University of Mpumalanga, South Africa

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This specific project undertaken by IWMI was titled *Environmental flows for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources*

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Below is the list of Project Reports. This report is highlighted

Report number	Report title E-FLOWS FOR THE LIMPOPO RIVER BASIN:
1	Inception Report
2	Basin Report
3	From Vision to Management
4	Specialist Literature and Data Review
5	Present Ecological State - Drivers of Ecosystem Change
6	Present Ecological State - Ecological Response to Change
7	Environmental Flow Determination
8	Risk of Altered Flows to the Ecosystem Services

Cover photo: The Limpopo River, May 2021. Picture G. Diedericks

SUMMARY

PROJECT TITLE:

E-flows for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources

REPORT TITLE:

E-flows for the Limpopo River Basin: Risk of Altered Flows to the Ecosystem Services

PROJECT OBJECTIVES:

This project will provide the necessary evidence to secure environmental flows (e-flows) for increasing the resilience of communities and ecosystems in the Limpopo Basin to changes in stream-flow resulting from basin activities and climate change.

TERMS OF REFERENCE:

USAID has funded Chemonics to implement the Resilient Waters Program. In turn this project was a response to a Grant call that had as its overall goal "*to build more resilient communities and ecosystems through improved management of transboundary natural resources……*".

The International Water Management Institute (IWMI) was commissioned by Resilient Waters to undertake a project titled: *Environmental flows (e-flows) for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources*. The study incorporated the PROBFLO method to determine e-flows and eveluate the risk of altered flows and non-flow variables to the ecosystems services in the Limpopo Basin. The project has resulted in two final reports including:

- Environmental flow determination in the Limpopo Basin.
- Risk of altered flows to the ecosystems services of the Limpopo Basin.

This report presents the "*Risk of Altered Flows to the Ecosystem Services of the Limpopo Basin*". This considers the socio-ecological consequences of altered flows and trade-off considerations between available scenarios to direct future management options.

PROJECT HIGHLIGHTS

The important outcomes of the Risk of Altered Flows to the Ecosystem Services of the Limpopo Basin are summarised as follows:

- The regional scale ecological risk assessment is based on available evidence including data collected during field surveys and historical data to determine the risk of flow and non-flow stressors to the 27 sub-basin areas of the Limpopo River Basin represented as risk regions.
- The risk assessment predicts how changes in a rivers flow regime will affect the various ecosystem services that the rivers of the Limpopo Basin provide, and services that the ecosystem and people depend on. The categories of ecosystem services considered in the assessment include the supporting, provisioning, regulatory and cultural services.
- The PROBFLO approach was initially used in this study to determine e-flows for 18 sites associated with the sub-basins of the study area. The e-flows are based on the supporting service requirements of fish, macroinvertebrates and riparian vegetation community wellbeing at the assessed sites. The risk to these supporting services (including ecosystem requirements) and other provisioning, regulatory and cultural service categories are included in this study.
- This PROBFLO assessment includes the prediction of risks of multiple flow and non-flow stressor to ecosystem services associated with Natural, Present day, E-flows and Drought scenarios.
- Apart from the sub-basins where field survey was carried out and evidence was generated for the stressor-ecosystem and stressor-ecosystem services relationships, limited historical data and inferences were made for some of the other sub-basins. There is a high amount of uncertainty associated with this approach in these sub-basins, with the Marico River sub-basin being the only one where a high risk associated with multiple stressors was observed. The Marico results should thus be considered with caution.
- Resulting from excessive flow reductions throughout the basin, the risk to all the services has increased from the Natural to Present day scenarios as expected.
    - In particular, the risk of altered flows to the supporting services is considerable where the majority of the sub-basin areas are in an unacceptably high-risk state. Only the Matlabas, Lephalale, Shashe, Mwanedzi, Luvuvhu and Shingwedzi Rivers, and mainstem Limpopo River from the Shahse River confluence to the floodplain in Mozambique are in a sustainable a moderate risk state. These sub-basins that are in a moderate state today, represent 32.1% of the Limpopo basin area. The remaining 67.9% of the basin is in a high risk, unsustainable, impaired state.
    - For provisioning and regulatory services most of the sub-basins are currently in a moderate risk but sustainable state.
    - The risk to the cultural services in the upper and middle parts of the basin have increased to high risk or unsustainable conditions, particularly in the Marico, Mokolo, Lotsane, Motloutse, Shashe, Sand and Bubye River Sub-basins (27.2% of the basin area).
- With the implementation of e-flows:
    - the risk to the supporting services decreases throughout the basin from high risk to moderate risk representing the return of the area to a sustainable state in 82.4% of the basin, an improvement from the present day 32.1%. This means that 50.3% of the total ecosystem area will return to a sustainable state. This includes not only the seasonal and ephemeral parts of the basin, but the naturally perennial parts of the basin in particular. Only the Olifants and Marico River sub-basins are proposed to remain in a high-risk state.

  - Similar trends were observed for the remaining provisioning, regulatory and cultural services where reductions in risk associated with the implementation of e-flows are expected. The cultural services for the Marico, Lotsane and Sand Rivers (10.5% of the basin) remained in a high-risk state, which is attributed to non-flow drivers.
- Should the e-flows not be implemented, and extensive droughts associated with climate change scenarios occur in the future:
  - the risk to the supporting services will increase significantly to 99% of the entire basin area with the Luvuvhu River alone remaining in a sustainable moderate risk state.
  - The regulatory services in the upper part of the catchment where the rivers are seasonal will in particular be at risk if no e-flows are implemented and climate change causes excessive droughts.
  - The provisioning and cultural services are not expected to change excessively if e-flows are not met but some areas in the upper and middle reaches of the basin will be affected.
- As there are 14 million people living within the Limpopo Basin that are reliant on the water resources it is imperative that they are managed sustainably.
- The PROBFLO approach was used to predict the proposed risk to the above services for four flow scenarios: Natural, Present Day, E-flows and Drought.
- This ecological risk assessment approach can be used by water resource managers to determine the risk that potential developments will have on the ecosystem services the river provides in a specific area and subsequently how it will affect the associated environment and the communities.
- The socio-economic costs associated with implementation of e-flows are outweighed by the long-term risks of not doing so as the river will degrade into an unsustainable state.
- The present-day total supply of unused water in the basin exceeds the e-flow requirements. This suggests that current use and e-flows can both be achieved in the basin, however such a consideration is based on total flows which include floods and freshets that are seasonal in nature. Thus there is an uneven distribution of flow, with the result that during low-flow periods, the current flows cannot support the e-flows unless there is adequate storage capacity to provide these flows. Consequently the observed shift in state from perennial to seasonal and seasonal to ephemeral of many of the rivers is in the basin is indicative of the inability of base flows to meet existing water demand and e-flow requirements. This suggests that with current usage, storage or other forms of flow augmentation are imperative if the e-flows are to be provided.

SUMMARY

The Limpopo basin in southern Africa is shared by Botswana, Zimbabwe, Mozambique and South Africa and contains important water resources that have tremendous social, economic and ecological value that are required by large rural communities who make use of these resources and are highly vulnerable to any adverse impacts caused by climate change and excessive upstream use. The water resources of the Limpopo Basin are limited, over-utilised and the goods and services provided by the rivers in the basin are affected by droughts, resulting in water and food insecurity. Attaining a sustainable balance between the use and protection of the resource of the Limpopo River is urgently required. To contribute to the sustainable management of the water resources in the Limpopo Basin, environmental flows (e-flows) have been established that consider the volume, timing and duration of flow needed to sustain critical ecosystems in the basin, which in turn support ecosystem services and the livelihoods of human communities in the basin. In this study a regional scale ecological risk assessment using the PROBFLO method has been undertaken to evaluate the risk of flow and non-flow alteration stressors affecting ecosystem services throughout the Limpopo Basin. The spatial extent of the study includes the entire Limpopo Basin upstream of the floodplain and estuary in Mozambique, which has been divided into 26 sub-basin areas or risk regions for the relative risk assessment. The aim of the study is to evaluate the socio-ecological consequences of altered flows and non-flow stressors associated with four alternative water resource scenarios established for the study, including the e-flows established in the study using PROBFLO and reported in Report 7: *Environmental Flow Determination for The Limpopo Basin*. In this report, we include consideration of the relative risk of flow alterations and non-flow stressor alterations to four scenarios (see Table i);

Table i: Scenarios used for the evaluation of risk to ecosystem services

Scenario	Title	Description
1	Natural (NAT)	This scenario is representative of the characteristics of the sub-basins prior to anthropomorphic impacts on the systems (>1960). The flows of the rivers are based on historical hydrology from 1920.
2	Present (PRS)	This scenario is representative of the characteristics of the sub-basins during the present day, taking into consideration all anthropogenic impacts. The flows of the rivers are based on historical hydrology from 1980 to 2010 and available daily flow data.
3	E-flow (EFLOW)	An e-flow was determined that would maintain the resilience of the ecosystem and communities in their present form, that considers increasing resilience of the present days condition and also provides possible restoration options.
4	Drought (DRGHT)	This scenario represents the worst climate change possibilities for each sub-basin based on 10 years observed lowest flows

The PROBFLO approach used in the study combines Relative-Risk Modelling (RRM) and the use of Bayesian Network (BN) probability modelling in a combined BN-RRM approach. Bayesian networks are graphical models that use conditional probability distributions to represent relationships between the variables in the model. The PROBFLO approach is based on ten procedural (RRM) steps that have been used to structure this report.

From existing and available knowledge or evidence describing the bio-physical attributes of the water resources of the Limpopo Basin, and ecosystem services and their use, and within the context of existing country and regional legislation, a vision for the water resources of the Limpopo Basin has been described. The detailed methods and the vision itself are documented in the Report 3: *"From Vision to Management Report"*. This vision requires the establishment of a suitable, sustainable balance between the use and protection of water resources. Our study was based on this vision and included the collection of bio-physical and social information to establish endpoints that would represent the successful implementation of this vision throughout the basin. In addition, in this study e-flows that would secure this balance were determined which included socio-ecological system integrity/condition requirements for different reaches of rivers throughout the basin, that, if met, would meet the vision requirements and would ensure a sustainable balance between the use and protection of the water resources in the basin. In this report, where the socio-ecological consequences of altered flows are considered, the trade-offs between development or continued use, climate change and EFLOW scenarios, are available to support decision making. The summarised outcome is that the e-flows that have been determined for the Limpopo Basin, if implemented, will meet user and environmental water requirements so that the system can continue providing ecosystem services (supporting, provisioning, regulatory and cultural services) and thus achieve the associated endpoints.

Through a review of available information and field surveys where a suit of bio-physical and social system components were evaluated, the location of potential sources of stress, habitats and impacts were identified. The data provided evidence of the status quo of the ecosystem, and at the same time provided evidence that can be used to determine the relationship between the drivers of change and the response of the ecosystem. The drivers of ecosystem change all exert their influence over the instream and riparian ecosystem. To monitor the response of the ecosystem health, fish, macro-invertebrates and the riparian vegetation were selected as indictors to describe the present state of the ecosystem.

The Limpopo Basin was divided into a number of risk regions (see Figure i). Risk regions are major sub-basin regions delineated by a combination of socio-economic and biophysical characters including transboundary issues. In this study a combination of the management objectives, source information, and available biophysical and habitat data also contributed. By using these risk regions, the dynamism of flow and non-flow variables of different regions can be incorporated into the study and allow for a holistic assessment of the basin. The approach addresses the spatial and temporal relationships of variables between risk regions, such as the downstream effects of a source of stress on multiple risk regions, in the context of the assimilative capacity of the ecosystem or the requirements of ecosystem response components.

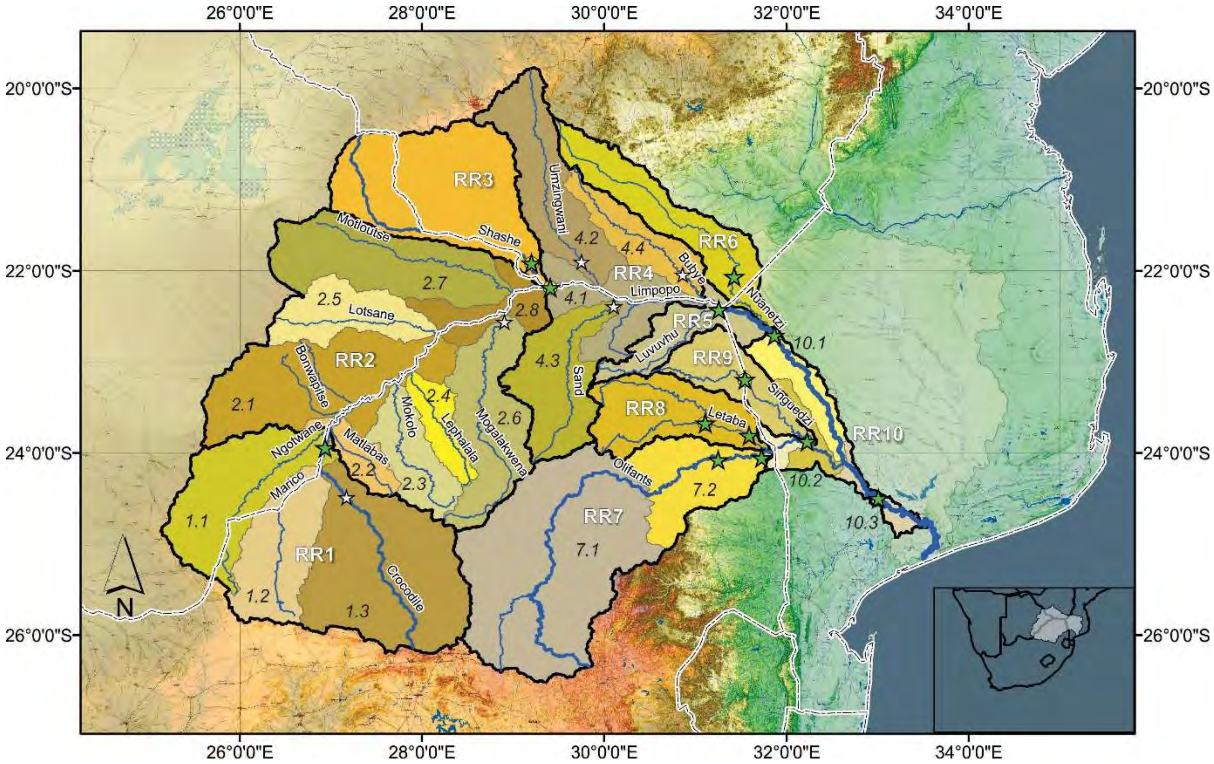

Figure i: Risk Regions (RR) and sub-regions used for the risk assessment in this report

For the RRM-BN a conceptual risk model that represents the spatial causal relationships between source, stressors, receptors and endpoints was developed (see Figure ii and the more detailed conceptual model in section 2.4). The conceptual model was used to generate BN models for each site (see detailed BN in section 2.4). The BN models describe in detail the exposure pathway of the model, which is combined with the effects to describe the overall risk to the endpoints of the study. The BN model structures and conditional probability tables that represent relationships between variables selected to represent the system were modified per RR to represent the dynamism of each RR, and thus for the entire basin. For the study a ranking scheme that allows for the calculation of relative risk for each endpoint and represents the range of well-being conditions, levels of impacts and management ideals, was established (i.e. zero, low, moderate and high risk). Zero risk usually represent a reference state with low-risk states representing management targets with little impact. Moderate risk represents partially suitable ecosystem conditions that usually warrant management/mitigation measures to avoid high-risk conditions that are deemed unacceptable. Bayesian network modelling is a robust probabilistic approach established in the late 1700s and is now used as a foundation probabilistic modelling approach in actuarial, medical and environmental sciences. The inclusion of BN modelling in PROBFLO facilitates the evaluation of relative comparable risk between endpoints using comparable ranks where risk is presented as a frequency or profile with a probable percentage for each rank occurring. This is particularly important where the possibility of failure or high-risk rank needs to be considered. In a PROBFLO assessment, socio-ecological system indicators of flow and non-flow variables are identified and used to represent the system (Figure iii). These indicators are linked through relationships that can be defined and represented in a PROBFLO model, and then linked to study endpoints or what we care about managing. Unique measures and units of measurement for indicators are converted into and represented by ranks for integration in BN assessments. The outputs of the model are relative risk calculations per ecosystem service (*viz.* provisioning, regulatory and cultural services that represent the social parts of the system, and supporting services that represent the ecological requirements of the system).

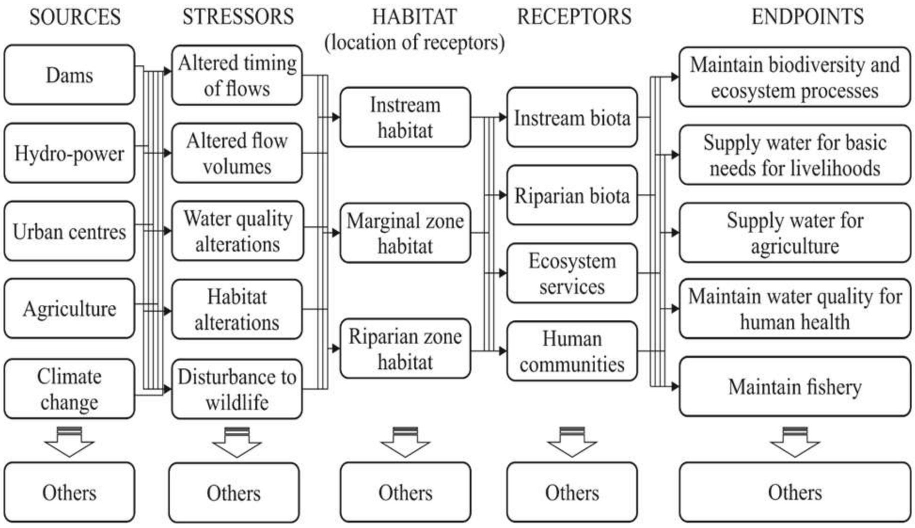

Figure iii: Basic conceptual model of the socio-ecological system for the Limpopo e-flow study

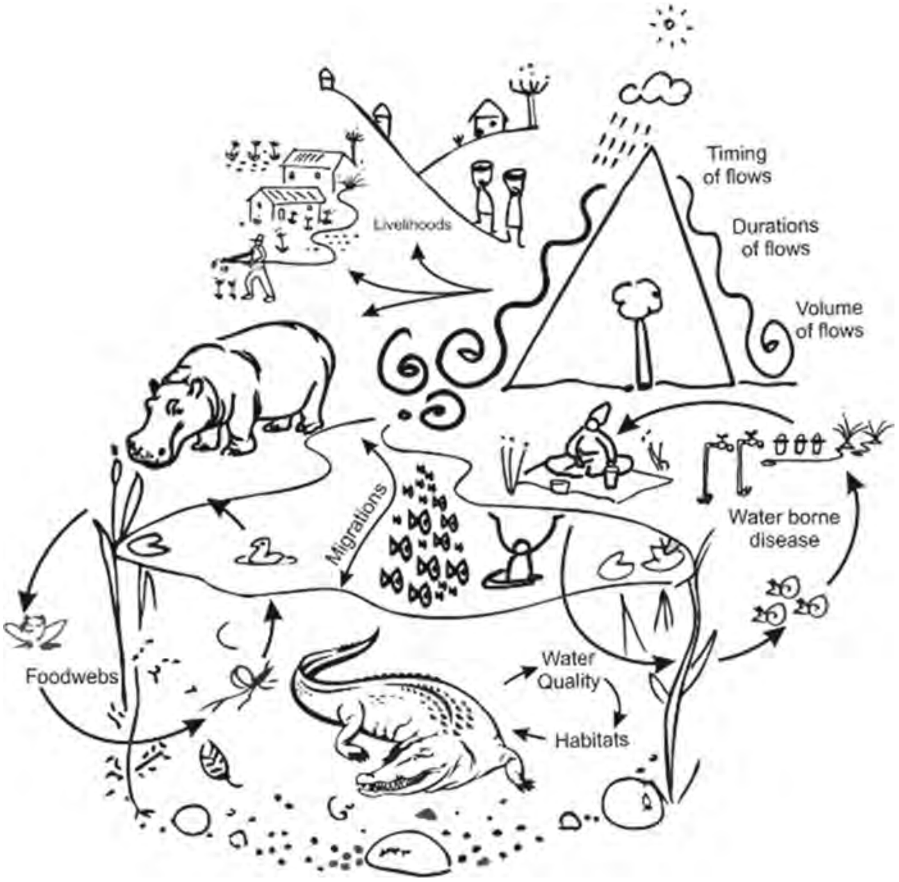

Figure iii: Schematic representation of a dynamic socio-ecological system associated with the Limpopo River including indicators of the system that can be used to model the socio-ecological consequences of multiple stressors.

The water resources within the Limpopo basin provide supporting services to the associated fish, vegetation and invertebrate communities. This service primarily represents the requirements of the ecosystem for flows and was used to establish the EFLOW scenario in the study. The condition of this service is determined by the quantity and quality of the water resources and the habitat provided. The risks that the ecosystem may not be sustained, as represented by the supporting service endpoints, indicate that under NAT conditions, the relative risk is low to zero for all risk regions, but under PRS conditions the risk increases into the moderate category for most risk regions and into the high category for the Olifants sub-basin as well as for the Groot Letaba sub-basin. The Luvuvhu sub-basin remains in a low-risk category for PRS and EFLOW conditions. Implementation of e-flows would result in a reduction in risk for many risk regions but due to the requirement for e-flows to maintain Moderately Modified or Largely Modified ecological states (C&D categories – see Table ii), the risk to the supporting services at many of the sites would remain the same as at PRS when under EFLOW conditions, or would increase slightly into the moderate or threshold of potential concern categories. While the impact of present day altered flows to the supporting services of the Limpopo Basin, including the fauna and flora and other services is severe, the vision for the river which considers the suitability of the river to provide other services for social and economic benefits has resulted in a hardworking but sustainable resource vision for the majority of the basin (C&D categories). Most of the risk regions will remain in a moderate risk category under the EFLOW scenario except for the whole Olifants sub-basin as well as for the Groot Letaba sub-basin that will still remain in a high-risk category with a high probability of these endpoints will become unsustainable. These risk projections for the Letaba and Olifants Rivers are excessive and suggest that the e-flows are not sufficient to maintain the ecosystem, however these e-flows have been formally gazetted through the National Water Act in South Africa as a part of the Resource Directed Measures (RDM) of the country and can only be formally updated when the RDM process is revised for this basin. In the interim, the knowledge that these requirements may be unsuitable will be communicated to the stakeholders in this sub-basin. The risk associated with the DRGHT or worst-case climate change scenario is variable but includes very high risk of failure for the supporting service (including the ecosystem) components considered in the study. Maintaining the status quo without implementing e-flows and if this worst-case climate change event occurs, the ecological impacts on the water resources would be catastrophic.

Table ii: EcoClassification classes to represent the state of rivers/river components in the study.

Colour (class)	State
A	Natural/pristine
B	Largely natural
C	Moderately modified
D	Largely Modified
E	Seriously modified
F	Critically modified

The relative risk posed to the combined provisioning services endpoints (i.e., fish for food, vegetation for livelihoods and grazing, water for human use) under NAT conditions has indicated low risk of failure of provisioning services in all risk regions except the Shingwedzi sub-basin that would be in a moderate relative risk category. For the present-day scenario, most risk regions will be subject to a moderate relative risk. The e-flows scenario will lead to some reduction in risk compared to the present. The worst-case DRGHT scenario will result in an increase in the relative risk for most risk regions.

The relative risk to the combined regulatory services endpoints (i.e., flood attenuation, nutrient assimilation, diseases, and resource resilience) indicates that for the NAT scenario, the risk regions would be in a low to moderate relative risk category. There has been a noticeable increase in the relative risk for all risk regions for the PRS scenario, while for the proposed EFLOW scenario there would be a reduction in relative risk for some risk regions but they all remain in a moderate risk category. The worst-case DRGHT scenario has an increase in the relative risk for all risk regions with the whole of RR1 and most of RR2 in Botswana including the Matlabas, Mokolo and Sand Rivers, being in a high-risk category. An example of the outputs of the risk assessment is given for the regulatory services below (Figure iv). The risk is summarised onto a map format, and clearly shows how the risk to the regulatory ecosystem services changes with each of the development scenarios. Such maps are provided for each of the ecosystem services.

The combined risk to the cultural services (i.e., recreation, spiritual activities, and tourism) provided by the water resources within each sub-basin, for the NAT scenario, would range from moderate to low for all the risk regions. The PRS scenario, the Marico, Mokolo, Lotsane, Motloutse, and Sand River sub-basins would be in a high relative risk category while the remaining risk regions are in a low to moderate relative risk category. The EFLOW scenario would lead to a reduction in risk for some of the risk regions with the Mokolo and Lotsane sub-basins returning to a moderate risk category. The worst-case DRGHT scenario shows an increase in risk for many of the risk regions but the Olifants and Luvuvhu sub-basins have remained in a low-risk category for all four scenarios. The 10 worst drought years observed in the Olifants River prior to present day flows have all included relatively good base flows and have been better than present day flows. These surprising results demonstrate how severe the present day reductions in flows are for the Olifants River, and that in the future if these flows are maintained and droughts occur the historical resilience of the system would be lost.

The regional scale ecological risk assessment undertaken in this study has demonstrated how multiple stressors are potentially impacting on the socio-ecologically important river resources of the Limpopo Basin. All the risk regions considered in the study are exposed to considerable changes in the volume, timing, duration and frequency of river flows, with many rivers that have historically been perennial, with no evidence of zero flow conditions observed, over time becoming seasonal and or episodic today. In addition, due to noticeable transformation of the landscape in the basin through urbanization and agriculture, mining and industrial development, additional water quality, habitat alterations and disturbance to wildlife stressors are evident, which exacerbate the impacts to water resources due to reduced flows. In the Limpopo River Basin, the supporting services (i.e. supporting the ecosystem) were identified as the most vulnerable components of the study.

It has been reported in Report 7: *Environmental Flow Determination for the Limpopo Basin* how the e-flows of the Limpopo River have been determined using the minimum volume, timing, duration and frequency of river flows required to maintain the supporting services. That report shows that a noticeable increase in resilience of the water resource will be achieved through the implementation of the e-flows. They require however, a noticeable increase in river flows relative to present-day flows, which would result in the recovery of the ecosystem and associated key supporting service components of the ecosystem. There is potential that this would present economic challenges to the existing formal water use sector that is using the available water from the basin, although no evidence of this is provided. If no mitigation measures (e-flows) are provided and worst-case climate change predictions for the region occur, including a prolonged and or extensive drought, the risk to the supporting services, including the ecosystem and associated processes, will increase considerably from the present-day levels of risk and render the wellbeing of the ecosystem in a Critically Modified and unacceptable state. This would include significant losses of biodiversity and important ecosystem processes.

The provisioning services were demonstrated in the study to deteriorate from the NAT scenario to the PRS conditions, however they are considerably less vulnerable to the flow and non-flow stressors compared to supporting services. This can explained in that the supporting services are based on support of all species and their ecosystem preferences, while the provisioning services are required only by human communities who could use any fish or food source for food, can clean polluted water for drinking purposes and can even transition from cattle to goats, for example, in response to reduced grazing. Presently the provisioning services are generally in a Moderately Modified state (Table ii), particularly where many vulnerable human communities occur and depend on the ecosystem services.

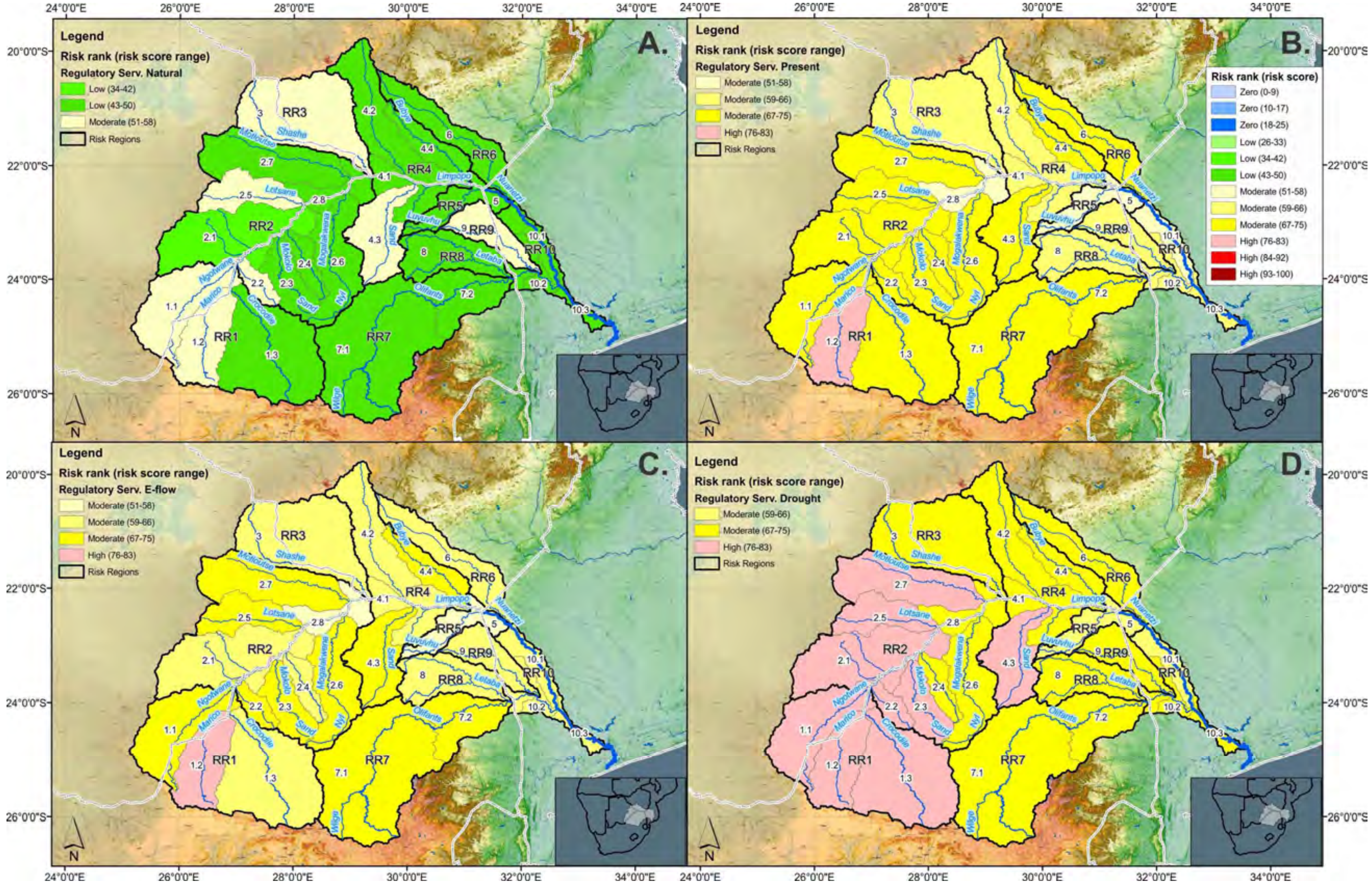

Figure iv: Relative risk scores to regulatory services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

This study demonstrates that through the implementation of e-flows local vulnerable human communities will benefit from e-flows and will be more resilient to climate variability for example. This study shows that if no e-flows are provided, and the worst-case climate change impacts occur including a prolonged drought in the region, a deterioration of provisioning services is expected to result which will include increased stress and hardships for local human communities.

Outputs of the risk assessment include increased risk to all the regulatory services from natural to PRS conditions, which has resulted in changes in use-dynamics due to new protected and wilderness areas and reduced quality of the water resource that affects water borne disease vectors. These trends are similar to those for the provisioning services, where e-flow will also result in a slight improvement to the regulatory services. Interestingly while the regulatory services are potentially less vulnerable to multiple stressors compared to supporting and provisioning services, the potential impacts of climate change on regulatory services in the upper reaches of the basin in particular are noticeably greater than the risk expected to occur to provisioning services.

Finally, the cultural services important in the Basin include recreation and spiritual activities, and tourism. Interestingly while the risk to tourism is highly dependent on the demand for tourism in the basin, which did not exist in the NAT scenario, today due to the presence of the Great Limpopo Transfrontier Conservation Area and the many wilderness areas in the upper parts of the Crocodile River (West) sub-basin and middle Limpopo River, this ecosystem service is being well provided to stakeholders. These results demonstrate how important tourism is as a cultural service with associated socio-economic benefits. The spiritual and recreational activities however, which occur outside of the protected areas, are dependent on the water resource and its quality. Changes in risk for this important social service of the Limpopo River follows trends where, compared to today, there has been a considerable increase in risk compared to NAT conditions. This service is however, more tolerant to changes in flows and non-flow stressors compared to the supporting and provisioning services. If e-flows are not implemented and a worst-case climate change scenario including a prolonged drought occurs in the region, the state of the cultural services will deteriorate considerably in the tributaries of the Limpopo Basin where perennial or seasonal streams occur. The Olifants River has surprisingly been identified as a very resilient sub-catchment of the Limpopo Basin where tourism and other cultural services are proposed to be maintained even during a prolonged drought.

The Limpopo River is an important, dynamic socio-ecological system with a high diversity of endemic and unique aquatic biota and important ecosystem processes that affects the more than 14 million people who live in the basin and depend on its resources. The limited water resources of the basin are over-utilised, with most of the rivers that were perennial, now seasonal, and where previously seasonal rivers are now episodic. Additional water quality stressors in the Crocodile (West) and Olifants Rivers and other stressors such as habitat alteration, alien invasive fauna and flora and disturbance to wildlife impacts have been shown to have a synergistic effect of the wellbeing of the water resources in the basin. While most of the rivers in the basin today occur in a Largely Modified state, many parts of the basin are in an unsustainable deteriorating state with an associated loss of biodiversity, ecosystem processes and services that people depend on. The evidence-based risk assessment undertaken in this study can contribute to stakeholders' understandings of how water resources have been developed in the Limpopo Basin, and the impacts of the stressors associated with developments. The assessment includes relative risk to ecosystem services which facilitates the consideration of trade-offs that are spatially linked to the basin so that in different places stakeholders can consider what is presently occurring in the basin, what the socio-economic potential of the developments are, and how the management of the environment will affect these socio-economic attributes. While we acknowledge that there are socio-economic costs associated with flow mitigation (providing e-flows), the long-term costs of maintaining a system in an unsustainable state may out-way these short-term costs.

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1 INTRODUCTION

The Sustainable Development Goals report for 2021 (UN, 2021) indicates that many countries around the world are dealing with degraded water-related ecosystems and water scarcity due to climate change, underinvestment in water and sanitation and insufficient cooperation on transboundary waters and affirms the need for integrated and holistic approaches to water resource management. This would include the consideration of not just river flow, but also non-flow related stressors on water resource and the effect that these would have on social and ecological consequences; with the ultimate aim of finding a sustainable balance between the use and protection of water resources.

The Limpopo basin in southern Africa is shared by Botswana, Zimbabwe, Mozambique and South Africa and contains important water resources that have tremendous social, economic and ecological value that are required by large rural communities who make use of these resources in the basin and are highly vulnerable to any adverse impacts caused by climate change (Mwenge Kahinda et al, 2015). Sixty nine percent (69%) of Botswana's total population lives within the Limpopo basin and 22% of South Africa's population, which results in water requirements for domestic use being the second largest user of water within the basin after irrigation. Other uses include industrial, mining, forestry, livestock and power generation (Mwenge Kahinda et al, 2015). The water resources of the Limpopo Basin are limited, over-utilised and the goods and services provided by the rivers in the basin are affected by droughts, resulting in water and food insecurity (Petri et. al. 2014).

Presently in the Limpopo Basin the mainstem Limpopo River, from its source at the confluence of the Marico and Crocodile Rivers, has been transformed from a perennial river into a seasonal river, with many tributaries also being transformed from perennial into seasonal rivers and some seasonal rivers into episodic rivers. It is clear that the rivers in the catchment are being over utilised and that no sustainable balance between the use and protection of the river, its ecosystem and the services it provides to vulnerable human communities, has been attained. Attaining a sustainable balance between the use and protection of the resource of the Limpopo River is urgently required, but due to the shared nature of the transboundary resource, the dynamism of the socio-ecological system of the basin, the plethora of stressors impacting on both the social and ecological attributes of the resource, and new emerging stressors such as climate variability associated with climate change in the region, it is difficult to understand how these stressors affect the resource and probably more difficult to bring all of the information and the stakeholders of the resource together in an attempt to manage it.

As an emerging threat in the region, climate variability has resulted in the unpredictability of the hydrological regime leaving the river in parts without flows for nearly 70% of the year (ADB, 2014). Foundationally, river flows and the management of flow, and non-flow stressors in the catchment through environmental flow (e-flow) frameworks is very important in the basin, for the future sustainability of the water resources especially as growing populations will impose greater demands on available freshwater and associated ecosystem services. In this study the e-flows for selected sites in the Limpopo Basin have been determined (Reference Report 6: *Present Ecological State of the Limpopo River: Ecological Responses to Change*) using the PROBFLO approach, which includes e-flow framework functionality (Horne et al., 2017; O'Brien et al, 2018; 2021). This functionality includes the application of the evidence-based probability models established for each of the e-flow sites in the study (consider e-flow report), with additional hydrology data and limited socio-ecological evidence/information, to model the e-flow requirements for risk regions or sub-catchments of the entire basin.

The PROBFLO regional-scale risk assessment approach that was used to determine e-flows also includes the functionality to evaluate the risk of multiple stressors associated with different flow management scenarios. In this project application of PROBFLO, we included consideration of the relative risk of flow alterations and non-flow stressor alterations to;

Scenarios used in this report:

1. Natural (NAT) or pre-anthropogenic flow conditions,
2. Present day (PRS) flows,
3. E-flows (EFLOWS)
4. Worst-case climate change "dry" scenario (DRGHT) [represented by a prolonged drought derived from the lowest 10 years of flow from the flow record].

The aim of this report is to detail the approach followed to determine the relative risk that altered flow scenarios would have on the ecosystem services provided by the water resources within the 26 sub-basins of the Limpopo basin. ***See the "risk information" box below that describes the use of "risk" in this study.***

The PROBFLO approach (O'Brien et al, 2018) is a holistic e-flow determination that includes an e-flow consequence evaluation, nested in a framework approach that has been adapted in Africa and applied throughout the continent. It has now been implemented to determine the e-flows for the Limpopo basin and the methodology and results are documented in Report 7: *Environmental Flow Determination for the Limpopo Basin.* PROBFLO incorporates the use of relative-risk assessment and Bayesian Networks (BN) into a holistic, probabilistic approach that can be used to determine the relative risk of multiple stressors to ecosystem services and socio-ecological endpoints (Landis and Wiegers, 1997; 2007, O'Brien et al, 2018). In this study, the flow-related risks to the resilience of ecosystems and communities were linked to socio-ecological endpoints, for example, food security needs being met by fisheries, with sustainable e-flows. The tool's modular structure quantitatively shows the causal linkages between change drivers (e.g., climate, pollution, water withdrawal from both surface and groundwater) and ecosystem service degradation. It allows users to evaluate the drivers of change and the impact of mitigation measures (e.g., re-establishing flows in tributaries) on the provision of ecosystem services to users.

INFORMATION BOX: ECOLOGICAL RISK ASSESSMENTS

Formal risk assessment methods have been established for actuarial, human health/medical and environmental sciences. They are all generally designed to evaluate the probability or potential for a hazard/stressor to occur and affect an endpoint like a financial asset, health of a person or attribute of the environment. Ecological risk assessments have been established (Ayre and Landis 2012; O'Brien et al. 2018; Landis 2021) to evaluate the magnitudes and probabilities of multiple stressors associated with anthropogenic activities, that affect the social, and or ecological attributes of ecosystems (in our case study we're interested in the water ecosystems of the Limpopo River).

Ecological risk assessments traditionally incorporate two relationships, the *exposure* and *effects* relationships, which are required to establish risk pathways. The *exposure relationship* considers the potential for a stressor (e.g. altered water quality, quantity or habitat characteristics of an ecosystem) to affect an ecosystem, while the *effects relationship* describes how the ecosystem will dynamically respond to the exposure. The effects relationship considers, for example, on a relative scale what the ecosystem consists of, how resilient it may be and what, and or who, utilizes the resource. All of this information contributes to our understanding of the risk of multiple stressors to social and ecological attributes of an ecosystem.

In the context of using PROBFLO in e-flow determination studies and regional scale risk assessments, the term *risk* is thus used to describe the potential for a stressor or hazard to occur and enter an ecosystem (*exposure relationship*), affect changes to the environmental characteristics of the system and how the biodiversity, ecosystem processes and people of that system, will respond to these changes (*effects relationship*). This approach allows us to communicate not only how socio-ecological systems responded to multiple stressors in the past, and present (which we can measure), but also to predict the potential for stressors and associated impacts to occur in the future! *Continues in next box…*

INFORMATION BOX: ECOLOGICAL RISK ASSESSMENTS (CONT.)

PROBFLO assessments result in two outputs; (1) the potential risk or likelihood of occurrence and severity, of stressors to impact an endpoint, and (2) the probability of the endpoint failing, or occurring in an unacceptable state. The potential risk or likelihood of occurrence, and severity of stressors to impact an endpoint is based on the highest probable point of a PROBFLO output risk profile or frequency distribution. These risk profiles represent the modelled probable states, conditions or integrity of an endpoint, with the highest probable point, or most likely outcome communicated. In addition to the relative risk outcome, information about the risk profile itself, specifically the probability of an endpoint occurring in an unacceptable state, is communicated.

Example:

An example from this study is consideration of the fish community wellbeing or integrity as an important component of the upper Limpopo River ecosystem at the Spanwerk site. This is an endpoint selected to contribute to our understanding of the availability, and condition, of supporting ecosystem services in the study. The risk assessment implemented, included consideration of multiple flow alteration and non-flow (water quality and habitat changes etc.) stressors to the wellbeing of the fish communities during the four scenarios namely; (1) NAT - natural pre-anthropogenic scenario (pre-1960s), (2) PRS - (1980-2010), (3) EFLOW - e-flows and (4) DRGHT - worst-case climate change or prolonged drought scenario.

Scenario 1: During the NAT scenario in the upper Limpopo River at the Spanwerk site, the fish community most likely occured in a pristine condition with only 18% out of 100% chance of the fish community occurring in an unsustainable or unacceptable condition. This 18% represents how the fish communities have naturally responded to natural environmental variability, or it may represent our uncertain knowledge of the processes affecting fishes in the assessment.

Scenario 2: In the PRS scenario the probable risk to the fishes has increased from the 18% risk in the NAT scenario to a probable Largely Modified state today with a massive 62.5% chance of failure. This is attributed to significant changes in the volume, timing, duration and frequency of flows in the Limpopo River, with additional water quality, habitat and disturbance to wildlife stressors associated with the unsustainable development of the river resources in this area. These risk results suggest that while the fish community can potentially tolerate high stress during no- or low-flow periods, there are some opportunities for the stressed community to recover during high flow periods. The 62.5% probability of high risk however suggests that the fish communities at this site today are unsustainable and their wellbeing is probably declining.

Scenario 3: In the EFLOW scenario the improved base flows and maintenance of a perennial state of the upper Limpopo River through the implementation of e-flows would result in the state of the community regaining a Largely Modified state, where the chances of failure of the endpoint will reduce considerably to 47%. These results demonstrate how e-flows can build resilience of the fish community to environmental variability, and synergistic affects of the multiple stressors affecting the upper Limpopo River. *These results are aligned to the vision for this part of the river which described a hard-working but sustainable resource.*

Scenario 4: In the DRGHT scenario, the risk which is associated with worst-case climate change predictions and no e-flow provisions, will result in an unsustainable high risk state for fish communities and a 75% chance of failure of these communities. This scenario is unsustainable and unacceptable in the context of the vision for the resource.

The use of the risk assessment approach here demonstrates that the impact of multiple flow and non-flow stressors has increased considerably from NAT to PRS conditions, probably resulting in an unsustainable, deteriorating fish community. The risk assessment also demonstrates that e-flows would reduce the present high flow variability between no-flow and seasonal flows improving the resilience of the fish communities in the river and contributing to a sustainable ecosystem. Finally, without implementation of the e-flows, and if climate change results in prolonged droughts in the region, the wellbeing of the existing fish community would deteriorate further into an unsustainable state with a 75% chance of loss of biodiversity and associated ecosystem processes in the region.

2 APPLICATION OF THE PROBFLO APPROACH FOR THE LIMPOPO

The Limpopo e-flows study utilised the ecological risk assessment approach of a scenario-based e-flow assessment tool called PROBFLO (O'Brien *et al*, 2018) to a) determine the e-flows for the rivers within the Limpopo basin (*Report 7: Environmental flow determination for the Limpopo Basin*) and b) evaluate and determine the risk various scenarios related to altered flows will have on selected socio-ecological endpoints. PROBFLO combines Relative-Risk Modelling (RRM) and the use of BN in a BN-RRM approach. Bayesian networks are graphical models that use conditional probability distributions to represent relationships between the variables in the model (Wade *et al*, 2021). The PROBFLO approach is based on ten procedural (RRM) steps (Figure 2-1 - O' Brien *et al*, 2018), that were implemented to determine and evaluate the relative risk of four hydrological scenarios (

Table 2-1) to various socio-ecological endpoints. These procedural steps will be discussed in further detail below.

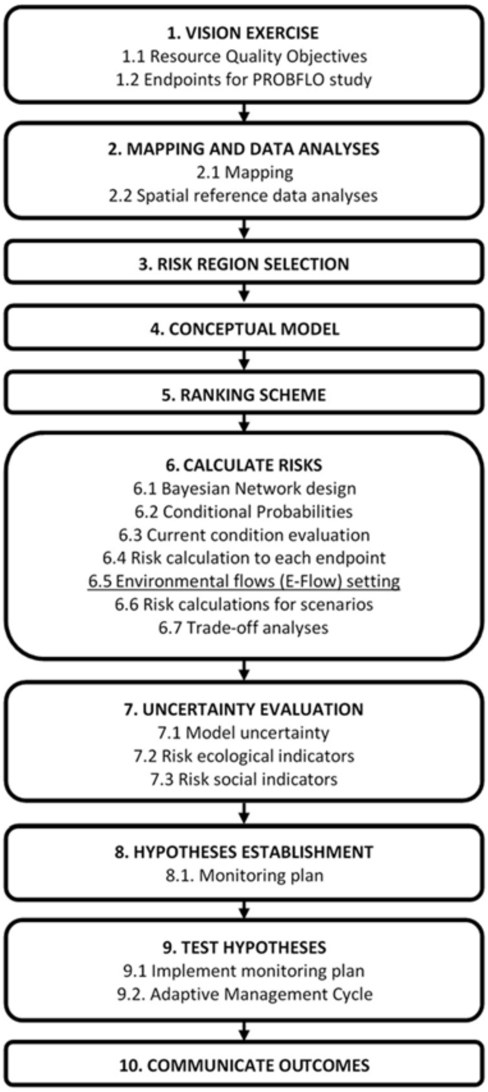


Figure 2-1: The PROBFLO framework including the 10 procedural steps that were implemented in the Limpopo Basin study

Table 2-1: The four hydrological scenarios selected for the relative risk assessment for the Limpopo basin (O'Brien et al, 2022)

Scenario	Title	Description
1	Natural (NAT)	This scenario is representative of the characteristics of the sub-basins prior to anthropomorphic impacts on the systems (<1960). The flows of the rivers are based on historical hydrology from 1920.
2	Present (PRS)	This scenario is representative of the characteristics of the sub-basins during the present day, taking into consideration all anthropogenic impacts. The flows of the rivers are based on historical hydrology from 1980 to 2010 and available daily flow data.
3	E-flow (EFLOW)	An e-flow was determined that would maintain the resilience of the ecosystem and communities in their present form, that considers increasing resilience of the present days condition and also provides possible restoration options.
4	Drought (DRGHT)	This scenario represents the worst climate change possibilities for each sub-basin based on 10 years observed lowest flows

In order to implement PROBFLO, large amounts of data and information have been produced and then synthesised into the derivation of the e-flows and likewise into the outputs of this report on the consequences of altered flows in the Limpopo River. This data and information cannot be presented in this final report but is contained in a series of reports shown in the table below. The reader is urged to make use of these reports to provide greater depth to what is presented in this report, which is the last in the series, Report 8.

Report number	Report title E-FLOWS FOR THE LIMPOPO RIVER BASIN:
1	Inception Report
2	Basin Report
3	From Vision to Management
4	Specialist Literature and Data Review
5	Present Ecological State - Drivers of Ecosystem Change
6	Present Ecological State - Ecological Responses to Change
7	Environmental Flow Determination
8	Risk of Altered Flows to the Ecosystem Services

2.1 VISION AND ENDPOINTS

E-flows can only be set in relation to a vision and management objective for the condition of the river within the basin and for the communities that the river supports. This already exists in different styles for the different parts of the basin as part of policy, strategies and resource objectives within riparian governments and LIMCOM have completed a study on the vision for the basin. The detailed methods and outputs of the visioning exercise for this study are documented in the *"From Vision to Management Report"* that is Annexed to Report 2*: E-Flows for the Limpopo River Basin: Basin Description*. The summarised outcome is that the e-flows that are to be determined for the Limpopo Basin, need to meet user and environmental water requirements so that the system can continue providing ecosystem services as per the categories provided in the Millennium Ecosystems Assessment (MEA 2005) (supporting, provisioning, regulatory and cultural services) and associated endpoints (Table 2-2). The determination of e-flows for the Limpopo is thus based on support provided primarily by river flow to the ecosystem services associated with the river.

Supporting services are those that are necessary in the production of other ecosystem services and play a crucial role to maintain them (Rodríguez 2005). They also contribute directly and indirectly to the wellbeing and livelihoods of people. The ability of ecosystems to provide habitat for species, produce biomass, soil and atmospheric oxygen are some examples of supporting services, while the abundance of biodiversity may also be considered a supporting service. For this study, the maintenance of fish, invertebrates and vegetation were selected as endpoints for the supporting ecosystem services as these were also used to determine the e-flows for each sub-basin.

Provisioning services are the tangible products that people obtain from ecosystems, and they include food, water, raw materials, energy and genetic resources and most often are considered as the most fundamental benefits of nature to livelihoods (Darwall et al. 2009). The provisioning services considered most important for the Limpopo basin and selected as endpoints are the maintaining of fisheries and plants for livelihoods, the maintaining of plants for domestic livestock and the maintaining of water for domestic use.

The prevention and mitigation of natural disasters such as floods and human induced impacts like pollution of water bodies are some of the regulating service benefits that are derived from ecosystems (MEA 2005). The endpoints chosen to represent this ecosystem service included; flood attenuation, river assimilation, water-borne diseases and resource resilience. River assimilation is the ability for the water resources to dilute or absorb pollution, whereas resource resilience is the extent of disturbance that a system can tolerate before it deteriorates into a different state.

The last ecosystem services considered are cultural services, which are the non-material benefits that people obtain from nature, which include recreation, aesthetic enjoyment, physical and mental health benefits and spiritual experiences (MEA 2005). The two endpoints selected for this service are maintaining water resources for recreational and spiritual activities, as well as for tourism.

Table 2-2: Endpoints selected for the Limpopo e-flow study

Ecological Service	Endpoint
Supporting services	Maintain fish communities to ensure a healthy ecosystem (FISH-ECO-END)
	Maintain invertebrate communities to ensure a healthy ecosystem (INV-ECO-END)
	Maintain vegetation communities to ensure a healthy ecosystem (VEG-ECO-END)
Provisioning services	Maintaining fisheries for livelihoods (SUB-FISH-END)
	Maintain plants for livelihoods (SUB-VEG-END)
	Maintain plants for domestic livestock (LIV-VEG-END)
	Maintain water for domestic use (DOM-WAT-END)
Regulatory services	Flood attenuation services (FLO-ATT-END)
	River assimilation capacity (RIV-ASS-END)
	Limit water borne diseases (WAT-DIS-END)
	Resource resilience (RES-RES-END)
Cultural services	Maintain recreation and spiritual activities (REC-SPIR-END)
	Maintain tourism (TOURISM-END)

The present ecological state (PES) for each ecological component (Figure 2-2 A-C) was determined through extensive field surveys. This information combined with existing literature was used to identify indicator species, populations, and communities to represent the ecosystem. Based on this, the recommended ecological category (REC) (Figure 2-2D) was also determined to represent the vison for the sustainable use and protection of water resources in the Limpopo Basin.

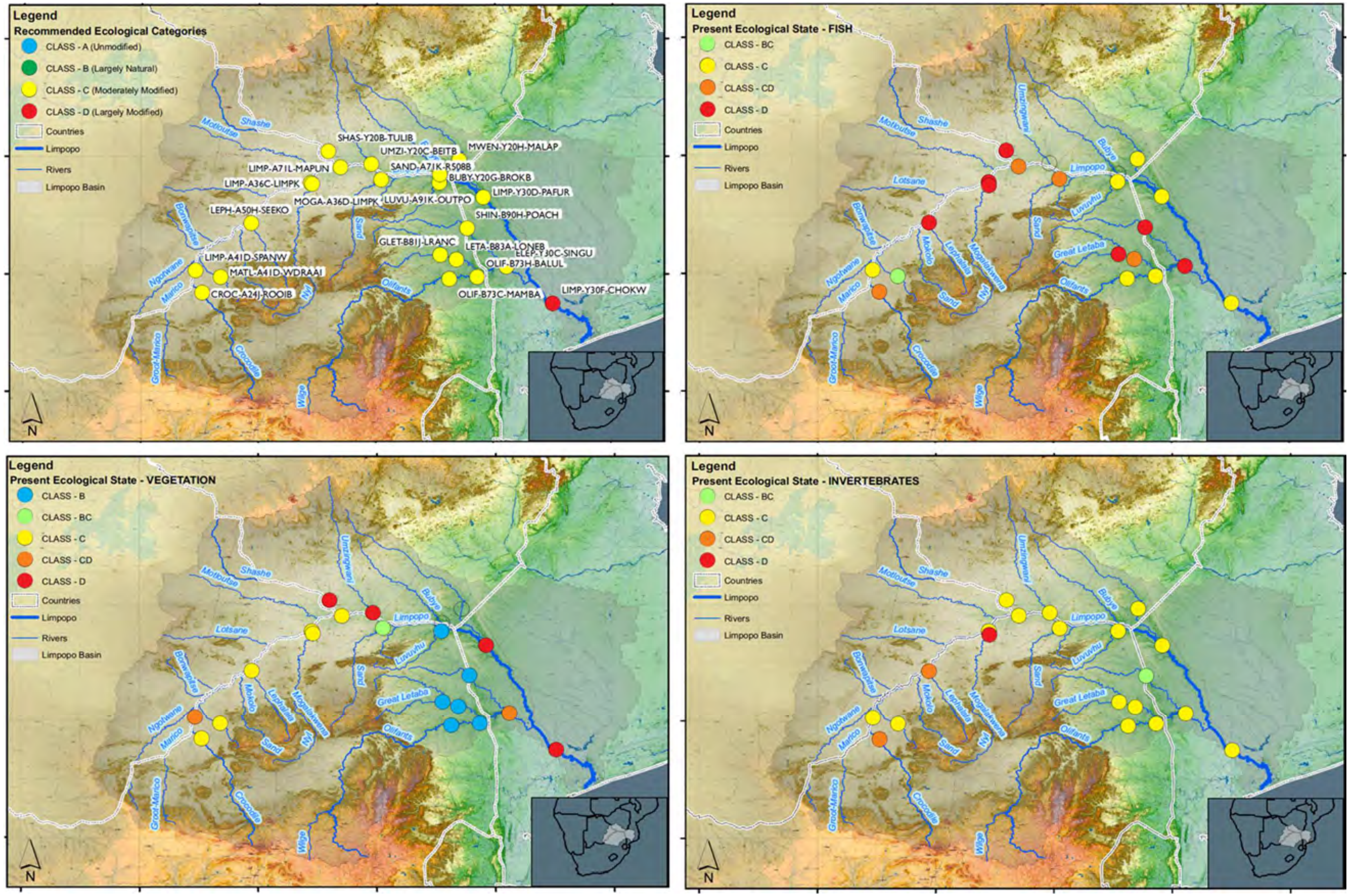


Figure 2-2: Present ecological state classification using A-F EcoClassification classification range for the recommended ecological category representing the vision for the sustainable use and protection of water resources in the Limpopo Basin, and for fish, invertebrates and vegetation.

2.2 DATA EVALUATION & MAPS

The spatial extent of the Limpopo basin was defined, and the location of potential sources of stress, habitats and impacts were identified. Large amounts of data provided evidence of the status quo of the ecosystem, and at the same time provided evidence that can be used to determine the relationship between the drivers of change and the response of the ecosystem (see Reports 1-5).

The drivers of ecosystem change all exert their influence over the instream and riparian ecosystem and are documented in Report 5. To monitor the response of the ecosystem health, fish, macro-invertebrates and the riparian vegetation were selected as indictors to describe the present state of the ecosystem, the results of which are presented in Report 6. The categories listed in Table 2-3 were used to describe the state of the rivers within the Limpopo Basin.

Table 2-3: Guidelines used to delineate the present ecological state categories based on observed and expected intolerance ratings (Kleynhans 2008).

Category	Description
A	**Natural**, unmodified, or approximating natural conditions.
B	**Largely Natural** with few modifications. A change in community characteristics may have taken place but species richness and presence of intolerant species indicate little modification.
C	**Moderately Modified**. A lower-than-expected species richness and presence of most intolerant species. Some impairment of health may be evident at the lower limit of this class.
D	**Largely Modified**. A clearly lower than expected species richness and absence or much lowered presence of intolerant and moderately intolerant species. Impairment of health may become more evident at the lower limit of this class.
E	**Seriously Modified**. A strikingly lower than expected species richness and general absence of intolerant and moderately intolerant species. Impairment of health may become very evident.
F	**Critically Modified**. An extremely lowered species richness and absence of intolerant and moderately intolerant species. Only tolerant species may be present with a complete loss of species at the lower limit of the class. Impairment of health generally very evident.

Drivers of change

The drivers of change are those factors that are directly affected by land-use changes and developments, in particular water withdrawals, as well as by climate change, and include the hydrology, hydraulic characteristics, geomorphology and sediment movement, water quality, and groundwater. Each of these drivers will have impacts on the responding biology and are pivotal to understand what drives the ecosystem, so that the required amounts of water at the right time can be estimated. This data was presented in detail in Report 5: *Present Ecological State of the Limpopo River: Drivers of Ecosystem Change.*

The hydrology assessment included the analysis of the long-term natural hydrological flow time series at the selected e-flow sites for the main stem Limpopo River and the major tributaries. These include basic hydrographs, flow duration curves and statistics based on monthly modelled natural flow data at the e-flows sites. Additional information is also provided in terms of drought flows, sizes and duration of freshets and floods. Table 2-4 summarises the hydrological characteristics in terms of the Natural Mean Annual Runoff (nMAR) and the variability index (CV_Index) which indicates the seasonal, perennial or ephemeral character of the rivers (between 1 and 4 indicates a perennial system, 5 a seasonal and >6 an ephemeral system). It can be seen from the table that a number of systems are naturally ephemeral, especially those in Botswana. It should be noted that this index was calculated for the flows at the e-flow sites that are mostly situated in the lower reaches of the rivers and some systems may differ in the upper reaches.

INFORMATION BOX:

For some rivers within the Limpopo Basin in South Africa, e-flows have already been gazetted as the Reserve or Resource Quality Objectives (RQO) and are legally binding and therefore no new e-flow requirements were determined for these sites. The rivers where requirements (Reserves/ RQOs) have been gazetted include the Crocodile (West), Marico, Matlabas, Mokolo, Olifants and Letaba Rivers. Most of the sites on these rivers have previously been assessed on at least an intermediate level of detail, except for the lower reaches of the Crocodile (West) and Matlabas Rivers where only desktop results were available for gazetting (https://www.dws.gov.za/rdm/RR.aspx)

The hydraulic and geomorphology assessment determined the hydraulic habitat that includes a combination of the water depth, velocity and the underlying sediments and the river shape. This specialist component of the e-flow study described this habitat at all of the available sites. The water quality assessment indicated pH and orthophosphate issues for some sites on the Limpopo River and pH, electrical conductivity, orthophosphate and nitrate issues in some of the tributaries. The results of the groundwater assessment indicated that chemistry of groundwater and surface water for sites in the Limpopo River Basin, were characterized by similar mixtures of constituents and reflects water with similar history, origin and interactions. This supports the hypothesis that there is a strong interaction between surface water and groundwater to provide environmental water flows, even under the high flows in the wet season.

Table 2-4: Summary of nMAR and CV_Index et e-flow sites in the Limpopo Basin

Risk region	Rivers	E-flow site	nMAR (106m^3)	CV_Index
RR1	Ngotwane	Lim_EF01	92	5
	Marico	Lim_EF02	154	3
	Crocodile (West)	Lim_EF03	596	2
RR2	Bonwapitse	Lim_EF04	81	11
	Matlabas	Lim_EF05	35	3
	Mokolo	Lim_EF06	230	3
	Lephalale	Lim_EF07	142	2
	Lotsane	Lim_EF08	35	10
	Mogalakwena	Lim_EF09	244	2
	Motloutse	Lim_EF10	125	8
	Limpopo to Lotsane confluence	Lim_EF11	591	2
	Limpopo – Lotsane to Shashe	Lim_EF12		
RR3	Shashe	Lim_EF13	687	9
RR4	Limpopo – Shashe to Mzingwani	Lim_EF14	1684	2
	Mzingwani	Lim_EF15	438	7
	Sand	Lim_EF16	91	6
	Bubye	Lim_EF17	200	11
RR5	Luvuvhu	Lim_EF18	560	2
RR6	Mwanedzi	Lim_EF19	412	11
RR7	Olifants – to Blyde	Lim_EF20	1322	2
	Olifants – to Letaba	Lim_EF21	1910	2
RR8	Letaba – to Little Letaba	Lim_EF22	441	2
	Letaba – to Olifants	Lim_EF23	642	3
RR9	Shingwedzi	Lim_EF24	96	9
RR10	Limpopo – Mzingwani to Mwanedzi	Lim_EF25	2792	3
	Elephantes	Lim_EF26	2712	2
	Limpopo – to estuary	Lim_EF27	5572	3
Perennial system – 1-4				
Seasonal system – 5				
Ephemeral system - > 6				

Ecological responses

The ecological responses to the drivers of change in this PROBFLO implementation have focused on three biological components, the fish, benthic macroinvertebrates, and riparian vegetation. While it would be possible to consider other responses as well, these components were the most wide-spread, well known and amenable to interpretation. The detail of the information collected was provided in Report 6: *Present Ecological State of the Limpopo River: Ecological Responses to Change*.

The fish assessment indicated that there is a noticeable and significant change in the fish community structure of the Limpopo River Basin with most sites assessed being in a Moderately to Largely Modified state; mainly due to altered flows, altered habitats, barriers, water quality, alien invasive species and overexploitation. The sites closest to anthropogenic activities were in a worst state whereas sites within Kruger National Park had a higher present ecological status. The invertebrate communities were categorised as Moderately impaired over most of the basin, with a worse state in the Mogalakwena River, where flow was restricted to a trickle despite most other tributaries in the region experiencing high to moderate flows. The Shingwedzi River was categorised as Largely Natural to Moderate. The riparian vegetation at most of the sites was significantly degraded from natural, with the Luvuvhu and Shingwedzi being the only two sites approaching natural. The vegetation of the Shashe, Umzingwani and Limpopo at Chokwe were the most degraded mostly due to over-utilisation.

Ecosystem services

The results of the ecosystem service assessment showed that at most of the sites, there is major competition between users and the ecosystem in the basin. In the upper reaches of the catchment (Lephalale, Marico) irrigation and commercial agriculture competes with smallholder livelihoods like fishing and subsistence agriculture. In the middle parts of the basin (Luvuvhu, Mogalekwena, Olifants) cultural services (eco-tourism) are the most common and compete with small holder provisioning services, for example fishing and household water use. In the lower reaches of the basin (Chokwe), the major competition is between irrigation and subsistence water use and fishing. Most of the rural local communities rely on the ecosystem services for subsistence needs, food security and livelihood activities. However, their degree of dependency differs across communities and regions, with very high dependency in Mozambique and Zimbabwe.

It has been shown that there is uneven distribution of wealth, resources and opportunities across the basin and that people from Botswana and South Africa tend to be less dependent on ecosystem services. Based on interactions with communities, there has been loss of ecosystem services at some sites (Chokwe and Groot-Letaba) where unpredictable low flows were identified as the main reason for loss of ecosystem services affecting livelihoods. Communities along the Groot-Letaba explained that they have experienced some periods of water shortage during their agriculture growing season which have resulted in lower-than-expected yields. Since these rural communities are highly dependent on the basin's ecosystem goods and services, changes in the supply of these services would have major impacts on the sustainability of local livelihoods, and human well-being. A study undertaken in 2021 (Dickens et al, 2022) however showed that with active supplementation of river flow levels to maintain both environmental and livelihoods-oriented river flows, water shortages for the crops within the Letaba Basin could be fully eliminated. This supplementation of river flows that might be through dam releases, would improve irrigation water availability and have positive implications for the livelihoods of subsistence farmers, who would be able to cultivate crops all year round. For this scenario to be realistic, it would depend on the availability of upstream water resources that may entail restriction of current water uses further upstream. Thus, sustainably maintaining the e-flow and smallholder farmers in the Letaba area may not be possible or may require limiting water abstraction upstream, an option that could create conflicts with upstream commercial farmers.

2.3 RISK REGION SELECTION

Risk regions are major sub-basin regions as determined by a combination of socio-economic and biophysical characters including transboundary issues. For the selection of risk regions in this study a combination of the political boundaries and associated socio-ecological activities, management objectives from existing IWRM, source information, and available habitat data was used to establish geographical risk regions for the relative risk assessment (Landis 2004; O'Brien and Wepener, 2012). Note that political boundaries do NOT play a major role in the allocation of risk regions. These regions allow the outputs of the assessment to be presented at a spatial scale with multiple regions compared in a relative manner. Through this approach, the dynamism of different regions can be incorporated into the study and allow for a holistic assessment of flow and non-flow variables. The approach can address spatial and temporal relationships of variables between risk regions, such as the downstream effect of a source of stress on multiple risk regions, in the context of the assimilative capacity of the ecosystem or the requirements of ecosystem response components e.g., fish.

The results of the PROBFLO assessment will be reported under the ten risk regions identified in the Limpopo basin, namely: 1) Marico Crocodile, 2) Upper Limpopo, 3) Shashe, 4) Middle Limpopo, 5) Luvuvhu, 6) Mwenedzi, 7) Olifants, 8) Letaba, 9) Shingwedzi and 10) Lower Limpopo (Figure 2-3). The Changane area in Mozambique has not been included in the project and is thus not considered as a risk region. The reason for this exclusion is based on the experience gathered while collecting data for the Monograph e-flow study, where although the basin is large with many inhabitants, the area is largely wetland with little flowing river channel. The water was also highly saline resulting from groundwater intrusion. The Changane catchment is also relatively independent of the rest of the river, entering near to the estuary, and thus does not contribute to the overall Limpopo main-stem hydrology.

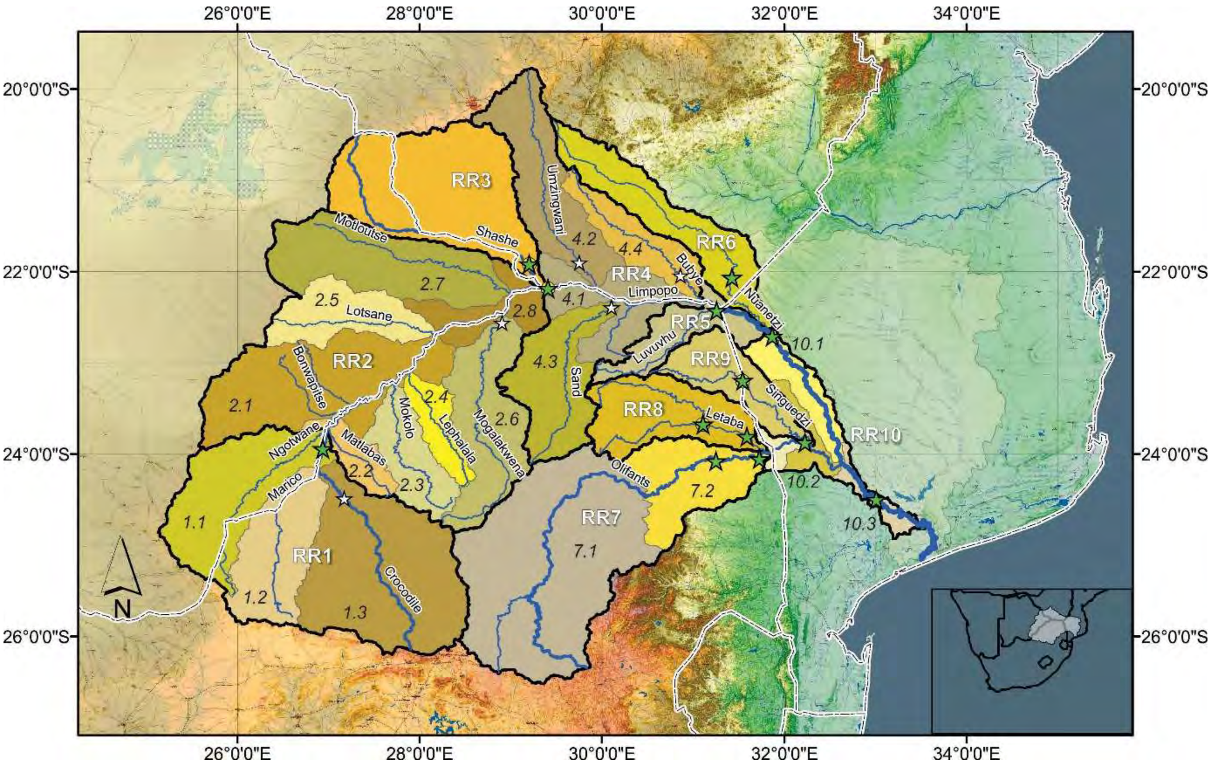


Figure 2-3: The ten risk regions selected for the Limpopo e-flow study

The present ecological state of the water resources was determined by undertaking surveys of sites in the upper, middle and lower Limpopo Basin (Table 2-5) with the results reported in Report 6. Each site was located in the lower reaches of important tributaries, and within the Limpopo River main stem at selected locations to consider changes in instream habitat and consider the effect of upstream drivers of change to the ecosystems.

In addition to the 18 sites that were surveyed in the study, the PROBFLO approach was used in an e-flow framework context (Horne et al., 2017) where desktop e-flows were established for five additional seasonal tributaries, four in Botswana and one in Zimbabwe. This approach was implemented in the study to fill gaps in available e-flow data using a desktop extrapolation e-flow determination approach for sites where no field data was collected. This approach to infer ecosystem requirement data from one site to another is based on a holistic e-flows framework approach such as ELOHA (Poff et al., 2010; Horne et al., 2017). The Ngotwane sub-basin's requirements were inferred from the Matlabas sub-basin, the Marico sub-basin from the Crocodile sub-basin, the Bonwapitse, Mokolo, Lotsane, Motloutse and Bubye sub-basins from the Sand sub-basin and the upper Olifants sub-basin from the lower Olifants sub-basin.

Table 2-5: The risk regions, rivers/sub-basin and description for the sub-basins assessed in the Limpopo Basin

Risk Region	River/sub-basin	Description
1. Marico Crocodile	1.1 Ngotwane River	The Ngotwane is naturally a seasonal system with very low to no flows during the drier months and large floods during summer. Water use in upper catchment for urban, mining and irrigation with two dams, namely Gaborone (FSC = 141.4 MCM) and Bokaa (FSC = 18.5 MCM). Significant transmission losses in the lower reaches of the river. Requirements inferred from Matlabas River
	1.2 Marico River	The Marico is naturally a perennial system with large quantities of dolomitic water in the upper reaches. The Molatedi Dam (FSC = 200.95 MCM) on the lower reaches release water to the Twasa Weir for irrigation downstream at Derdepoort. Water can also be transferred to Botswana if required. Requirements inferred from the Crocodile River
	1.3 Crocodile River	The Crocodile (West) is naturally a perennial system. Water use is extensive in the upper reaches for urban and industrial. Large WWTW also release water into the rivers after treatment. A number of large dams are situated on the main stem as well as major tributaries, with the larger dams the Hartbeespoort (FSC = 194.8 MCM), Roodekopjes (FSC = 102.61 MCM), Vaalkop (FSC =55.3 MCM), Roodeplaat (FSC = 43.57 MCM) and Klipvoor (FSC = 42.4 MCM). Water is released from these dams for domestic, industrial and irrigation purposes. There are no major dams in the lower reach of the Crocodile (West) River, but extensive irrigation occurs, both from the river and aquifers.
2. Upper Limpopo	2.1 Bonwapitse River	The river is naturally an ephemeral system with no significant water uses. Significant transmission losses in the lower reaches of the river. Requirements inferred from the Sand River.
	2.2 Matlabas River	The upper reaches of the Matlabas is naturally a perennial system, but the lower reaches can be dry during dry periods. Water use is mainly small dams for livestock and game watering with small areas of irrigation.
	2.3 Mokolo River	The Mokolo River is naturally a perennial system.

Risk Region	River/sub-basin	Description
		The Mokolo Dam (FSC = 146.0 MCM) in the middle reaches of the river provides water for extensive irrigation downstream. Requirements inferred from the Sand River.
	2.4 Lephalala River	This river is naturally a perennial system. Extensive irrigation occurs in the upper and middle reaches with numerous small dams on the main stem river and tributaries.
	2.5 Lotsane River	The river is naturally an ephemeral to episodic river with long periods of no flow and large floods. The Lotsane Dam (FSC = 40.0 MCM) is situated in the middle reaches with the purpose to supply urban water. Significant transmission losses in the lower reaches of the river. Requirements inferred from the Sand River.
	2.6 Mogalakwena River	This system is naturally a perennial system. Extensive irrigation occurs in the system from numerous small dams and a few larger dams namely Doorndraai (FSC = 44.2 MCM), Rooiwal (FSC = 6.81 MCM) and Glen Alpine (FSC = 19.95 MCM).
	2.7 Motloutse River	The river is naturally ephemeral with no flows for a large percentage of time during the low flow month and larger floods during the wet months. Water use is mainly by the mining sector A number of large dams are situated on the river, with the Letsibogo (FSC = 100.0 MCM) and Thune (FSC = 90.0 MCM) dams the main source of water. Significant transmission losses in the lower reaches of the river. Requirements inferred from the Sand River.
	2.8 Limpopo River	This reach of the Limpopo River is naturally perennial. The Crocodile, Marico, Ngotwane, Matlabas Bonwapitse, Mokolo and Lephalale contributes to the flows in this reach. Most of the water uses occur in the tributaries with some irrigation from the main stem. Significant transmission losses and alluvial storage in this reach of the river.
	2.9 Limpopo River	This reach of the Limpopo River is naturally perennial. The Mogalakwena, Lotsane and Motloutse contributes to the flow s in this reach of the Limpopo. Some abstractions for irrigation from the main stem. Significant transmission losses and alluvial storage in this reach of the river.
3. Shashe	3. Shashe River	The Shashe is naturally an ephemeral system, especially in the lower reaches with no flows during most of the winter months. A number of large dams for urban water supply are present in this catchment with the largest urban user Francistown. The larger dams are the Shashe Dam (FSC = 87.9 MCM), Ntimbale (FSC = 26.4 MCM) and the Dikgathong (FSC = 400.0 MCM). These dams are mostly for urban water use within the catchment, but water is also transferred to other catchments. Significant transmission losses and alluvial storage in the lower reaches of the river.
4. Middle Limpopo	4.1 Limpopo River	This reach of the Limpopo River is naturally perennial. The Shashe is the only major tributary of the Limpopo in this reach. Abstractions for extensive irrigation occurs in this reach. Significant transmission losses and alluvial storage in this reach of the river.

Risk Region	River/sub-basin	Description
	4.2 Umzingwani River	The river is naturally ephemeral with almost no flows during the low flow months and larger floods during the wet months. A large number of dams, including the Mzingwane Dam (FSC = 42.1MCM) occur within this catchment, mostly for urban (Bulawayo and others) and irrigation demands. Significant transmission losses and alluvial storage in the lower reaches of the river.
	4.3 Sand River	The Sand River is naturally a seasonal to ephemeral system. A number of dams (Houtrivier, FSC = 6.93 MCM; Turfloop, FSC = 3.35 MCM; Dikgale, FSC = 8.25 MCM) are situated within the catchment for mainly irrigation demands.
	4.4 Bubye River	The river is naturally ephemeral with almost no flows during the low flow months and larger floods during the wet months. No major dams in the catchment, but a number of smaller dams mainly for irrigation purposes. Significant transmission losses and alluvial storage in the lower reaches of the river.
5. Luvuvhu	5. Luvuvhu River	The Luvuvhu River is naturally a perennial system. Water uses include afforestation in upper reaches of the catchment, irrigation and domestic. A number of large dams are in the catchment, including Albasini (FSC – 28.3 MCM), Vondo (FSC = 30.3 MCM) and Nandoni (FSC = 164.0 MCM).
6. Mwenedzi	6. Mwenedzi River	This river is naturally ephemeral with almost no flows during the low flow months and large floods during summer. The main water uses are irrigation and domestic. The Manyuchi Dam is the largest in the catchment (FSC = 309.0 MCM). Significant transmission losses and alluvial storage in the lower reaches of the river.
7. Olifants	7.1 Upper Olifants River	The Upper Olifants River is naturally perennial with a number of large tributaries contributing to the flows, including Little Olifants, Elands, Wilge and Steelpoort as the larger rivers. Large dams in the upper catchments for irrigation, mining and urban water supply include Middleburg (FSC = 47.9 MCM), Bronkhorstspruit (FSC = 58.0 MCM), Witbank (FSC = 104.0 MCM), Loskop (FSC = 374.3 MCM), Mkhombo (FSC = 206.0 MCM), Flag Boshielo (FSC = 347.6 MCM) and De Hoop (FSC = MCM). Water is also transferred from Flag Boshielo Dam to neighbouring catchments for domestic water supply. Requirements inferred from the lower Olifants River.
	7.2 Lower Olifants River	The river is natural perennial. The Blyde River contributes the largest percentage of flow to the lower Olifants River with smaller tributaries (Ga-Selati, Klaserie). No major dams are in the main stem river, with the Blyderivierspoort Dam the largest (FSC = 54.6 MCM) on tributaries. A number of smaller dams and weirs are in some of the other smaller tributaries. A major abstraction from the Olifants River is just downstream of the Ga-Selati confluence.
8. Letaba	8.1 Groot Letaba River	The river is natural perennial. Extensive forestry and irrigation together with urban and industrial water use in the upper catchment. Major dams include the Ebenezer (FSC = 70.0 MCM) and Tzaneen (FSC = 157.3 MCM) and few smaller dams in tributaries.
	8.2 Letaba River	The river is natural perennial. Tributaries contributing most to the flows in the lower Letaba are the Middle and Little Letaba rivers.

Risk Region	River/sub-basin	Description
		Lorna Dawn (FSC = 11.7 MCM), Middle Letaba (FSC = 173.1 MCM) and Nsami (FSC = 29.5 MCM) are the major dams on tributaries in the lower Letaba. No major dams are situated on the main stem Letaba. Some forestry and irrigation abstractions are present in this catchment.
9. Shingwedzi	9. Shingwedzi River	This river is naturally seasonal to perennial in the upper reaches where the e-flow site is situated. The lower reaches (especially in Mozambique) is ephemeral with almost no flows year round and large floods during summer. Abstractions for irrigation and domestic water use occur outside the KNP with the Makulele Dam the largest (FSC = 13.0 MCM). Significant transmission losses and alluvial storage in the lower reaches of the river.
10. Lower Limpopo	10.1 Limpopo River	This reach of the Limpopo River is naturally perennial. The major tributaries contributing to flow in this reach are the Mzingwani, Nzhelele, Sand, Bubye, Luvuvhu and Mwanedzi. Very little water use occurs from the main stem river. Significant transmission losses and alluvial storage in this reach of the river.
	10.2 Elephantes River	The Elephantes is naturally a perennial system. The Massingir Dam (FSC = 2840 MCM) is situated at the top of this reach and releases water for irrigation purposes in Mozambique. Significant transmission losses and alluvial storage in the lower reaches of the river.
	10.3 Limpopo River	This reach of the Limpopo River is naturally perennial. Major tributaries in this reach are the Elephantes and Changane (mainly a large wetland system). Water use is mainly abstractions for extensive irrigation in the lower reaches of the Limpopo River. Significant transmission losses and alluvial storage in this reach of the river.

2.4 CONCEPTUAL MODEL

A conceptual model was developed that represents hypothesised cause-effect relationships between stressors and receptors that represent the ecosystem services and endpoints. The basic conceptual model that is used is shown in Figure 2-4, showing how the SOURCES of change (dam development etc) lead to STRESSORS on the river (altered timing of flows, volumes of water etc). These in turn affect either the instream, riparian or floodplain HABITATS, where most of the RECEPTORS (Instream biota, etc) will be impacted. These in turn impact on socio-ecological ENDPOINTS (supply of water for agriculture, biodiversity etc).

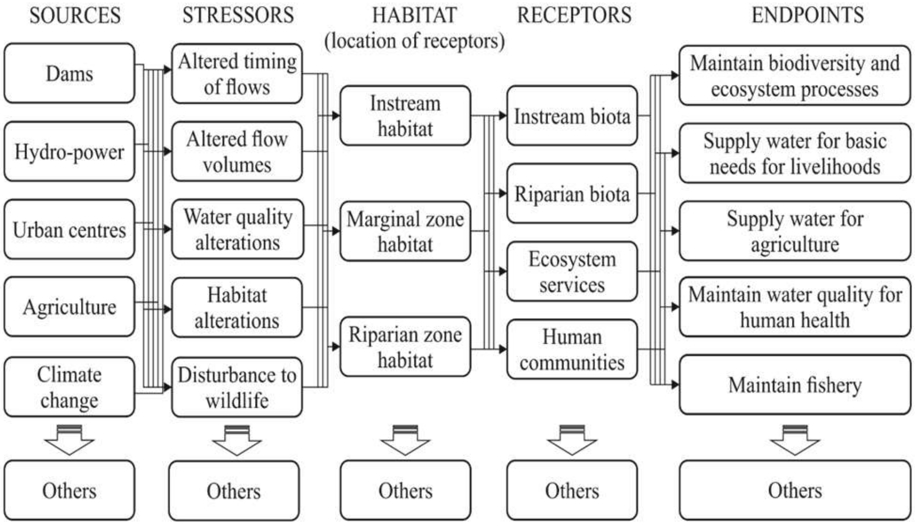


Figure 2-4: Basic conceptual model of the socio-ecological system for the Limpopo e-flow study

The basic conceptual model was expanded upon to generate a more detailed model for the project during a workshop held with the specialist team in August 2021. Due to COVID restrictions, the workshop was held on-line and spanned two days. The first day was dedicated to specialists providing an overview of the data obtained from the field surveys, and the second day to the development of the conceptual model of the socio-ecological system in a mind map format (Figure 2-5 to Figure 2-8). The conceptual model addressed the requirements of the PROBFLO approach by directing the hydrologic foundations for the study, classifying ecosystem types and incorporating evidence-based flow-ecosystem relationships and flow-ecosystem service relationships, with relevant non-flow variable relationships.

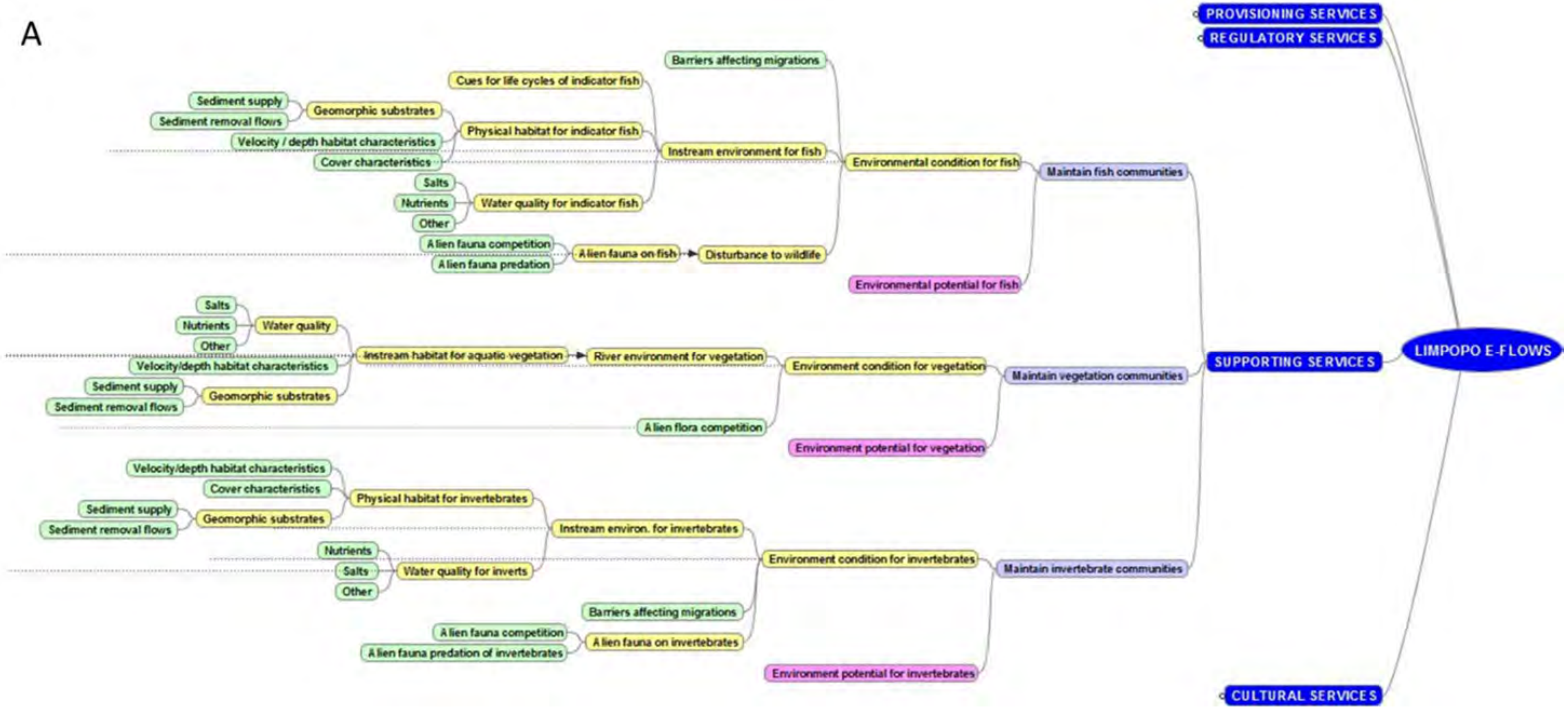


Figure 2-5: Conceptual model of the socio-ecological system for the Limpopo e-flow study A) supporting services

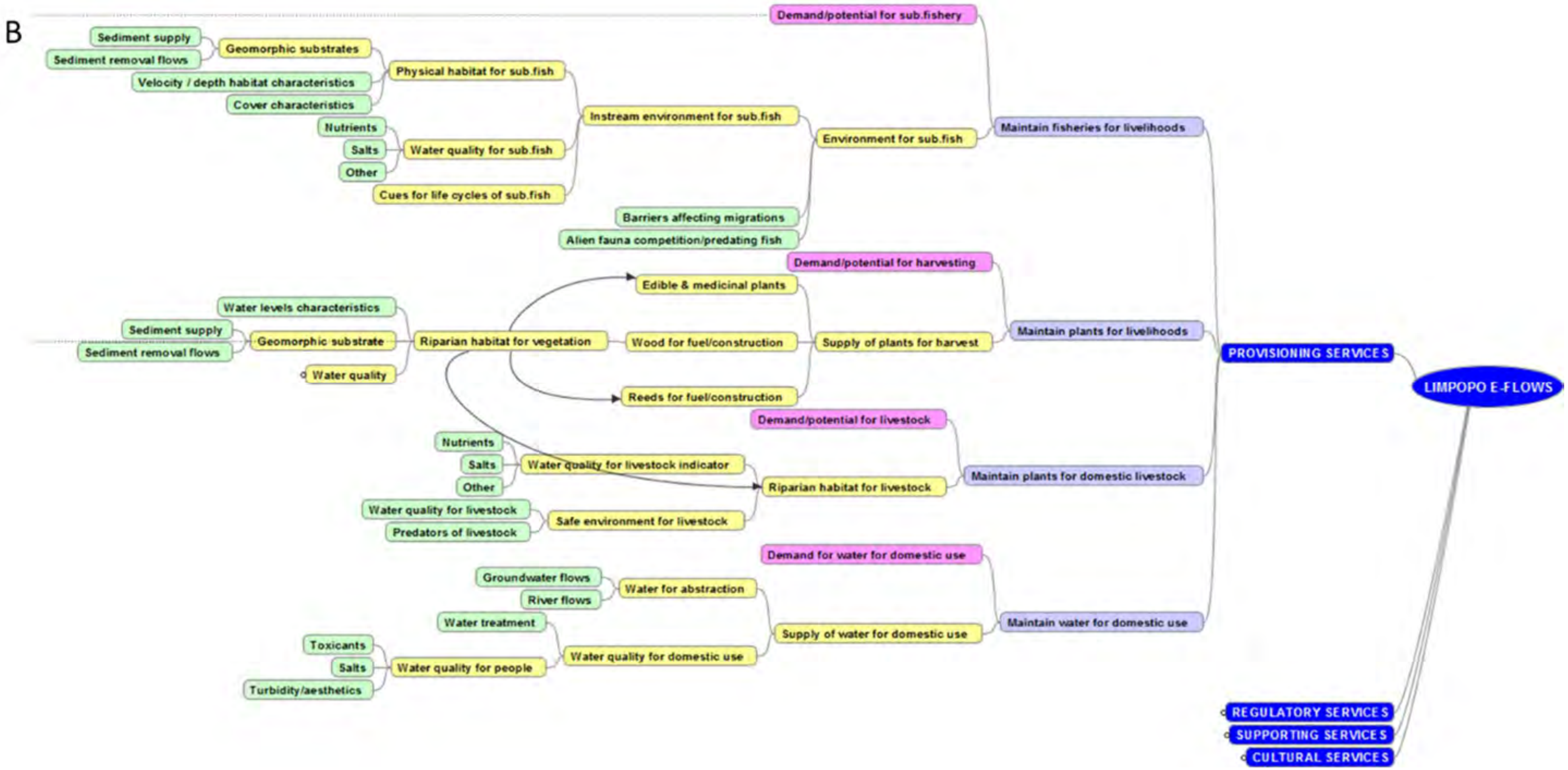


Figure 2-6: Conceptual model of the socio-ecological system for the Limpopo e-flow study B) provisioning services

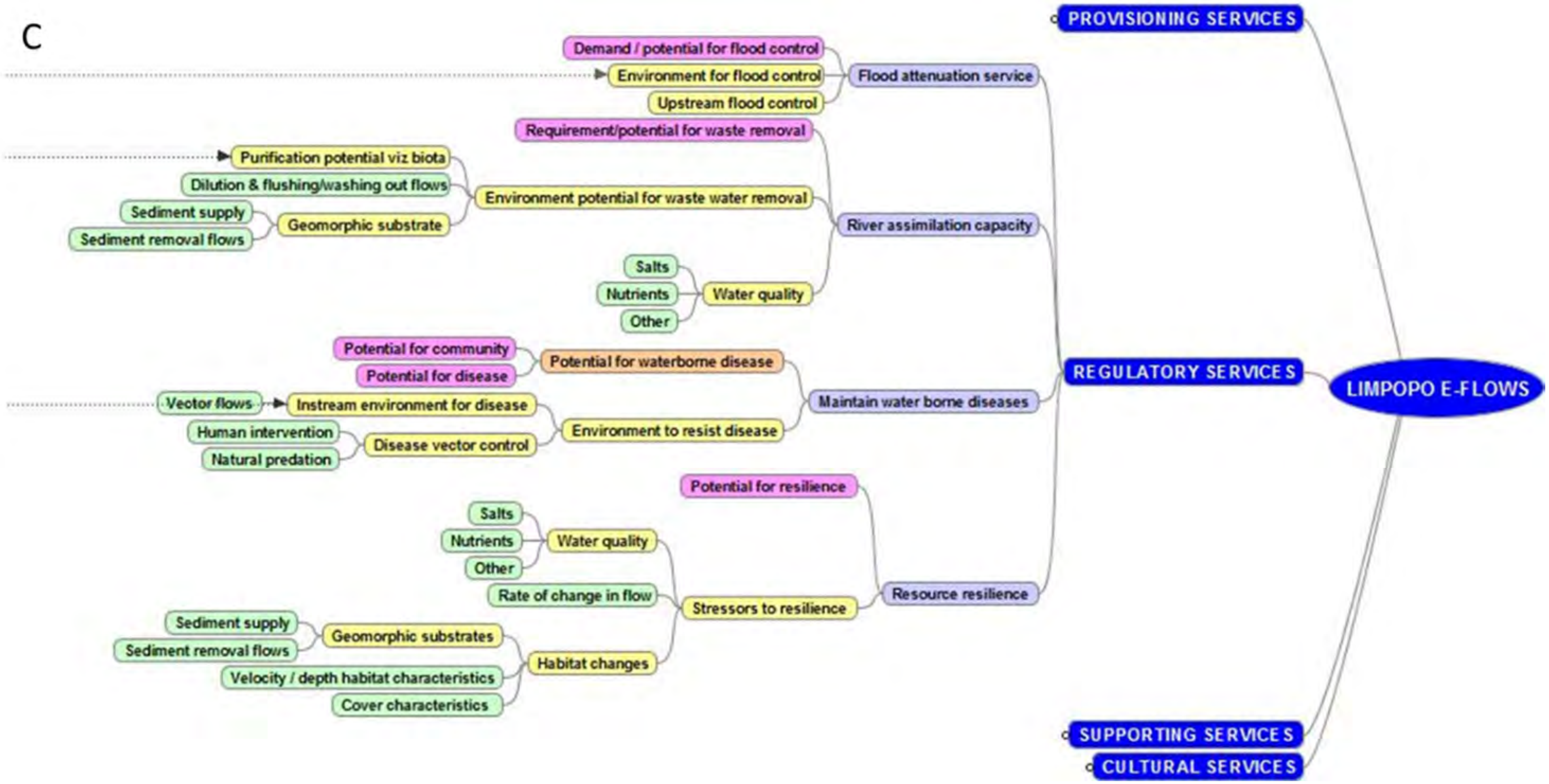


Figure 2-7: Conceptual model of the socio-ecological system for the Limpopo e-flow study C) regulatory services

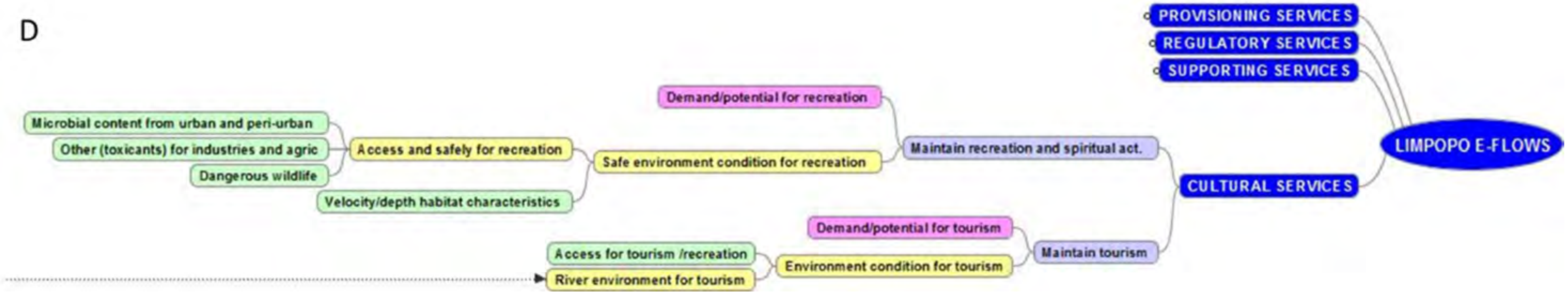


Figure 2-8: Conceptual model of the socio-ecological system for the Limpopo e-flow study D) cultural services. Node colours are aligned with the nodes in the Bayesian Network.

Explanation of the Conceptual Model

To explain the models in Figure 2-5 to Figure 2-8, it is necessary to start from the right-hand side of the Conceptual Model, with the determination of the risk of multiple flow (and non-flow) stressors to the ecosystem services endpoints (see the detail shown in Figure 2-9). The links between variables indicate that one variable is conditionally dependant on the other. The final model Figure 2-5 to Figure 2-8) is an overview that is subsequently used as the basis for the development of the BN (Figure 2-13) using the Netica software.

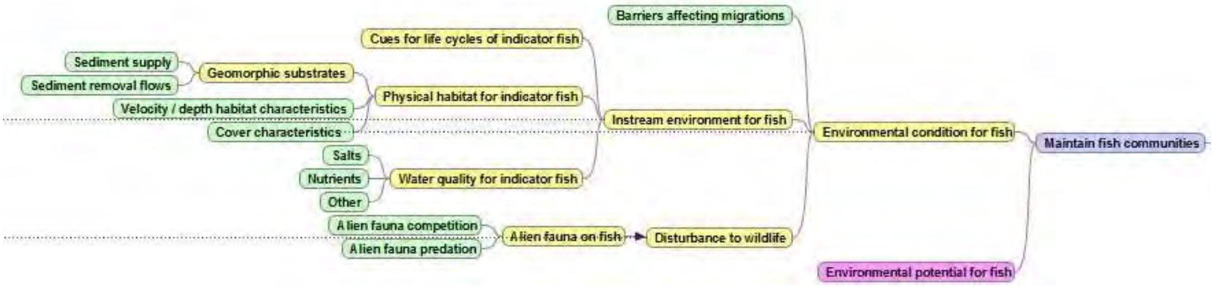


Figure 2-9: Extract from the complete Conceptual Model provided in Figure 2-5

For explanation of how the Conceptual Model works, here is an example (explaining Figure 2-9):

- The risk to the fish endpoint (MAINTAIN FISH COMMUNITY NODE) is a function of the environmental conditions that support or pose a threat to fish (ENVIRONMENTAL CONDITION FOR FISH NODE) and the potential diversity and sensitivity of fishes that may occur at the site (ENVIRONMENTAL POTENTIAL FOR FISH NODE). The data available to represent the potential for fish is available from historical data and survey results to the study area.

- The ENVIRONMENTAL CONDITIONS node is a function of the presence of, and potential for, barriers to affect river connectivity and fish migrations (BARRIERS AFFECTING FISH MIGRATION NODE), INSTREAM ENVIRONMENT FOR FISH and DISTURBANCE TO WILDLIFE potential which is in itself a function of alien fauna (ALIEN FAUNA ON FISH).

- The Data required for barriers to fish movement has been derived from a dam database, while the instream environment for fish itself is a function of CUES FOR LIFE CYCLE ACTIVITIES for fish, the PHYSICAL HABITAT FOR INDICATOR FISH and WATER QUALITY REQUIREMENTS FOR FISH. The cue node represents our knowledge of the flow requirement of migratory and summer (high flow) spawning fishes and the instream habitat characteristics of the river for these cues based on the volume and timing of flows. Available and new information obtained in this study that represents the timing and volume of water required for these indicator fish, has been used to establish a flow-ecosystem relationship that will query available flow data and represent the suitability of flows for those species. The data and how the data is used to query the suitability of flow data will be provided in the Bayesian Network report.

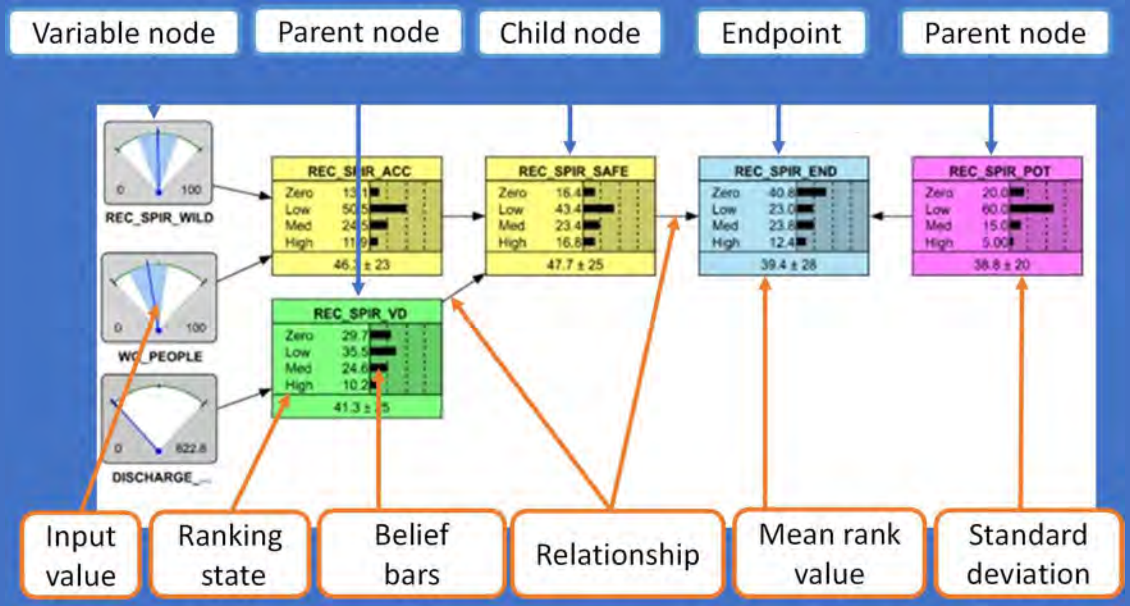
- The PHYSICAL HABITAT FOR INDICATOR FISH node is a function of the geomorphic substrate (NODE) characteristics, velocity/depth habitat characteristics (NODE) of indicator fishes and cover characteristics (NODE) for indicator fishes. The WATER QUALITY INDICATOR FOR FISH node represents the overall condition of water quality including consideration of the salts, nutrients and other (system variables and toxicants).

All input nodes are evidence based and use existing or collected (in this study) and modelled data to represent a flow (or non-flow for water quality and geomorphology characteristics) relationship with ecological variables. All of the daughter nodes are conditional to the parent nodes and integrate response relationship distributions in the form parent nodes using Conditional Probability Tables or rules that represent how the data is integrated. These relationships will also all be presented as evidence for the model.

The detailed conceptual model was used to generate BN models for each site using NeticaTM BN software (by Norsys Software) (Figure 2-13 to Figure 2-13 for example). The BN models include exposure relationships with socio-ecological system structure and function variables (green nodes) which contribute to the exposure pathway of the model (yellow nodes). The exposure component of the system is then combined with the effects (pink) component where they contribute to the overall risk to the endpoints of the study (blue nodes).

INFORMATION BOX:

BAYESIAN NETWORKS.



Grey variable node: The variable nodes are used to input variable data into the model.

Green parent node: Input nodes represent input environmental variable information related to the exposure of the system by multiple stressors

Yellow child node: All of the child nodes are conditional to the parent nodes and integrate response relationship distributions in the form of parent nodes using CPT or rules that represent how the data is integrated.

Pink parent node: The pink nodes introduce risk region or site dynamics which represents the exposure pathways of the risk framework. It represents the potential for an endpoint to occur in a risk region that represents the effects part of the risk model

Endpoint: Presents the overall risk to the endpoints.

Ranking state: The name of each ranking state (zero, low, medium, high) and the number representing the belief (probability) of the state as a percentage.

Belief bars: The belief (probability) percentage of the state presented graphically. The dotted vertical lines me the 25%, 50% and 75% levels.

Relationships: Represents the relationships or links between the nodes.

Mean rank value: The average rank value most likely to occur, weighted by the probability of the occurrence of the ranks. For example in this case the most likely rank score is 39.4 or a low risk rank.

Standard deviation: Represents the risk rank variability and the confidence of the risk projections.

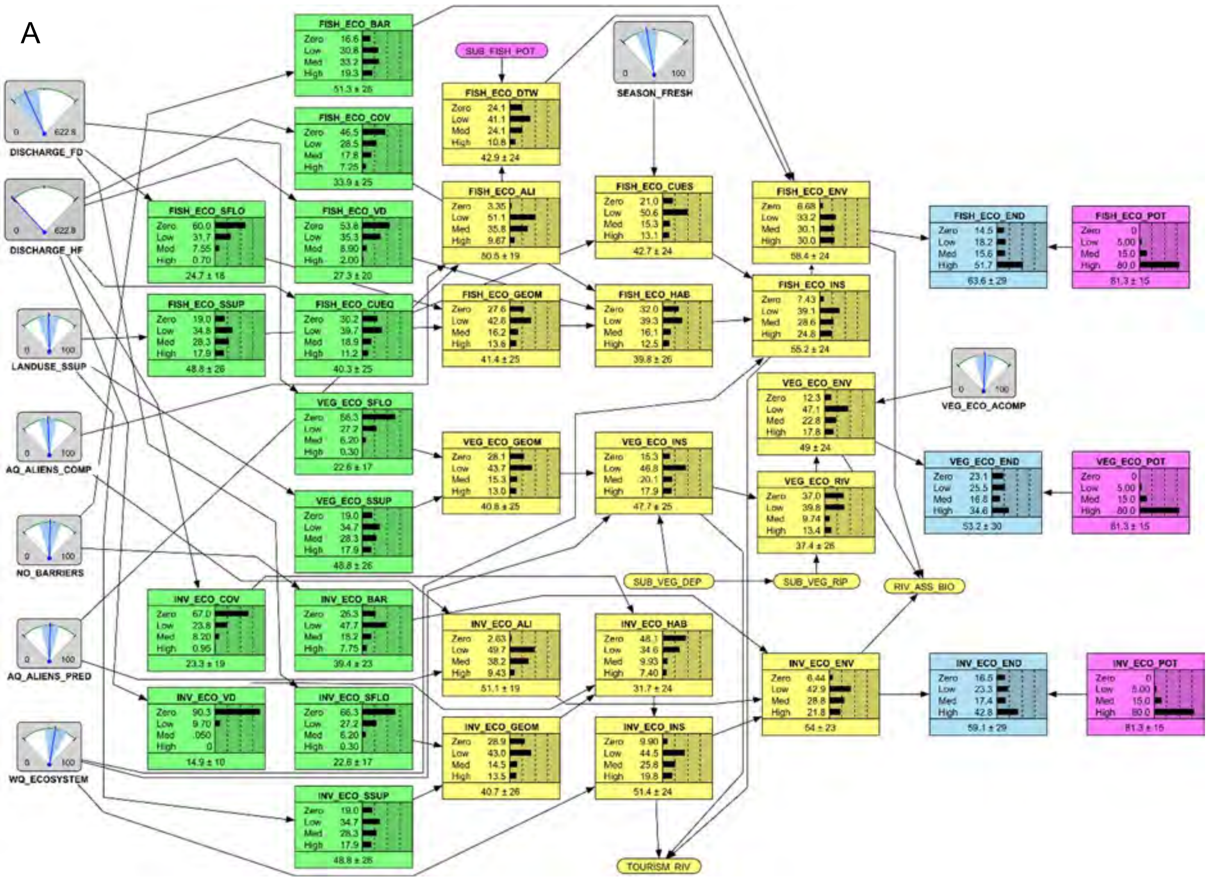


Figure 2-10: Bayesian network developed using Netica software for the Limpopo e-flow study (prior to population with data). (A: Supporting services)

2.5 RANKING SCHEME

The ranking scheme allows for the calculation of relative risk for each endpoint and represents the range of well-being conditions, levels of impacts and management ideals as detailed in Table 2-6 (O'Brien et al, 2018; Wade et al, 2020). These ranks are based on the four states traditionally used in RRM, namely zero, low, moderate and high (Colnar & Landis, 2007; O'Brien and Wepener, 2012; Hines & Landis 2014).

Zero risk usually represent a reference state with low risk states representing management targets with little impact. Moderate risk states represent partially suitable ecosystem conditions that usually warrant management/mitigation measures to avoid high-risk conditions that are deemed unacceptable. The incorporation of BN modelling into PROBFLO, allows the approach to incorporate the variability between ranks as a percentage for each rank. Indicator flow and non-flow variables are selected (linked to endpoints), and unique measures and units of measurement are converted into and represented by ranks for integration in BN assessments (O'Brien et al, 2018). For comparison between the use of ecological state (EcoClassification classes) and risk ranks a comparison is provided in Table 2-7.

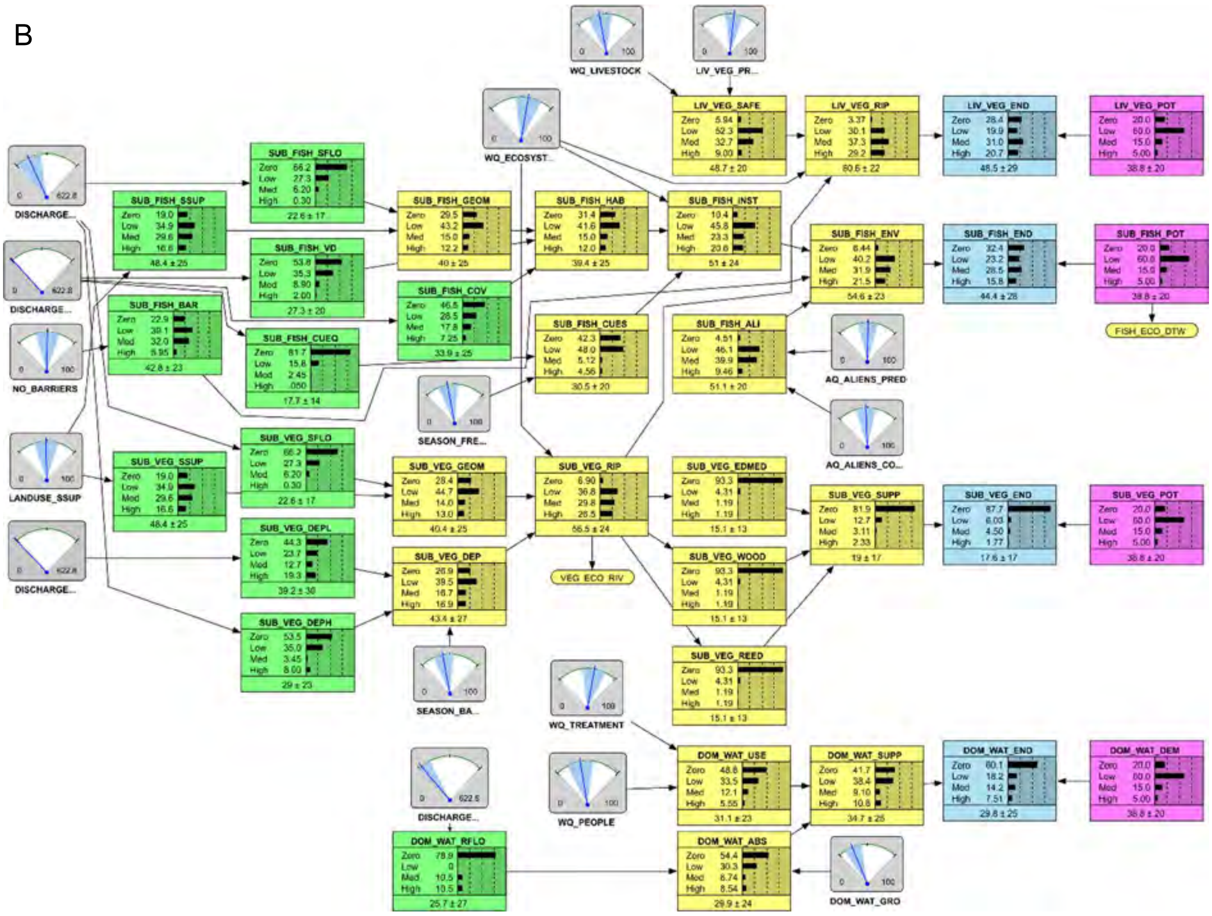


Figure 2-11: Bayesian network developed using Netica software for the Limpopo e-flow study (prior to population with data). (B: Provisioning Services)

Table 2-6: Ranking scheme selected for the Limpopo e-flow study (O'Brien et al, 2018)

State (risk score)	Description
Zero (0-25)	Pristine/baseline/reference state with no impact or risk compared to the pre-anthropogenic source establishment
Low (26-50)	Largely natural state with low impact /risk, ideal range of sustainable ecosystem use
Moderate (51-75)	Moderate use/risk/impact or modified state representing a threshold of potential concern and possible failure threshold
High (76 -100)	Significantly altered/impaired state with unacceptably high impact/risk

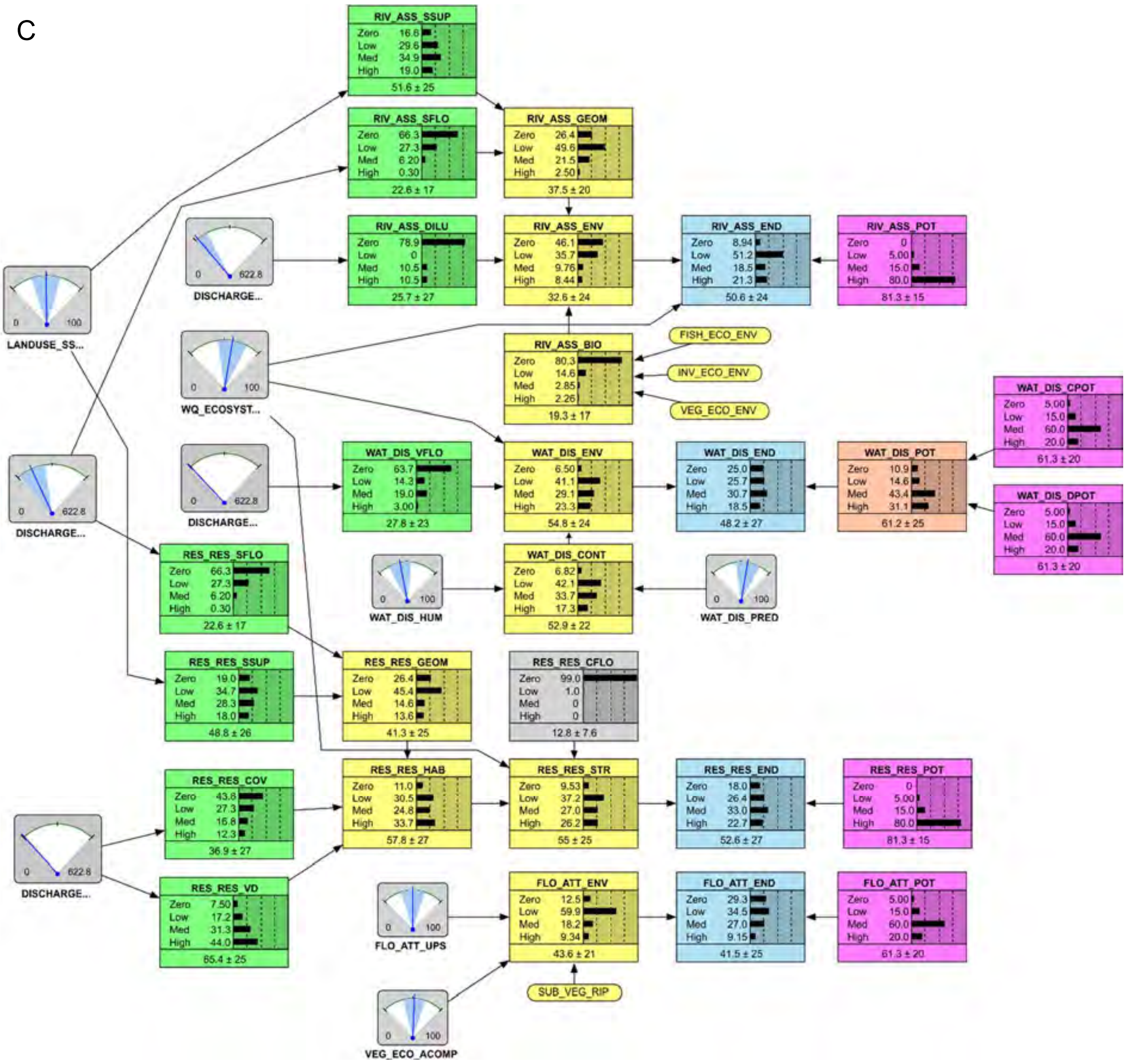


Figure 2-12: Bayesian network developed using Netica software for the Limpopo e-flow study (prior to population with data). (C: Regulatory services)

Table 2-7: Comparison between EcoClassification A-F and risk rank system used in the study.

Ecoclassification system		Risk rank classification system	
Colour (class)	**State**	**Risk rank**	**Definition**
A	Natural/pristine	Zero	Zero risk or no potential to change variable from natural/ideal state.
B	Largely natural		
C	Moderately modified	Low	Low risk with moderate potential for change. Suitable condition.
D	Largely Modified	Moderate	Threshold of potential concern
E	Seriously modified	High	High risk, unacceptable, unsustainable condition
F	Critically modified		

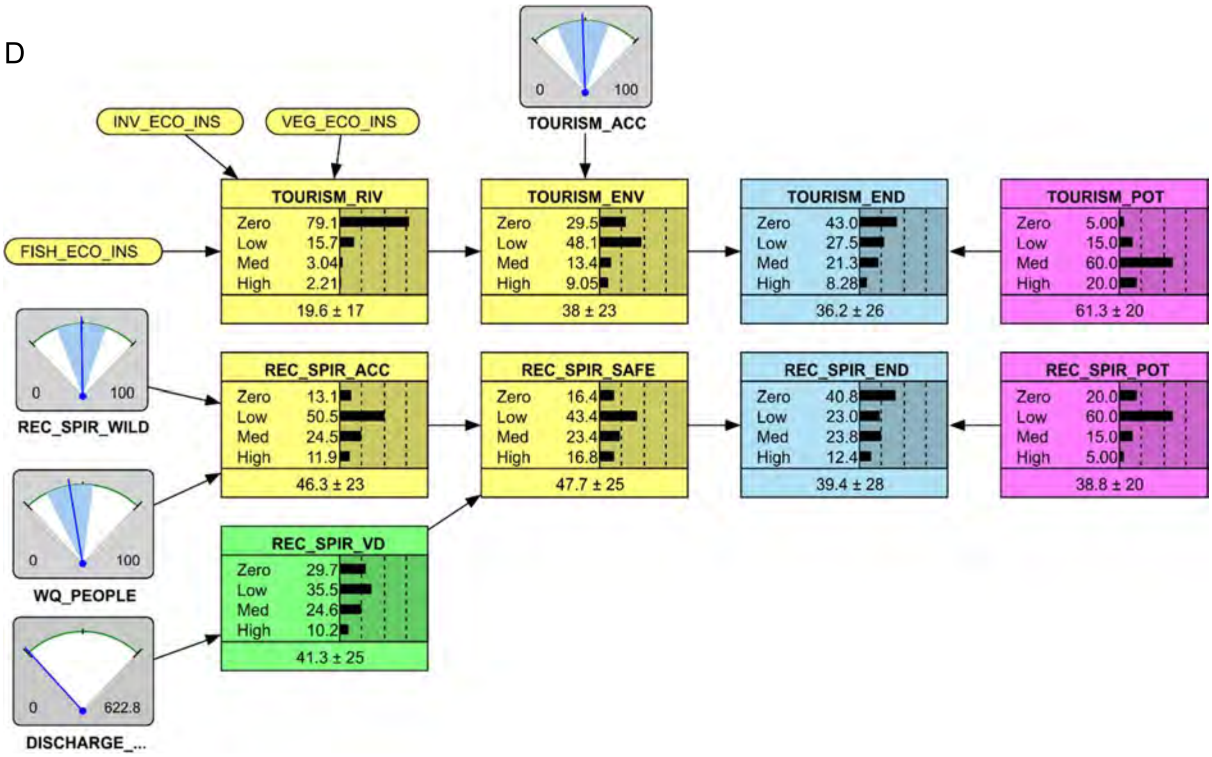


Figure 2-13: Bayesian network developed using Netica software for the Limpopo e-flow study (prior to population with data). (D: Cultural services)

3 RISK TO ECOSYSTEM SERVICES

This section presents the results and a discussion of the outcome of the relative risk calculations per ecosystem service (provisioning, regulatory and cultural services that represent the social parts of the system and the supporting services that represents the ecological requirements of the system). The graphs and corresponding maps present the trends in the relative risk scores for the four scenarios (natural, present, e-flows and drought) for each risk region representing the sub-catchment areas of the Limpopo Basin. Detailed results are provided for each endpoint in APPENDIX B, with graphs of probable risk. While the relative risk of the flow and non-flow stressors to the endpoints of the study have been determined using the RRA-BN approach, resulting in risk distributions for each endpoint or component of the socio-ecological system we have selected in the study to represent the whole system, we have used a Monte Carlo randomisation approach (1 000 iterations) to integrate the risk from endpoints per ecosystem service category (refer to the information box below).

INFORMATION BOX:

MONTE CARLO METHOD USED TO INTEGRATE RISK TO ECOSYSTEM SERVICES.

The approach adopted is to integrate the risk scores into ecosystem service categories as described in detail in O'Brien et al. (2018) and includes the use of Oracle Crystal Ball ® software. The risk profiles of each endpoint per ecosystem service category have been combined through addition where risk ranks (zero, low, moderate and high) have been assigned to each of the 1 000 random iterations, based on the risk distribution outcomes of the RRM-BN assessment.

For example, for each scenario where the wellbeing of the fish (FISH-ECO-END), invertebrates (INV-ECO-END) and riparian vegetation (VEG-ECO-END) endpoints are combined, their risk profiles which may include, for example for FISH-ECO-END for NAT scenario, 66.4% chance of a zero risk rank and a 16.5% chance of a low risk rank with an 8.5% and 8.4% chance of a moderate and high risk rank respectively. Using this information the Monte Carlo assessment assigns a rank score of 25 to the FISH-ECO-END 66.4% of the time and for low 16.5% of the time etc., for the 1 000 random iterations. These scores are then randomly added to the ranks associated with the frequency distribution of the INV-ECO-END and VEG-ECO-END endpoints.

This approach is somewhat conservative as any risk outcome between 0 and 25 is allocated a zero risk rank (25) etc. with any score between 75 and 100 allocated a high risk rank (100) for the integration. This approach has been established as a suitable risk endpoint integration approach where there are no links between co-variables or endpoints of each ecosystem service that can be modelled using the RRM-BN. This approach is only used to communicate the probable socio-ecological consequences of altered flow and non-flow stressors per ecosystem category.

3.1.1 Supporting Services

The water resources within the Limpopo basin provide supporting services to the associated fish, vegetation and invertebrate communities (Table 2-2). This service primarily represents the requirements of the ecosystem for flows and was used to establish the EFLOW scenario in the study. The condition of this service is determined by the quantity and quality of the water resources and the habitat provided.

Figure 3-1 to Figure 3-3 provides an example of the graphs and maps generated that illustrate the probable risk posed to the fish communities (FISH-ECO-END) endpoint within each risk region for each scenario (NAT - natural, PRS – present, EFLOW – e-flow and DRGHT – drought) distinguished by different colours. *Graphs and maps for the other endpoints are in APPENDIX B.*

3.1.1.1 FISH-ECO-END Endpoint

The results for the FISH-ECO-END indicate that under NAT conditions, the relative risk posed to the fish community endpoint is dominated by a low to zero rank for all risk regions (Figure 3-1, Figure 3-3A) but under PRS conditions (Figure 3-1, Figure 3-3B), the risk increases into the moderate category for most risk regions and into the high category for the whole Olifants sub-basin (RR7.1 and RR7.2), as well as for the Groot Letaba sub-basin (RR8.1). These three risk regions have a 78% probability of the high risk occurring (Figure 3-2) and the fish communities being in a Seriously Modified state under PRS conditions. The Luvuvhu sub-basin (RR5) remains in a low-risk category for PRS and EFLOW conditions.

The proposed e-flows scenario results in a reduction in risk for many risk regions but due to the requirement for e-flows to maintain Moderately Modified or Largely Modified ecological states, the risk to the fish at many of the sites remains the same as present when under EFLOW conditions, or increases slightly into the moderate or threshold of potential concern (RR1.2 Marico, RR2.2 Matlabas, RR.2.5 Lotsane, RR2.6 Mogalakwena, RR2.7 Motloutse, RR5 Luvuvhu, RR6 Mwenedzi, RR7.2 Olifants, RR8 Letaba, RR10.1 Limpopo and RR10.2 Elephantes) (Figure 3-1, Figure 3-3C).

While the impact of altered flows to the supporting services of the Limpopo Basin, including the fish, is severe, the vision for the river, which considers the suitability of the river to provide other services for social and economic benefits, has resulted in a hardworking but sustainable resource vision for the majority of the basin (Refer to Report 3 where the vision was used to determine e-flows). In this study the states of the fish communities are still considered to be sustainable (moderate risk or Largely Modified states) and may be appropriate for hard working rivers.

The majority of the risk regions remained in a moderate risk category for the e-flows scenario except for the whole Olifants (RR7) and Groot Letaba (RR8.1) sub-basins that still remained in a high-risk category with probability of failure varying between 77.8% (RR7.1) and 82.3% (RR8.1) (Figure 3-2). These risk projections in the Letaba and Olifants Rivers are excessive and suggest that the e-flows are not sufficient to maintain suitable fish communities in these rivers, but these e-flows cannot be adjusted as they have been formally gazetted through the National Water Act (108 of 1998) in South Africa as a part of the Resource Directed Measures of the country.

The worst-case DRGHT scenario places many more risk regions within a high risk category (RR1.2 Marico, RR1.3 Crocodile, RR2.6 Mogalakwena, RR2.8 Limpopo, RR3 Shashe, RR4.1 Limpopo, RR4.2 Umzingwani, RR4.4 Bubye, RR5 Luvuvhu, RR7 Olifants, RR8 Letaba and RR10.3 Limpopo) (Figure 3-1, Figure 3-3D). The risk regions with more than 75% probability of fish communities being in a serious to critical condition during a worst-case drought include: Marico (RR1.2), Mogalakwena (RR2.6), Limpopo mainstem (RR2.8), Shashe (RR3), Olifants (RR7.1 and RR7.2), Groot Letaba and Letaba (RR8.1 and RR8.2) (Figure 3-2).

3.1.1.2 INV-ECO-END Endpoint

As with the FISH-ECO-END endpoint, the relative risk posed to the invertebrate community (INV-ECO-END) endpoint under NAT conditions was zero to low (Figure 9-4 and Figure 9-6A). Under PRS conditions, many of the risk regions are within a moderate risk category except for the Limpopo mainstem from RR2.9, downstream (RR4.1, RR10.1 and RR10.3) towards the floodplain, as well as the Luvuvhu sub-basin (RR5), which are in a low risk category (Figure 9-4 and Figure 9-6B). The Marico sub-basin (RR1.2) presents the highest probability of failure (69.8%) under PRS conditions with RR2.1, RR2.3, RR2.5, RR4.3, RR7 all having between 55.45% and 58.56% change of failure (Figure 9-5). The

EFLOW scenario shows a reduction in the relative risk scores for some risk regions but many had similar or slightly increased relative risk scores (RR2.2 Matlabas, RR2.3 Mokolo, RR2.5 Lotsane, RR2.6 Mogalakwena, RR2.7 Motloutse, RR3 Shashe, RR4.2 Umzingwani, RR4.3 Sand, RR6 Mwenedzi, RR7 Olifants, RR8.1 Groot Letaba, RR10.2 Elephantes and RR10.3 Limpopo), although still within the low to moderate risk ranges (Figure 9-4 and Figure 9-6C). The Lephalale (RR2.4) and Shingwedzi (RR9) sub-basins were the only two sub-basins where the relative risk improved to a low risk category for the e-flows scenario compared to the moderate risk predicted for the PRS scenario. The EFLOW scenario showed similar or a reduction in the probability of failure for all sites with only the Marico and Olifants basin having a probability over 50% (59.3% and 55.5% respectively) (Figure 9-5). The DRGHT scenario does not impact the INV-ECO-END endpoint as dramatically as predicted for the FISH-ECO-END endpoint with most risk regions falling within the upper range of the moderate risk category (Figure 9-4 and Figure 9-6D). Only the Marico (RR1.2) sub-basin falls with the high-risk category with a 72.1% probability of failure during DRGHT conditions (Figure 9-5). Most of the remaining risk regions had a probability of failure between 51.2% and 67.2% with only RR4.1, RR5 and RR10 being below 50% (Figure 9-5).

3.1.1.3 VEG-ECO-END Endpoint

The VEG-ECO-END endpoint also reflects zero to low relative risk to all risk regions for the NAT scenario (Figure 9-7 and Figure 9-9A) but under PRS conditions, the relative risk for most sites increases into the upper range of the moderate risk category (Figure 9-7 and Figure 9-9B), uniformly high relative to the fish and invertebrates. The relative risk predicted for the Crocodile (RR1.3) and Groot Letaba sub-basins (RR8.1) falls within the high-risk category with a probability of failure being 73.8% and 72.5% respectively (Figure 9-8). Although the Marico (RR1.2) sub-basin is within a moderate risk category, its probability of failure under PRS conditions is 81.2% (Figure 9-8). The average probability of failure for all risk regions for the PRS scenario is 61.6% compared to the average for the e-flows scenario which is 47%. The VEG-ECO-END endpoint reflects a greater reduction in risk between the present and EFLOW scenarios for most of the sites when compared to the other supporting services, although all the sites still remained within the moderate risk category (Figure 9-7 and Figure 9-9C). Only the Ngotwane (RR1.1), Sand (RR4.3) and Luvuvhu (RR5) sub-basins showed similar or slight increases in the relative risk scores for the EFLOW scenario compared to the PRS scenario. The DRGHT scenario predicts high relative risk for the whole of RR1-4, 6, and 8 with probability of failure ranging from 74.3% - 82.6%. Risk regions 5, 7, 9 and 10 were in the upper range of the moderate risk category (Figure 9-7 and Figure 9-9D) with probability of failure ranging between 60.7% and 70.7% (Figure 9-8). The vegetation community of the Matlabas sub-basin (RR2.2) has the highest relative risk score of 88.3 and a probability of failure of 80.1% under DRGHT conditions. While the probable ecological consequence of the altered flows associated with the e-flows will improve riparian vegetation communities from present states, the high potential for high risk or periodic failure is concerning and need to be monitored.

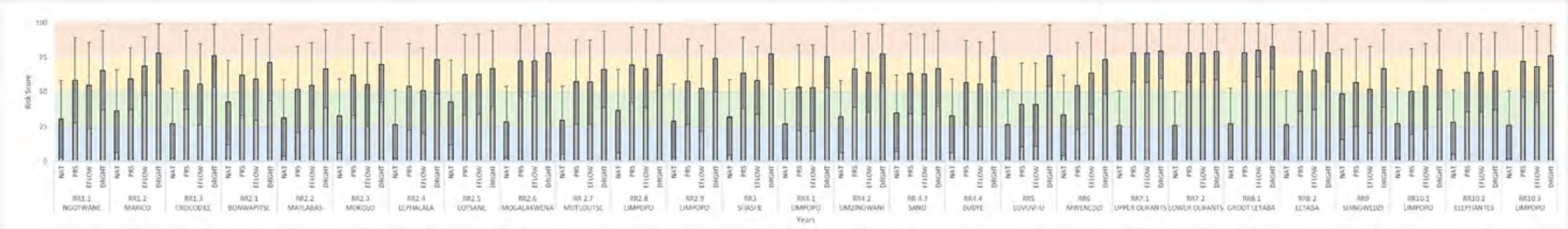


Figure 3-1: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to FISH-ECO-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

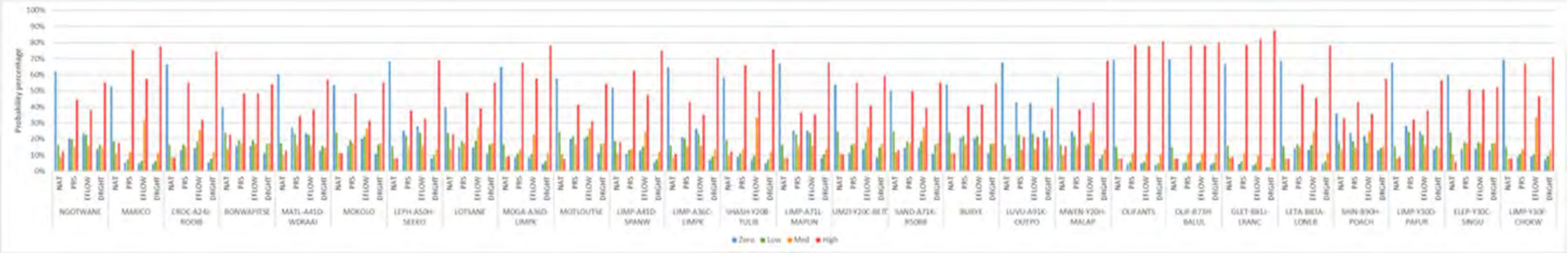


Figure 3-2: Probability of each risk rank occurring as a percentage to the FISH-ECO-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

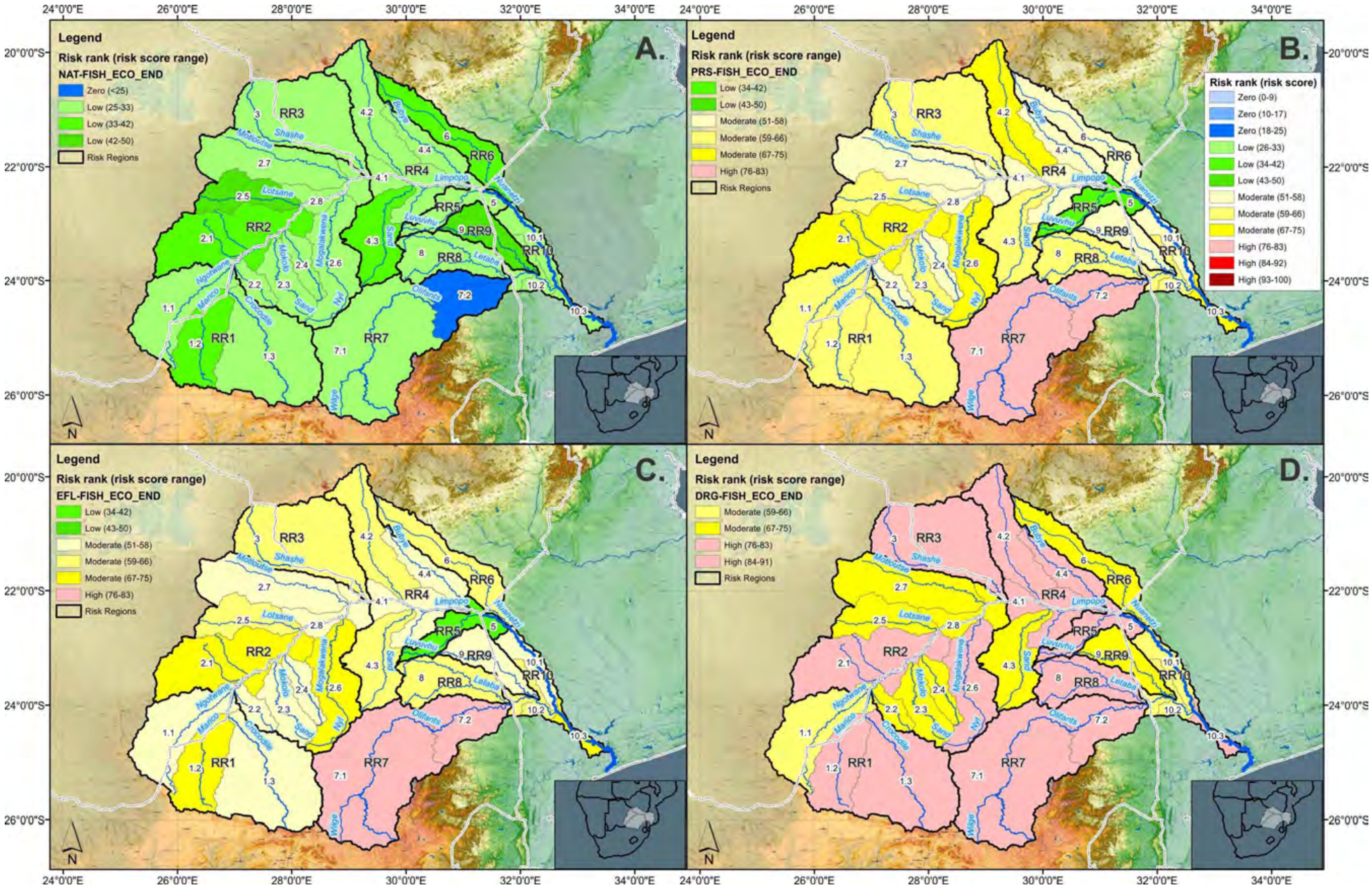


Figure 3-3: Relative risk scores to FISH-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

3.1.1.4 Combined risk for supporting services

The combined relative risk scores for the three supporting services for each scenario is represented in Figure 3-4A-D. As expected, the relative risk for the NAT scenario is low for most risk regions but for the PRS scenario a high risk is predicted for many of the risk regions, especially most of the more ephemeral sub-basins with the Marico (RR1.2) and Olifants sub-basins (RR7) reflecting the highest predicted risk. The relative risk predicted for the risk regions in which the Kruger National Park is located (RR4.1 Limpopo, RR5 Luvuvhu, RR9 Shingwedzi, RR7 Olifants, RR9 Shingwedzi), as well as those in Mozambique (RR10) are in the upper range of the moderate risk category. These results indicated that for the PRS scenario, the water resources of the Limpopo basin are at a moderate to high risk of not being able to provide the supporting services to the associated aquatic ecosystems. The EFLOW scenario reflects a noticeable reduction in the risk posed to most of the risk regions to a moderate risk range. The Marico (RR1.2) and Olifants sub-basins (RR7) still remain in a high relative risk category, but this may be related to quality and not quantity impacts within these sub-basins. The DRGHT scenario predicts high relative risk to the supporting services for all risk regions except the Luvuvhu (RR5) sub-basin which is in the upper range of the moderate risk category. During DRGHT conditions, there is a high relative risk that the water resources will not be able to support the associated aquatic ecosystems which could result in complete failure of the aquatic ecosystem.

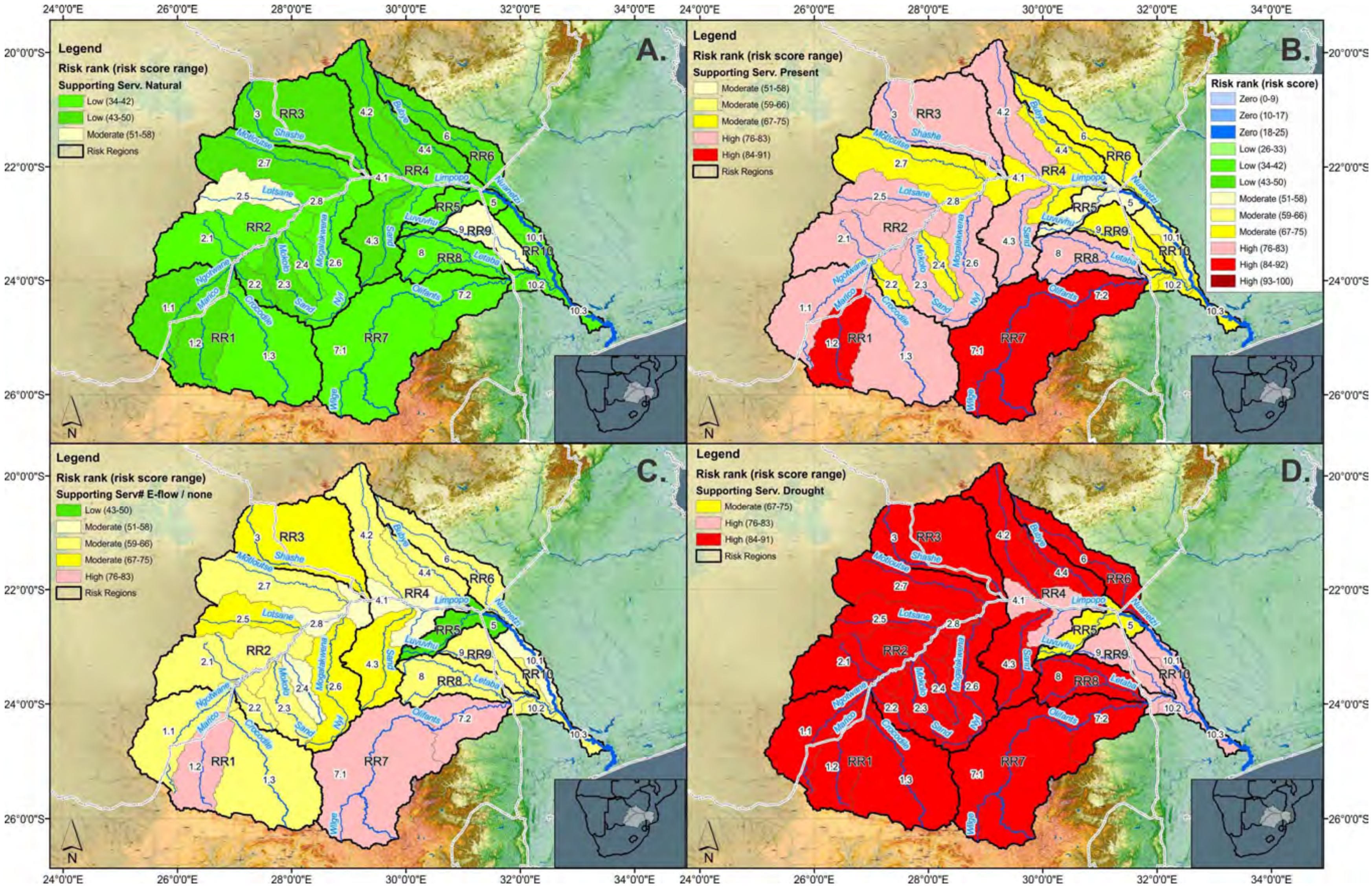


Figure 3-4: Relative risk scores to supporting services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

3.1.2 Provisioning Services

The provisioning services provided by the water resources within the Limpopo basin include the maintaining of fisheries (SUB-FISH-END) and plants (SUB-VEG-END) for livelihoods, maintaining plants for domestic livestock (LIV-VEG-END) and maintaining water for domestic use (DOM-WAT-END) (Table 2-2).

3.1.2.1 SUB-FISH-END Endpoint

The SUB-FISH-END endpoint considers the risk of altered flows to the maintaining of fisheries for livelihoods and for NAT conditions the risk to all risk regions was zero to low (Figure 9-10 and Figure 9-12A). For the PRS scenario, there is an increased risk for all risk regions but most risk regions still remain in a low risk category although for a few of the more ephemeral sub-basins the relative risk increases to moderate risk (RR1.2 Marico, RR2.1 Bonwapitse, RR2.3 Mokolo, RR2.5 Lotsane, RR2.7 Motloutse, RR4.3 Sand, RR4.4 Bubye and RR8.1 Groot Letaba) (Figure 9-10 and Figure 9-12B). The probability of failure to the SUB-FISH-END endpoint also remained low for the PRS scenario with an average of 18.6% (Figure 9-11). The EFLOW scenario reflected marginal changes to the relative risk scores and the probability of failure for most risk regions, the most noticeable being the increase in the relative risk for the Marico (RR1.2) and Shashe (RR3) sub-basins (Figure 9-10 and Figure 9-12C). The DRGHT scenario further increases the risk for many risk regions to moderate risk, especially the ephemeral rivers in Botswana and Zimbabwe and some of the more perennial systems located in the central region of the Limpopo Basin, highlighting the increased risk for those community's dependant on subsistence fish as an important food source. The probability of failure for the DRGHT scenario did not exceed 37.6% (Figure 9-11). The Ngotwane (RR1.1), Matlabas (RR2.2), Luvuvhu (RR5), Mwanedzi (RR6), Olifants (RR7), Shingwedzi (RR9) and sections of the Limpopo systems (RR10.1 and RR10.3) all remained in a low risk category for the present, e-flow and DRGHT scenarios because the potential or need for subsistence fisheries in these systems was low and many of these risk regions contain nation parks were subsistence fishing is not allowed.

3.1.2.2 SUB-VEG-END Endpoint

The SUB-VEG-END endpoint also reflects zero to low relative risk for the NAT scenario (Figure 9-13 and Figure 9-15A). The PRS scenario indicates that the relative risk increases to a moderate category for many of the risk regions, especially the more ephemeral risk regions where many of the communities in Botswana and Zimbabwe are reliant on water resources for their crops (RR2.1 Bonwapitse, RR2.3 Mokolo, RR2.5 Lotsane, RR2.7 Motloutse, RR3 Shashe, RR4.2 Umzingwani, RR4.3 Sand, RR4.4 Bubye and RR8.1Groot Letaba) (Figure 9-13 and Figure 9-15B). The EFLOW scenario indicates decreases in the relative risk for most of the risk regions although the risk to some risk regions did increase marginally, with the relative risk to the Sand (RR4.3) sub-basin being the most noticeable (Figure 9-13 and Figure 9-15C). A more distinct positive impact of the e-flows is shown in the average reduction of the probability of failure from 21% for the PRS scenario to 18.6% for the e-flows scenario (Figure 9-14). Under DRGHT conditions, the average probability of failure increased to 31.04% with RR2.1 (Bonwapitse), RR2.3 (Mokolo), RR2.5 (Lotsane) and RR4.4 (Bubye) having the greatest percentage (45%). The DRGHT scenario indicates moderate risk for not just the ephemeral sub-basins but also some perennial sub-basins (Figure 9-13 and Figure 9-15D). The Marico (RR1.2), Crocodile (RR1.3), Luvuvhu (RR5), Olifants (RR7) and sections of the Limpopo systems (RR2.8, RR10.1 and RR10.3) all remained in a zero to low-risk category for all four scenarios. This is mainly due to a combination of low flow requirements for the SUB-VEG-END endpoint and a low dependence of communities on this ecosystem service in these sub-basins.

3.1.2.3 LIV-VEG-END Endpoint

As expected, the LIV-VEG-END endpoint reflects low relative risk to all risk regions under NAT conditions (Figure 9-16 and Figure 9-18A) compared to the PRS scenario where most of the risk regions indicate moderate risk, especially the ephemeral risk regions in Botswana (RR2.1 Bonwapitse, RR2.5

Lotsane and RR2.7 Motloutse) (Figure 9-16 and Figure 9-18B). These risk regions indicated a reduction in the relative risk for the EFLOW scenario with the Crocodile (RR1.3) sub-basin and RR2.9 on the Limpopo mainstem indicating a reduction in risk to low risk (Figure 9-16 and Figure 9-18C). The DRGHT scenario predicts an increase to moderate risk for most risk regions, including the Limpopo mainstem at RR10.1 that have remained in a low risk category for the other three scenarios (Figure 9-16 and Figure 9-18D). The Luvuvhu (RR5) sub-basin and downstream Limpopo mainstem (RR10.2 and RR10.3) remain in a low-risk category for all scenarios also due to a combination of low flow requirements for the endpoint and a low dependence of communities on this ecosystem service in these sub-basins. The probability of failure for this endpoint remained low with average percentages ranging from 14% under NAT conditions, 25% and 22% for the present and EFLOW scenarios respectively and 32% for the DRGHT scenario (Figure 9-17).

3.1.2.4 DOM-WAT-END Endpoint

The DOM-WAT-END endpoint also predicts low risk for all risk regions under NAT conditions (Figure 9-19 and Figure 9-21A) but under PRS conditions the risk has increased to moderate risk for the Nogotwane (RR1.1), Bonwapitse (RR2.1), Matlabas (RR2.2), Mokolo (RR2.3), Lotsane (RR2.5), Mogalakwena (RR 2.6), Motloutse (RR2.7), Sand (RR4.3), Bubye (RR4.4) and Groot Letaba (RR8.1) sub-basins (Figure 9-19 and Figure 9-21B). The e-flows scenario indicates marginal decreases in the relative risk for these risk regions (Figure 9-19 and Figure 9-21C), but DRGHT conditions increases the risk to these risk regions (Figure 9-19 and Figure 9-21D). The DRGHT scenario also indicates moderate risk for most of the risk regions in Zimbabwe (RR3, RR4.2, RR4.4 and RR6). The Marico (RR1.2), Crocodile (RR1.3), Limpopo mainstem (RR2.8, RR2.9, RR4.1, RR10.1 and RR10.3), Luvuvhu (RR5), Olifants (RR7), Letaba (RR8.2), Shingwedzi (RR9) and Elephantes (RR10.2) sub-basins all remained in a zero to low risk category for the present, e-flow and DRGHT scenarios because either the potential or need for domestic water use in these systems was zero or low, for example the Kruger National Park or the water is being treated before it is used, reducing the relative risk. The average probability of failure for this endpoint remained low for all scenarios with the average percentage for the DRGHT scenario being 19.7% (Figure 9-20).

3.1.2.5 Combined risk for provisioning services

The relative risk posed to the combined provisioning services endpoints indicated low relative risk for all risk regions except the Shingwedzi (RR9) sub-basin that is in a moderate relative risk category under NAT conditions (Figure 3-5A). For the PRS scenario, most risk regions fall within the moderate relative risk range with only RR1.3 (Crocodile), RR5 (Luvuvhu) and RR10.1 (Limpopo) remaining in a low relative risk category (Figure 3-5B). The e-flows scenario indicates some reduction in risk, especially for RR2.8 and RR4.1 that also reflect a low relative risk score (Figure 3-5C). The DRGHT scenario reflects an increase in the relative risk for most risk regions, especially RR2.3 (Mokolo) and RR.2.5 (Lotsane) that fall within a high-risk category.

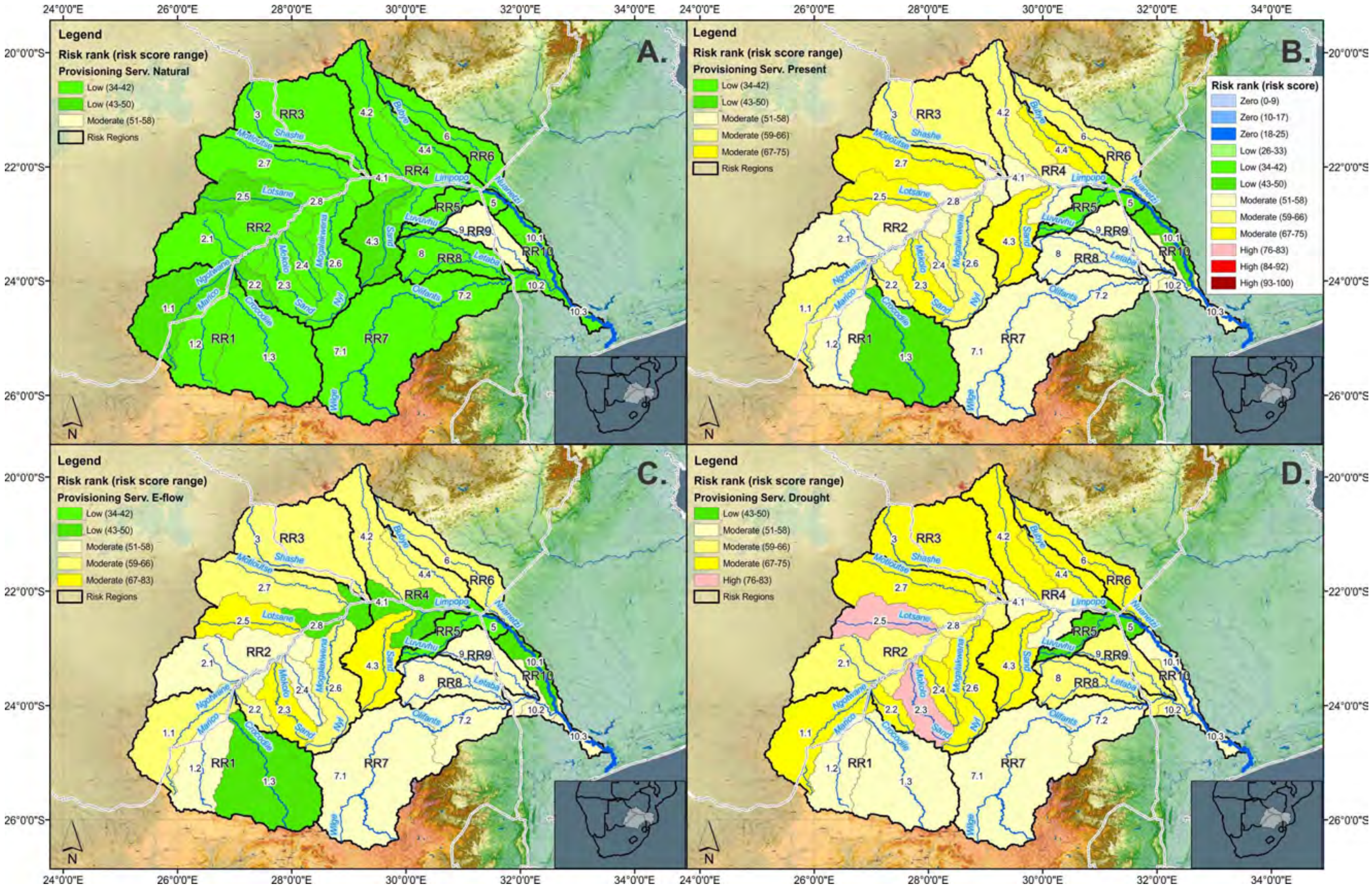


Figure 3-5: Relative risk scores to provisioning services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

3.1.3 Regulatory Services

The regulatory services provided by the water resources within the Limpopo basin include flood attenuation services (FLO-ATT-END), river assimilation capacity (RIV-ASS-END), maintenance of water-borne diseases (WAT-DIS-END) as well as resource resilience (RES-RES-END) endpoints.

3.1.3.1 FLO-ATT-END Endpoint

The risk posed to the FLO-ATT-END endpoint relates to the ability for the water resources to perform the regulatory services of reducing the threat posed by flooding events. For NAT conditions, the relative risk to this endpoint for all risk regions is zero to low (Figure 9-22 and Figure 9-24A) with an average probability of failure of only 4% (Figure 9-23). For the PRS scenario, the relative risk increases into a moderate category for most risk regions (Figure 9-22 and Figure 9-24B), except for RR2.9 (Limpopo), RR5 (Luvuvhu), RR9 (Shingwedzi) and RR10.1 (Limpopo) which remained in a low relative risk category. The average probability of failure increased to 29% for the PRS scenario and reduced marginally to 26% by the e-flows scenario (Figure 9-23). The EFLOW scenario indicates a reduction in relative risk for most risk regions with RR4.1 (Limpopo) falling within the low relative risk category (Figure 9-22 and Figure 9-24C). Some marginal increases in relative risk were noted for RR1.1 (Ngotwane), RR2.2 (Matlabas), RR3 (Shashe), RR4.3 (Sand), RR5 (Luvuvhu), RR9 (Shingwedzi) (increasing in relative risk to a moderate risk category), RR10.2 (Elephantes) and RR10.3 (Limpopo). The DRGHT scenario indicates an increase in risk for all risk regions as they all fall within the moderate risk range (Figure 9-22 and Figure 9-24D) with the average probability of failure increasing to 37%.

3.1.3.2 RIV-ASS-END Endpoint

River assimilation capacity (RIV-ASS-END) endpoint is the regulatory service water resources provide by absorbing or diluting waste and under NAT conditions this regulatory service is in a zero to low risk category except for the Shingwedzi (RR9) sub-basin that is in a moderate risk category (Figure 9-25 and Figure 9-27A) with a 33.6% probability of failure (Figure 9-26). For the PRS scenario, most of the risk regions are in a moderate risk category except for those associated with the Limpopo mainstem (RR2.9, RR4.1, RR10.1 and RR10.3) as well as the Luvuvhu (RR5) sub-basin which remain in low risk as there is sufficient flow to provide assimilation services (Figure 9-25 and Figure 9-27B). The Marico (RR1.2) sub-basin had the highest probability of failure of 54.8% with an average percentage for all risk regions of 27.3%. The EFLOW scenario shows a reduction in relative risk for most risk regions, with the relative risk to Lephalala (RR2.4), Limpopo mainstem (RR2.8) and Letaba (RR82) sub-basins reducing to a low risk category (Figure 9-25 and Figure 9-27C). The probability of failure for the Marico (RR1.2) sub-basin remained the same for the e-flows scenario, when compared to the PRS conditions but the average percentage decreased to 25.4%. The DRGHT scenario predicts moderate risk for all risk regions except the Luvuvh (RR5) sub-basin that remains in a low risk category (Figure 9-25 and Figure 9-27D). The probability of failure for the Marico (RR1.2) sub-basin increase to 56.5% with RR1.3 (Corocodile), RR2.4 (Lephalala), RR2.6 (Mogalakwena), RR2.9 (Limpopo), RR8 (Letaba) and RR9 (Shingwedzi) ranging between 50.9% and 52.4%.

3.1.3.3 WAT-DIS-END Endpoint

The waterborne diseases (WAT-DIS-END) endpoint is an interesting one to consider because under NAT conditions, waterborne diseases like malaria occurred and possibly to a greater extent than PRS conditions as malaria controls are in place presently. This is reflected in a comparison between the natural (Figure 9-28 and Figure 9-30A) and PRS scenarios (Figure 9-28 and Figure 9-30B). For the NAT scenario, RR1.1 (Ngotwane), RR2.2 (Matlabas), RR2.6 (Mogalakwena), RR2.9 (Limpopo), RR4.1 (Limpopo), RR5 (Luvuvhu), RR7 (Olifants), RR8 (Letaba) and RR10 (Limpopo and Elephantes) are all in a moderate risk category whereas for the PRS scenario, the relative risk predicted for RR2.6 (Mogalakwena), RR2.9 (Limpopo), RR4.1 (Limpopo) and RR8.2 (Letaba) reduces to a low risk category but the relative risk to the other risk regions (RR1.2 Marico, RR1.3 Crocodile, RR2.3 Mokolo, RR4.3 Sand, RR4.4 Bubye) increased to a moderate risk category. The EFLOW scenario indicated marginal changes in the relative risk for most sites, the most noticeable being the Crocodile (RR1.3), Sand (RR4.3) and Bubye (RR4.4) sub-basins reducing in risk to a low-risk category and the Limpopo (RR4.1) and Letaba (RR8.2) sub-basins increasing in risk to a moderate risk category. The DRGHT scenario does not affect the WAT-DIS-END endpoint as much as for other endpoints as the reduction in water removes the possibility of some waterborne diseases from occurring (Figure 9-28 and Figure 9-30D). The average percentage probability of failure for this endpoint was the same for the nature and EFLOW scenarios (27%) with a reduction in the PRS scenario (25.9%) and the DRGHT scenario (23.8%) (Figure 9-26).

3.1.3.4 RES-RES-END Endpoint

The resource resilience (RES-RES-END) endpoint refers to a water resource's natural ability to deal with stressors. The NAT scenario indicates zero to low risk for all the risk regions (Figure 9-31 and Figure 9-33A) as there would not have been many stressors impacting the water resources. For the PRS scenario, the relative risk increases to a moderate category for many risk regions, including most of the seasonal and ephemeral rivers. RR1.1 (Ngotwane), RR2.2 (Matlabas), RR2.9 (Limpopo), RR4.1 (Limpopo), RR4.2 (Umzingwani), RR5 (Luvuvhu), RR7 (Olifants), RR8 (Letaba), RR10 (Limpopo and Elephantes) all remained in a low risk category (Figure 9-31 and Figure 9-33B). The relative risk for the EFLOW scenario was similar to those for the PRS scenario with marginal differences in the risk scores (Figure 9-31 and Figure 9-33C) and the percentage probability of failure (25% - Figure 9-32). The relative risk increases for the DRGHT scenario with most of the risk regions in a moderate risk category and only RR5 (Luvuvhu), RR7 (Olifants) and RR10 (Limpopo and Elephantes) still in a low-risk category. The average percentage probability of failure for the DRGHT scenario was 35% with RR2.1 (Bonwapitse), RR2.3 (Mokolo), RR2.5 (Lotsane), RR2.7 (Motloutse), RR4.3 (Sand) and RR4.4 (Bubye) showing the highest percentages ranging between 54.2% and 54.6%.

3.1.3.5 Combined risk for regulatory services

The proposed relative risk to the combined regulatory services indicates that for the NAT scenario, the risk regions are in a low to moderate relative risk category (Figure 3-6A). A noticeable increase in the relative risk for all risk regions for the PRS scenario is shown in Figure 3-6B with the Marico (RR1.2) sub-basin reflecting a high relative risk. The EFLOW scenario indicates a reduction in relative risk for some risk regions, but they all remain in a moderate risk category with the Marico (RR1.2) sub-basin still remaining in a high relative risk category. The DRGHT scenario indicates an increase in the relative risk for all risk regions with the whole of RR1 and most of RR2 that occurs in Botswana including the Matlabas (RR2.2), Mokolo (RR2.3) and Sand (RR4.3) in a high-risk category.

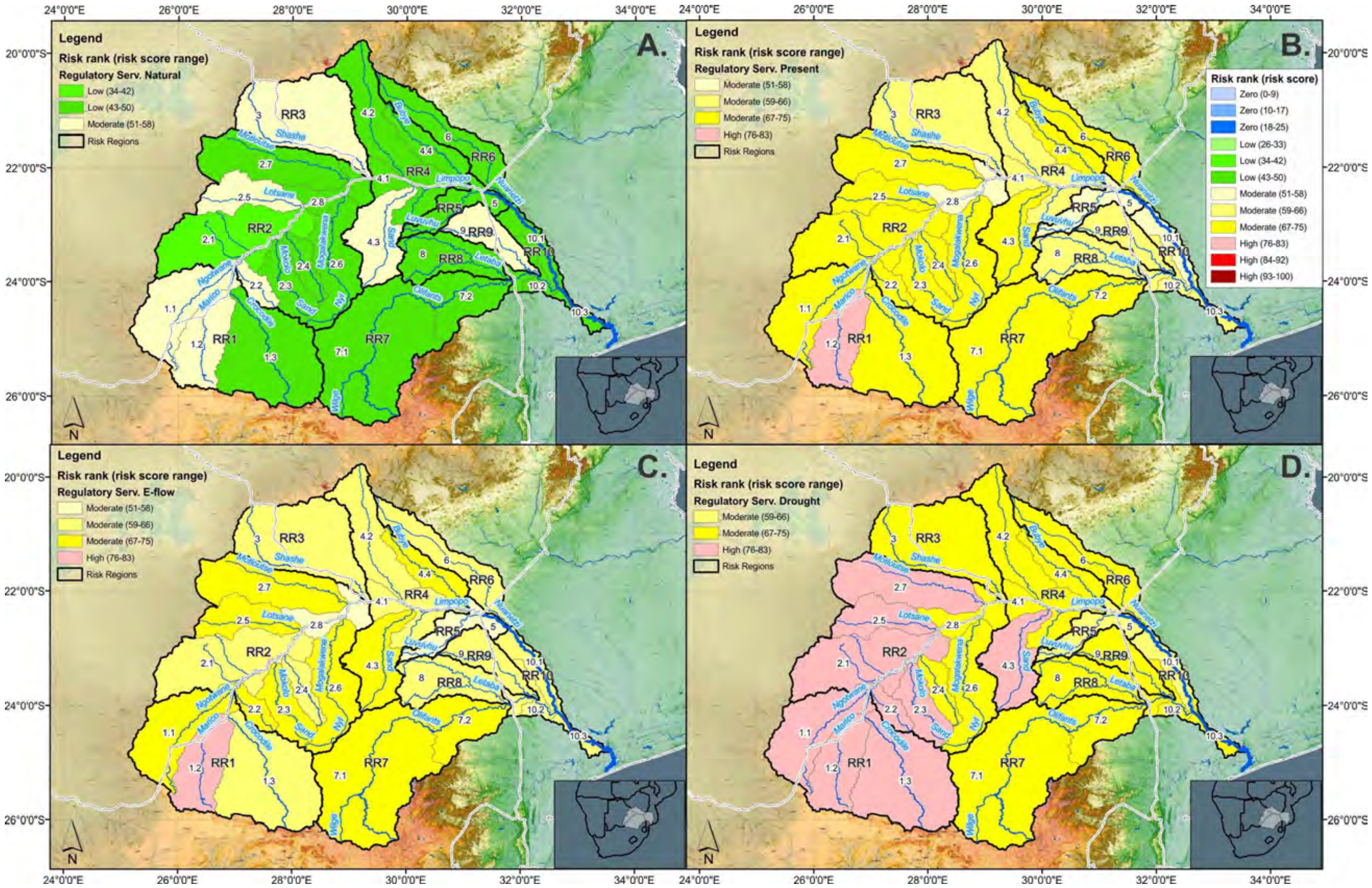


Figure 3-6: Relative risk scores to regulatory services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

3.1.4 Cultural Services

The two endpoints that were selected to represent the cultural services within the basis that are reliant on the water resources is the maintenance of recreational and spiritual activities (REC-SPIR-END) endpoint and the tourism (TOURISM-END) endpoint.

3.1.4.1 REC-SPIR-END Endpoint

The maintenance of recreational and spiritual activities (REC-SPIR-END) endpoint reflects interesting results as the Mogalakwena (RR2.6), Limpopo mainstem (RR2.9, RR4.1 and RR10.1), Luvuvhu (RR5), Olifants (RR7), Letaba (RR8.2) and Shingwedzi (RR9) sub-basins all reflect zero relative risk for the present, e-flow and some even for DRGHT scenarios compared to the low to moderate risk predicted under NAT conditions (Figure 9-34 and Figure 9-36 A-D). This is because under NAT conditions, increased flows or natural threats like crocodiles might have made it unsafe to undertake these activities at these sites. With the present and e-flows scenarios, many of these sub-basins contain national parks like the Kruger National Park, where access for these activities to take place is no longer available so the potential or demand for this endpoint is low. The average percentage probability of failure is highest for the natural and DRGHT scenarios (34.3% and 36% respectively) with a reduction to 30% and 26.6% for the present and e-flows scenarios respectively (Figure 9-35). The Groot Letaba (RR8.1) has the highest probability of failure for the DRGHT scenario (61.2%) with RR2.1 (Bonwapitse), RR2.3 (Mokolo), RR2.5 (Lotsane), RR2.7 (Motloutse), RR4.3 (Sand) and RR4.4 (Bubye) all having a 60% probability of failure (Figure 9-35).

3.1.4.2 TOURISM-END Endpoint

The tourism (TOURISM-END) endpoint reflects zero relative risk under NAT conditions and 0% probability of failure, for all the sites because under NAT conditions there is little potential or demand for tourism (Figure 9-37 and Figure 9-39A). The relative risk for the PRS scenario falls within the low to moderate categories for all the risk regions (Figure 9-37 and Figure 9-39B) with similar results for the EFLOW scenario with some noticeable reductions in risk in RR1.3 (Crocodile), RR2.3 (Mokolo), RR2.7 (Motloutse), RR2.9 (Limpopo), RR4.1 (Limpopo), RR4.2 (Umzingwani) and RR4.4 (Bubye). The Shashe (RR3) sub-basin was the only risk region where the risk increased for the e-flows scenario (Figure 9-37 and Figure 9-39C). The average probability of failure percentage also remains similar for the present and EFLOW scenarios (23% and 21.2% respectively) (Figure 9-38). Relative risk scores increased for most risk regions under DRGHT condition, especially those risk regions that are reliant on tourism like the Kruger Park (RR8 Letaba and RR9 Shingwedzi) (Figure 9-37 and Figure 9-39D). The average probability of failure percentage for the DRGHT scenario was 34.1% (Figure 9-38).

3.1.4.3 Combined risk for cultural services

The combined risk to the cultural services provided by the water resources within each sub-basin is represented in Figure 3-7A-D and shows that for the NAT scenario, there is moderate to low risk for cultural services for all the risk regions. For the PRS scenario, the Marico (RR1.2), Mokolo (RR2.3), Lotsane (RR2.5), Motloutse (RR2.7), and Sand (RR4.3) sub-basins would be in a high relative risk category while the remaining risk regions are in a low to moderate relative risk category. The EFLOW scenario reflects a reduction in risk for some of the risk regions with the Mokolo (RR2.3) and Lotsane (RR2.5) sub-basins returning to a moderate risk category. The DRGHT scenario shows in increase in risk for many of the risk regions but the Olifants (RR7) and Luvuvhu (RR5) sub-basins have remained in a low risk category for all four scenarios.

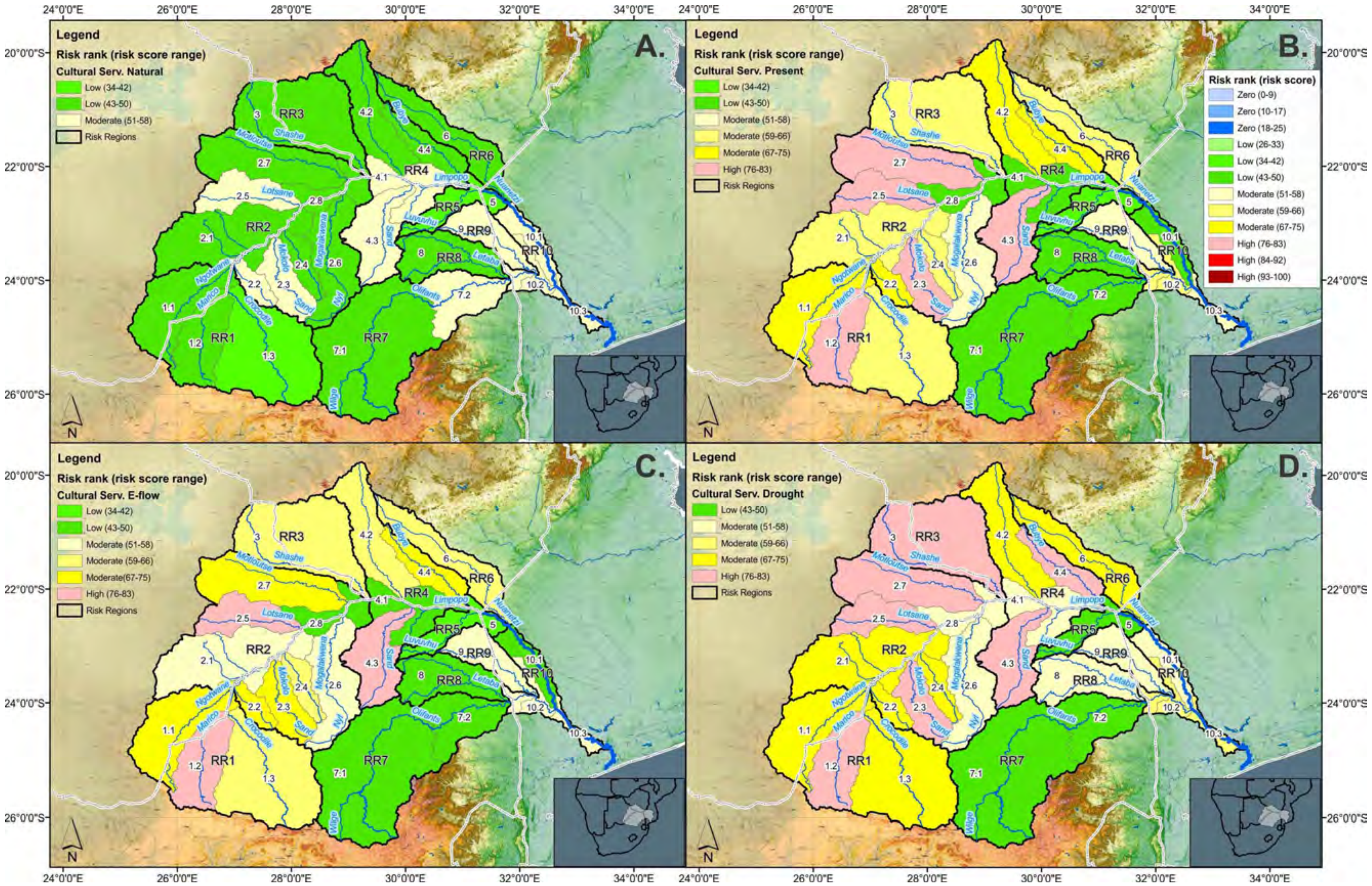


Figure 3-7: Relative risk scores to cultural risk services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

4 GENERAL DISCUSSION

The regional scale ecological risk assessment undertaken in this study demonstrated how multiple stressors occur and are potentially impacting on the socio-ecologically important river resources of the Limpopo Basin. All the risk regions considered in the study are exposed to considerable changes in the volume, timing, duration and frequency of river flows, with many rivers that have historically been perennial, with no evidence of zero flow conditions observed, having become seasonal and or episodic today. In addition, due to noticeable transformation of the landscape in the basin through urbanization and agriculture, mining and industrial development, water quality perturbations, habitat alterations and disturbance to wildlife, there has been considerable impact to water resources in the basin. The rivers of the Limpopo Basin are some of the most hard-working rivers of the region with for example the Olifants River sub-basin recognized globally as one of the worlds most altered and impacted river systems (Dabrowski and De Klerk, 2013; DWS 2014; Nkhonjera 2017).

The Crocodile-West and Olifants (including the Letaba) River sub-basins, have, in their present state, been identified in this study as the most severely threatened river ecosystems in the basin due to reduced flows and altered water quality and other stressors. Outputs of the risk assessment includes evidence that the Olifants and Letaba Rivers occur in unsustainable, unacceptable states with high risk to most of the ecosystem services that the biodiversity, ecosystem processes and vulnerable human communities depend on. The risk of the altered flows to the ecosystem services in the middle and lower reaches of the Limpopo River is currently moderate, with variability between moderate and high risk associated with no-flow vs. seasonal or episodic flows. During no-flow periods the risk is unacceptably high although there is some recovery during wet periods. Interestingly some of the services considered in the study are more resilient to the flow variability, while supporting services were identified as the most vulnerable, followed by provisioning services, regulatory and cultural services have been identified as relatively resilient.

The supporting services considered in the study included the wellbeing of the fish, macroinvertebrates and vegetation communities in the Limpopo Basin. These indicators represent the biodiversity of species and key ecosystem processes of the river that respond to environmental variability of the driver components (water quality, flow, habitat and other). In the Limpopo River Basin these supporting services were identified as the most vulnerable components of the study. Using multiple lines of evidence, the present-day wellbeing of these components was generally Largely Modified, but the relative risk assessment demonstrates that the integrated (i.e., when these are considered together) risk extends into the high or serious modified risk level, an unsustainable state that would occur in the upper and middle reaches of the basin in particular.

The “Largely Modified” state, derived from the application of selected eco-classification and multivariate statistical assessment approaches, represents a noticeable change from present, but still potentially sustainable in its present state. This state overlaps in terms of its definition with the threshold of potential concern for ecosystem components between a sustainable and unsustainable condition. While this Largely Modified state is generally “still acceptable” for a hard-working river and is “sustainable”, it is based on knowledge of noticeable changes in the diversity and state of many ecosystem processes. Importantly the present extent of the “Largely Modified” state of the rivers determined through eco-classification and multi-variate statically assessments, across the majority of the basin, is concerning as these outcomes suggest that there are no longer any rivers, or reaches of rivers in the basin that maintain a healthy diverse community of fishes and vegetation in particular. The “high risk” outputs of the risk assessment heighten this concern that the ecosystem across most of the basin has been significantly transformed, the development is unsustainable and the river ecosystem may be beyond recovery. These outputs are corroborated by the high percentage of threatened aquatic fauna that are endemic to the Limpopo River and or surrounding east-flowing basins in southern Africa.

The e-flows of the Limpopo River have been determined using the minimum volume, timing, duration and frequency of flows that would maintain the supporting services, and the outputs of the study demonstrate that a noticeable increase in resilience of the water resource will be achieved through the implementation of these e-flows. They include however a noticeable increase in river flows compared to the present day flows, that would result in the recovery of the ecosystem and associated supporting service components of the ecosystem, but this recovery may conflict with the water-use sector that is over-exploiting water resources in the basin. If no mitigation measures (e-flows) are provided and worst-case climate change predictions for the region occur, including a prolonged and/or extensive drought, the risk to the supporting services, including the ecosystem and associated processes will increase considerably from the present risk, and would depress the ecosystem into a Critically Modified, unacceptable state. This would include significant losses of biodiversity and important ecosystem processes.

The provisioning services provided by the water resources of the Limpopo Basin included consideration of fish and other natural products and grazing for livestock and water for domestic use. These provisioning services were shown to follow the trend in deterioration from natural to present day conditions, but are considerably less vulnerable to the flow and non-flow stressors compared to supporting services. This can easily be demonstrated in that the supporting services are based on all of the species and their ecosystem preferences, while human communities will use any fish or food source for food, can treat water for drinking purposes and can change livestock from cattle to goats, for example, to deal with reduced grazing.

Presently the provisioning services are generally in a Moderately Modified state, particularly where many vulnerable human communities occur and depend on the ecosystem services. In the wilderness areas, including wildlife ranching and protected areas, the demand for provisioning services by human communities is low to zero and, as such, the present risk to these services has decreased from natural conditions where historically human communities used to live close these resources and use their services. Through the implementation of e-flows, this study has shown that there will be an improvement of base flows in the rivers that will improve ecosystem conditions, and the associated supply of resources for provisioning services, especially along the mainstem of the Limpopo River. This study demonstrates that through the implementation of e-flows local vulnerable human communities will benefit more from the river and will be more resilient to climate variability for example. However, if no e-flows are provided, and the worst-case climate change impacts occur, including a prolonged drought in the region, a deterioration of provisioning services is expected to result which will include increased stress and hardships for local human communities.

The regulatory services in the study included consideration of flood attenuation potential, resource resilience, the assimilative capacity of the rivers, and limiting water borne disease outbreaks. The risk assessment shows increased risk to all of these regulatory services from natural to present conditions incorporating changes in use dynamics due to new protected and wilderness areas (from natural), and reduced quality of the water resource that affects water borne disease vectors. These trends are similar to those for the provisioning services, and implementation of e-flow will also result in a slight improvement to the regulatory services. Interestingly while the regulatory services are potentially less vulnerable to multiple stressors, compared to supporting and provisioning services, the potential impacts of climate change to the upper reaches of the basin in particular are noticeably greater than the risk expected to occur to provisioning services.

Finally, the cultural services selected for the study include recreation, spiritual activities and tourism. Interestingly while the risk to tourism is highly dependent on the demand for tourism in the basin, which did not exist in the NAT scenario, today due to the location of the Great Limpopo Transfrontier Conservation Area and wilderness areas in the upper parts of the Crocodile River (West) sub-basin and middle Limpopo River, this ecosystem service is in abundant supply. These results demonstrate how important tourism is as a cultural service with associated socio-economic benefits. The spiritual and recreational activities however, which occur outside of these protected areas are dependent on the water resource and its quality.

Changes in risk for this important cultural component shows there has been a considerable increase in risk from natural conditions, however this service is more tolerant to changes in flows and non-flow stressors compared to supporting services and provisioning services. Here the danger of crocodile attacks is considered to be reduced due to formal crossings established over dangerous rivers, and considers how the distribution of the predators has changed through resource development and changes in the state of resources, for example where perennial rivers have been changed into seasonal or episodic rivers and the populations of crocodiles have decreased. If e-flows are implemented, a reduction in risk to this service is expected due primarily to improved opportunities for recreation and spiritual activities. There are also expected to be less drownings if more stable base flows are provided and sudden erratic floods are controlled through releases. If, however, e-flows are not implemented and a worst-case climate change scenario including a prolonged drought in the region occurs, the state of the cultural services will deteriorate considerably especially in those tributaries of the Limpopo Basin where perennial or seasonal rivers have been changed to seasonal or episodic systems.

The Olifants River has surprisingly been identified as a very resilient sub-catchment where the 10 lowest flow or drought years obtained from historical data have all been identified as being “suitable”, as during prolonged droughts the tourism and other cultural services are likely to be maintained.

5 UNCERTAINTY EVALUATION

The probabilistic risk models used in this study incorporate available evidence and use justified solicitations (Appendix A) to establish the models and represent knowledge of the relationships between variables. Uncertainty associated with the availability and use of data, and the modelling process can influence the risk estimate. To reduce uncertainty in the study after implementing the RRM-BN model and the preliminary analyses, the model's structure, parametrization, and findings were evaluated by hydrology, hydraulic, water quality, ecology and social experts involved in the study. With their assistance the model was calibrated to best represent the risk of multiple stressors to natural pre-anthropogenic conditions for which some data is available, and to represent the risk to endpoints observed under PRS conditions that were evaluated in the study. The RRM-BN approach included the opportunity to incorporate uncertainty in the conditional probability tables where relationships between variables are represented as limited or high confidence, in the knowledge of the flow-ecosystem relationships using broad (low confidence with high SD) relationship profiles or high confidence (low SD) combinations. Uncertainty associated with available data specific to the reach of river being considered in the study, can be reduced though additional sampling and/or risk projection testing in monitoring and uncertainty reduction experimentation.

Additionally, the level of confidence of the assessment due to the large spatial scope and limited evidence is low, and uncertainty high for the sub-basins (Ngotwane, Marico, Bonwapitse, Mokolo, Lotsane, Motloutse and Bubye) that were not physically sampled in this study by the specialists, and requirements were instead inferred from other sub-basins with similar characteristics. For example, for the upper Olifants sub-basin evidence is inferred from the lower Olifants sub-basin within the Kruger National Park. This data skews the results for some of the ecosystem services as the upper catchment in not in the Kruger. If it were necessary to reduce the uncertainty of results for these sub-basins, it would be necessary to collect new data.

The RRM-BN approach includes an evaluation of the uncertainty to identify key drivers in the model and sources of uncertainty that may impact the overall uncertainty of the model (Ayre and Landis 2012). The results of uncertainty evaluation provide context of the uncertainty associated with the outcomes to stakeholders, and contributes to the water resource management decision-making process. The successful establishment and testing of risk hypotheses in the future will allow RRM to be validated, and reduce overall uncertainty. This includes the application of the "Sensitivity to findings" tool of Netica to evaluate the contribution of individual variables (nodes) to the risk outcomes (O'Brien et al. 2018) (Appendix C).

6 CONCLUSION AND RECOMMENDATIONS

The Limpopo River is an important, dynamic socio-ecological system with a high diversity of endemic and unique aquatic biota and important ecosystem processes that affects more than 14 million people who live in the basin and depend on its resources. The limited water resources of the basin are over-utilised with most of the rivers that were historically perennial now seasonal and seasonal rivers now episodic. Additional water quality stressors in the Crocodile (West) and Olifants Rivers and other stressors such as habitat alteration, alien invasive fauna and flora and disturbance to wildlife impacts have a synergistic effect of the wellbeing of the water resources in the basin. While most of the rivers in the basin today occur in a Largely Modified (but sustainable) state many parts of the basin are now in an unsustainable deteriorating state with an associated loss of biodiversity, ecosystem processes and services that people depend on. The evidence-based risk assessment undertaken in this study can contribute to stakeholders' understanding of how water resources have been developed in the Limpopo Basin, and the impacts of this development on ecosystems and people. The assessment includes an evaluation of the relative risk to ecosystem services, which can be used to facilitate consideration of trade-offs that are spatially linked, which can be used for more sustainable and appropriate development planning. While we acknowledge that there are socio-economic costs associated with implementation of e-flows (flow mitigation), the long-term costs of operating the system in an unsustainable state may out-weigh these costs.

The risk associated with e-flow scenarios to the ecosystem service endpoints considered in this study for the Olifants and Letaba Rivers is unacceptably high and will not provide sufficient flows for sustainability. This study shows that the current e-flows requirements are probably insufficient, but the e-flows were not determined during this study but have been gazetted and come from previous studies and should be re-evaluated. Some of the risk assessments for risk regions are based on socio-ecological system requirements inferred to those regions from adjacent regions and or from regions where socio-ecological systems are considered to be comparable. This approach allows for the determination of comparable risk of altered flows and other stressors for all scenarios using the hydrology from the relevant risk region but the requirements from others. This approach results in uncertainty as the availability of flows in a relevant risk region is compared to requirements from another region. In this study the risk proposed to the Marico and seasonal rivers in Botswana were shown to be moderate to high. These projections can contribute to planning and or management, but the uncertainty must be addressed. We recommend site specific data be obtained from these rivers.

The risk assessment includes four scenarios that generally consider how the risk to the ecosystem services have changed overtime and what may result if no consideration for sustainability is afforded in the form of implementing e-flows. Additional scenarios can be established and tested and the actual experiences or real scenarios that are implemented can be tested in an adaptive context to guide the balance between the use and protection of the resource and test the risk assessments. In an adaptive context the risk models will be able to learn from new information which will improve prediction accuracy and reduce uncertainty. Similarly in an adaptive context the current risk framework and associated risk regions can be increased to provide greater regional, spatial confidence. Here we recommend increasing the number of risk regions and colleting additional bio-physical information at multiple sites on the main rivers/tributaries to improve confidence of the assessment and support fine spatial scale development and or sustainable management of the resource.

The study did not include a hydrological model to budget water requirements to align or synchronise e-flow allocations between risk regions. The study presents the requirements and propose that through implementation, the contribution of e-flows in upstream reaches will need to be determined to meet downstream requirements. This is particularly important where requirements in the lower portion of the basin depends on upstream flows. We recommend an alignment process be undertaken with interested and affected parties to determine how to meet e-flows throughout the basin. We have also identified misalignments of legislation and or sustainable water resource management between riparian countries of the Limpopo Basin. For example, in South Africa e-flow requirements are gazetted as part of the Ecological Reserve and included as Resource Quality Objectives to force regulators to implement them. This has legal implications to developers and or polluters within South Africa. The other riparian states do not currently have comparable legislation. This misalignment should be addressed.

Finally, some parts of the water resources including for example the Luvuvhu and Shingwedzi Rivers are currently in good ecological conditions they should receive priority for protection, while the rivers in the Upper Limpopo Basin, and Olifants River basins are being used excessively and these rivers should be prioritised for rehabilitation.

This risk assessment can be implemented as a framework and make a direct, positive contribution to sustainable water resource management in the Limpopo Basin. The framework should be developed and applied in an adaptive context to meet these potential contributions.

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8 APPENDIX A

Table 8-1: Example Of The Justification Table For The Parent Nodes Of The Bayesian Network For The Limpopo E-Flow Study

Variable title (BN CODE)	Justification (Incl. indicator and measure (units) and specify rank descriptions, standard Zero, Low, Moderate (Mod) and High, or continuous or categorical etc.)	References
Demand/potential for sub.fishery (SUB_FISH_POT)	Risk of multiple stressors to fisheries for people requires people to occur and require/depend on fish as a source of food. Ranks selected for this node include no demand/people represented (measure of variable) by the abundance (unit) of people who live within 2km from river with knowledge of subsistence fishing practice (Zero-low rank), moderate demand or people (Mod rank) where people do not depend on fish but utilize fishery and high (High rank) demand and or dependence where livelihoods depend on seasonal or permanent fish provision.	DATA FROM THIS STUDY
Barriers affecting migrations (SUB_FISH_BAR)	Physical (structure or reduced flows), chemical and or disturbance to wildlife (impacts of alien fauna or people) representing measure of this variable that affects the migration of catadromous (*Anguillid spp.*) and potadromous species (cyprinids and siluriformes) used for subsistence fisheries in that basin. Potential (unit zero, low, moderate and high) of barrier on fish migrations used in establishment of no barrier (Zero rank), temporary barriers that may delay seasonal migrations (Low rank) partial/seasonal barrier that may hamper fish migrations during important life cycle phases but do not significant affect population (Mod Rank) and permanent barriers that restrict species migrations (High Rank). [NO_BARRIERS]	DATA FROM THIS STUDY
Sediment supply (SUB_FISH_SSUP)	Reduction or excessive increase in sediment from upstream or associated with runoff from terrestrial areas due to type and extent (km2 or %) of land use activities (measure) that will directly affect habitat availability within the river associated with river flows that will describe geomorphic/instream habitat characteristics for substrate and cover preferring indicator fishes targeted for subsistence (Cyprinids and large growing siluriformes). Ranks selected include condition of catchment, land use activities or upstream supply of sediment that provides potential for habitat diversity to be maintained in natural/pristine condition (Zero), near-natural conditions that do not affect indicator species (Low), acceptable condition to provide minimal requirements for indicator species (consider abundances on reach scale) (Mod) and unacceptable loss of substrate types that will significantly affect fish communities. [LANDUSE_SSUP]	DATA FROM THIS STUDY
Sediment removal flows (SUB_FISH_SFLO)	River flows measured as discharge (m^3/s) associated with velocities (m/s) using hydraulics to provide suitable shear stress to mobilise and sort sediments to maintain instream habitat diversity preferred by indicator fisheries species (cyprinids) in a near to natural condition (Zero rank), altered distributions but suitable abundances of required habitats for indicator species (Low rank), altered habitat distributions that will not significantly affect targeted fisheries species (tilapians, cyprinids and siluriformes) (Mod rank) and altered flows that significantly change substrate characteristics that will result in loss of instream substrates required by fisheries indicator species for lifecycle events. [DISCHARGE_YR]	DATA FROM THIS STUDY

Variable title (BN CODE)	Justification (Incl. indicator and measure (units) and specify rank descriptions, standard Zero, Low, Moderate (Mod) and High, or continuous or categorical etc.)	References
Velocity / depth habitat characteristics (SUB_FISH_VD)	Relative distribution and abundance (unit m^2) of instream velocity-depth habitat (slow-deep, slow-shallow, slow-very shallow, fast-intermediate, fast-shallow and fast-deep) distributions (measure) associated with requirements of indicator fishes targeted for subsistence fishery (large growing cyprinids). Ranks include distribution and abundances that will support pristine/natural community of indicator species (Zero), occurrence of (but altered) habitat distributions for indicator species (Low), modified velocity-depth habitat distributions for at least one fisheries indicator species while majority of indicator species is provided for (Mod) and significant alteration of velocity-depth habitat characteristics that affects fish community significantly. [DISCHARGE_YR]	
Cover characteristics (SUB_FISH_COV)	Relative distribution and abundance (unit m^2) of cover features preferred by fisheries indicator species from the study area (cyprinids). Ranks include distribution and abundances that will support pristine/natural community of indicator species (Zero), occurrence of (but altered) of cover distributions for indicator species (Low), modified cover distributions for at least one fisheries indicator species while majority of indicator species is provided for (Mod) and significant alteration of cover characteristics that affects fish community significantly. [DISCHARGE_YR]	DATA FROM THIS STUDY
Cues for life cycles of sub.fish (SUB_FISH_CUES)	Endpoint represent cues for the life cycles of subsistence fisheries. (Zero rank)There are no changes in cues, or life stages of subsistence fisheries, (Low rank) Changes have occurred but it does not impacted the cues or life stages of subsistence fisheries, (Mod rank) Changes in cues have impacted some of the life stages of subsistence fisheries, (High rank) Changes in cues has disrupted the life cycles of subsistence's fisheries [DISCHARGE_HF; SEASONALITY]	DATA FROM THIS STUDY
Demand/potential for harvesting (SUB_VEG_POT)	Risk of multiple stressors to plants for livelihoods requires people to occur and require/depend on plants as a harvestable resource. Ranks selected for this node include no demand/people represented (measure of variable) by the abundance (unit) of people who live within 2km from river with knowledge of plant harvest / use (Zero-low rank), moderate demand or people (Mod rank) where people do not depend on vegetation but utilize plants opportunistically and high (High rank) demand and or dependence where livelihoods depend on seasonal or permanent service from vegetation.	DATA FROM THIS STUDY
Water levels characteristics - high flow (SUB_VEG_DEPH)	An interactive output defining the range in discharge (Q; m^3/s) associated with the indicator activation discharge (discharge required at stem level) for the wet and dry season to maintain riparian vegetation communities. Flows should ideally fluctuate within this range for the duration of the hydro period, maintaining seasonality for each riparian community (Zero Rank). Where variation is beyond range limits, the potential exists for vegetation to respond accordingly. Where such response in distribution within the channel, including abundance and species compositional shifts is within current ecostatus (Low rank) the response is deemed expected variation dynamics. Greater shifts in the required discharge range have the potential to cause riparian vegetation community changes and/or shift beyond the current ecostastus limits (Mod, rank), and where change is sever or seasonality is lost, the change in riparian community integrity prevents acceptable functionality or service being rendered (High rank). [DISCHARGE_HF; SEASONALITY; DISCHARGE_LF]	DATA FROM THIS STUDY

Variable title (BN CODE)	Justification (Incl. indicator and measure (units) and specify rank descriptions, standard Zero, Low, Moderate (Mod) and High, or continuous or categorical etc.)	References
Water levels characteristics - low flow (SUB_VEG_DEPL)	An interactive output defining the range in discharge (Q; m^3/s) associated with the indicator activation discharge (discharge required at stem level) for the wet and dry season to maintain riparian vegetation communities. Flows should ideally fluctuate within this range for the duration of the hydro period, maintaining seasonality for each riparian community (Zero Rank). Where variation is beyond range limits, the potential exists for vegetation to respond accordingly. Where such response in distribution within the channel, including abundance and species compositional shifts is within current ecostatus (Low rank) the response is deemed expected variation dynamics. Greater shifts in the required discharge range have the potential to cause riparian vegetation community changes and/or shift beyond the current ecoststus limits (Mod, rank), and where change is sever or seasonality is lost, the change in riparian community integrity prevents acceptable functionality or service being rendered (High rank).	DATA FROM THIS STUDY
Sediment supply (SUB_VEG_SSUP)	Significant reduction or increase in sediment volume and fine-coarse ratio from upstream or laterally associated with runoff from terrestrial areas due to type and extent (% catchment degradation) of land use activities (degradation intensity) and degradation that will directly affect habitat availability within the river associated with river flows that will describe geomorphic/instream habitat characteristics for substrate availability and location for indicator vegetation. Ranks selected include condition of catchment, land use activities or upstream supply of sediment that provides potential for habitat diversity to be maintained in natural/pristine condition (Zero), near-natural conditions that do not affect indicator species (Low), acceptable condition to provide minimal requirements for indicator species (consider abundances on reach scale) (Mod) and unacceptable loss of substrate types that will significantly affect vegetation communities. [LANDUSE_SSUP]	DATA FROM THIS STUDY
Sediment removal flows (SUB_VEG_SFLO)	River flows measured as discharge (m^3/s) associated with velocities (m/s) using hydraulics to provide suitable shear stress to mobilise sediments to maintain instream habitat diversity preferred by indicator vegetation in a near natural condition (Zero rank), altered distributions but suitable abundances of required habitats for indicator species (Low rank), altered habitat distributions that will not significantly affect riparian vegetation (Mod rank) and altered flows that significantly change substrate characteristics that will result in loss of riparian substrates and morphological features required by indicator vegetation species for lifecycle events. [DISCHARGE_YR]	DATA FROM THIS STUDY
Demand/potential for livestock (LIV_VEG_POT)	Risk of multiple stressors to plants for livestock requires livestock (people proximity) to occur and require/depend on plants as a grazing resource. Ranks selected for this node include no demand/livestock represented (measure of variable) by the abundance (unit) of livestock who enter the riparian zone for grazing (Zero-low rank), moderate demand or livestock (Mod rank) where livestock do not depend on grazing in the riparian zone but graze opportunistically and high (High rank) demand and or dependence where livestock depend on grazing riparian vegetation for survival.	DATA FROM THIS STUDY
Demand for water for domestic use (DOM_WAT_DEM)	Risk of multiple stressors to domestic water use(volume)and number of people(population no) who depend on the water resource for domestic use. Ranks selected for this node include no volume of water demanded by the no of people who live within 2km from river (Zero-low rank), moderate demand water by the people (Mod rank) where people depend on the water use but they have alternatives (High rank) high amount of water demanded and dependence for livelihoods high	DATA FROM THIS STUDY
River flows (DOM_WAT_RFLO)	River flows measured as discharge (m^3/s) adequate to provide water(volume) as per domestic demands (Zero rank), altered river flow distribution but suitable and adequate volume for domestic use (Low rank), altered river flow that will not significantly affect volume of water required to meet domestic demands (Mod rank) and altered flows and domestic water use demands significantly not met and which affects livelihoods [DISCHARGE_YEAR]	DATA FROM THIS STUDY

Variable title (BN CODE)	Justification (Incl. indicator and measure (units) and specify rank descriptions, standard Zero, Low, Moderate (Mod) and High, or continuous or categorical etc.)	References
Demand/potential for flood control (FLO_ATT_POT)	The potential for floods to occur based on the riparian zone and habitats and flood attenuation structures like weirs.	
Sediment supply (RIV_ASS_SSUP)	Significant reduction or increase in fine sediment volume and fine-coarse ratio from upstream or lateral supply associated with runoff from terrestrial areas due to degradation type (degradation intensity) and extent (% catchment degradation). Connectivity and catchment position plays a role too, with distal or poorly connected sources having a smaller impact compared to local or well buffered sources. The shift in sediment supply will directly affect fine substrate availability within the river channel and associated with river flows that will inundate the existing finer sediment stores. Ranks selected include degradation condition of catchment, land use activities or upstream supply of sediment that provides potential for habitat diversity to be maintained in natural/pristine condition (Zero), near-natural conditions that do not affect the availability of substrates (Low), acceptable condition to provide minimal requirements for nutrient cycling (Mod) and unacceptable loss of substrate types that will significantly affect nutrient cycling. [LANDUSE_SSUP]	DATA FROM THIS STUDY
Sediment removal flows (RIV_ASS_SFLO)	River flows measured as discharge (m^3/s) associated with velocities (m/s) using hydraulics to provide suitable shear stress to mobilise and sort fine and medium sized sediments to maintain instream sediment transport and deposition (Zero rank), altered distributions but suitable abundances of a range of sediment sizes and volumes (Low rank), altered habitat distributions that will not significantly affect sediment erosion and deposition/transport processes (Mod rank) and altered flows that significantly change substrate characteristics that will result in loss of fine substrates and morphological features required to assimilate nutrients. [DISCHARGE_YR]	DATA FROM THIS STUDY
Potential for disease (WAT_DIS_DPOT)	Risk of waterborne diseases to occur based on presence or absence of aquatic predators to control diseases. Relates to high presence of aquatic predators to control all diseases (zero), Relates to moderate presence of aquatic predators to control some diseases(low), Relates to low presence of species of aquatic predators to control some diseases, most essential species missing (mod) and no presence of aquatic predators to control any diseases (high)	DATA FROM THIS STUDY
WAT_DIS_VFLO	Most host vectors of diseases are restricted to stagnant waters (e.g. Culicidae, Lymnaedidae, Planorbidae). Decreased in velocity-flow increase slow flowing to stagnant waters, and with high nutrient inputs allows for the establishment of aquatic plants. Low flows and high nutrient inputs therefore potentially provides perfect conditions for host vectors. Relates to high presence of fast velocity flows (zero), Relates to moderate presence of fast velocity flows (low), Relates to moderate to high presence of slow flowing to stagnant waters with aquatic plants present (mod) and the dominance of slow flowing and stagnant waters with aquatic plants abundant (high)	Lu et al. 2018; Haggerty et al. 2020
Potential for resilience (RES_RES_POT)	River flows measured as discharge (m3/s) associated with velocities (m/s) using hydraulics to provide suitable volume to allow for dilution / transport of contaminants. [DISCHARGE_YR]	

Variable title (BN CODE)	Justification (Incl. indicator and measure (units) and specify rank descriptions, standard Zero, Low, Moderate (Mod) and High, or continuous or categorical etc.)	References
Sediment supply (RES_RES_SSUP)	Significant reduction or increase in fine sediment volume and fine-coarse ratio from upstream or lateral supply associated with runoff from terrestrial areas due to degradation type (degradation intensity) and extent (% catchment degradation). Connectivity and catchment position plays a role too, with distal or poorly connected sources having a smaller impact compared to local or well buffered sources. The shift in sediment supply will directly affect fine substrate availability within the river channel and associated with river flows that will inundate the existing finer sediment stores. Ranks selected include degradation condition of catchment, land use activities or upstream supply of sediment that provides potential for habitat diversity to be maintained in natural/pristine condition (Zero), near-natural conditions that do not affect the availability of substrates (Low), acceptable condition to provide minimal requirements for nutrient cycling (Mod) and unacceptable loss of substrate types that will significantly affect the resilience of the resource. [LANDUSE_SSUP]	DATA FROM THIS STUDY
Sediment removal flows (RES_RES_SFLO)	River flows measured as discharge (m^3/s) associated with velocities (m/s) using hydraulics to provide suitable shear stress to mobilise fine and medium sized sediments to maintain instream sediment transport and deposition (Zero rank), altered distributions but suitable abundances of a range of sediment sizes and volumes (Low rank), altered habitat distributions that will not significantly affect sediment transport processes (Mod rank) and altered flows that significantly change substrate characteristics that will result in loss of fine substrates and morphological features required to maintain the resource resilience. [DISHARGE_YEARLY]	DATA FROM THIS STUDY
Environmental potential for fish (FISH_ECO_POT)	The availability of habitat preferences represents the environment potential to support fish communities. Ranks selected for this node include complete or sufficient environment potential to support expected fish community structure, function and composition (Zero-low rank), moderate environment potential (Mod rank) where the environment supports most but not all expected fish community and low environment potential (High rank) where environment support of fish communities is unsustainable and/or disfunctional.	DATA FROM THIS STUDY
Barriers affecting migrations (FISH_ECO_BAR)	Barrier (physical structure) stop the migration of fish species. This affects the life history, movement and distribution of fish communities. Zero: No barriers, life history, movement and distribution is not affected, low: Temporary barrier that affect seasonal migration (<1m causeways, culverts, floodgates), medium: Permanent barrier (<5m weirs without working fish way, road and rail crossings) that may affect migration during important lifecycle phases but do not significantly affect population, high: Permanent barrier (>5m dams without working fish way) that restrict species migration. [NO_BARRIERS]	Harris 2016

Variable title (BN CODE)	Justification (Incl. indicator and measure (units) and specify rank descriptions, standard Zero, Low, Moderate (Mod) and High, or continuous or categorical etc.)	References
Sediment supply (FISH_ECO_SSUP)	Increased sedimentation (erosion, agricultural and urban land use) cause abrasion of biota and habitats, cause suffocation of sessile organisms, reduces the availability of habitats (filled and covered with sand, aquatic vegetation are killed) and transport pollution. Complex habitats provide a wide range of niche space, thus decreasing niche overlap and increasing diversity. Zero: Condition of catchment, land use activities, upstream supply of sedimentation is limited and maintain habitat diversity (pristine condition), Low: Some evidence of sedimentation, sufficient amount of habitat diversity still present, Medium: Land use activities and upstream supply of sedimentation increasing, micro habitats covered in sedimentation, High: Unacceptable loss of substrate, no habitat diversity available for survival of fish communities.Significant reduction or increase in sediment volume and fine-coarse ratio from upstream or lateral supply associated with runoff from terrestrial areas due to degradation type (degradation intensity) and extent (% catchment degradation). Connectivity and catchment position plays a role too, with distal or poorly connected sources having a smaller impact compared to local or well buffered sources. The shift in sediment supply will directly affect habitat availability within the river associated with river flows that will describe geomorphic/instream habitat characteristics for substrate availability and location for indicator fish species. Ranks selected include degradation condition of catchment, land use activities or upstream supply of sediment that provides potential for habitat diversity to be maintained in natural/pristine condition (Zero), near-natural conditions that do not affect indicator species (Low), acceptable condition to provide minimal requirements for indicator species (consider abundances on reach scale) (Mod) and unacceptable loss of substrate types that will significantly affect fish communities. [LANDUSE_SSUP]	Berkman and Rabeni 1987
Sediment removal flows (FISH_ECO_SFLO)	River flows measured as discharge (m^3/s) associated with velocities (m/s) using hydraulics to provide suitable shear stress to mobilise and sort fine and medium sized sediments to maintain instream habitat diversity preferred by indicator fish communities in a near natural condition (Zero rank), altered distributions but suitable abundances of required habitats for indicator species (Low rank), altered habitat distributions that will not significantly affect fish communities (Mod rank) and altered flows that significantly change substrate characteristics that will result in loss of instream substrates and morphological features required by indicator fish species for lifecycle events. [DISCHARGE_YEAR]	
Velocity / depth habitat characteristics (FISH_ECO_VD)	Changes to the flow regimes affect resources and habitat availability. Hydrological variability influences the physical habitat of riverine systems and thus shapes the structure and diversity of aquatic communities. Different fish species can be used as indicators for different velocity depth classes (Slow-deep, slow-shallow, fast-deep, fast-shallow). Zero: All velocity depth classes are available in high abundances and distribution to support all indicator fish species , pristine condition, Low: There are changes in the abundances and distribution of different velocity depth classes. All indicator fish species are still present, medium: Some of the velocity depth classes abundances are reduced, majority of indicator fish species are still present, High: There are significant alteration of velocity depth classes which affect fish communities, most of the indicator fish species are absent. [DISCHARGE_YR]	Cattanéo 2005; Poff and Allan 1995

Variable title (BN CODE)	Justification (Incl. indicator and measure (units) and specify rank descriptions, standard Zero, Low, Moderate (Mod) and High, or continuous or categorical etc.)	References
Cover characteristics (FISH_ECO_COV)	There is a strong relationship between riparian vegetation, instream habitat and community structure in aquatic ecosystems. Different cover features included overhanging vegetation, marginal vegetation, aquatic vegetation, undercut bank, substrate. Different fish species have different preferences for different cover features. Zero: All cover features are available in good distribution and abundances all indicator species are present. Physical structure available and conditions comparable to pre-anthropogenic activities, ideal depth for indicator species to provide cover. Ideal marginal vegetation cover for indicator fish guild, Low: There are some indications of alteration, but all cover features and indicator species are present. Suitable availability of and conditions of physical structures, suitable depth available. Suitable percentage of cover available for indicator fish, Medium: Some of the cover features absent, majority of indicator fish species are still present. Concerning loss of physical structure associated potential impact on indicator species, moderate loss of depth for indicator species resulting in observable response of species to cover change. Low availability of cover for indicator fish guild representing threshold of potential concerns, High: There are significant alteration in cover features which affect fish communities, most of the indicator fish species are absent. Critical loss of substrate associates=d potential impact on fish indicators. Significant loss of depth for indicator species resulting in significant reduction of cover. Critical low to zero marginal vegetation cover available for indicator fish guild. [DISHARGE_YR]	Dala-Corte et al. 2016
Environment potential for vegetation (VEG_ECO_POT)	The availability of habitat preferences represents the environment potential to support riparian vegetation communities. Ranks selected for this node include complete or sufficient environment potential to support expected riparian community structure, function and composition (Zero-low rank), moderate environment potential (Mod rank) where the environment supports most but not all expected community components and low environment potential (High rank) where environment support of riparian communities is unsustainable and/or dysfunctional.	DATA FROM THIS STUDY
Sediment supply (VEG_ECO_SSUP)	Significant reduction or increase in sediment volume and fine-coarse ratio from upstream or laterally associated with runoff from terrestrial areas due to type and extent (% catchment degradation) of land use activities (degradation intensity) and degradation that will directly affect habitat availability within the river associated with river flows that will describe geomorphic/instream habitat characteristics for substrate availability and location for indicator vegetation. Ranks selected include condition of catchment, land use activities or upstream supply of sediment that provides potential for habitat diversity to be maintained in natural/pristine condition (Zero), near-natural conditions that do not affect indicator species (Low), acceptable condition to provide minimal requirements for indicator species (consider abundances on reach scale) (Mod) and unacceptable loss of substrate types that will significantly affect vegetation communities. [LANDUSE_SSUP]	DATA FROM THIS STUDY
Sediment removal flows (VEG_ECO_SFLO)	River flows measured as discharge (m3/s) associated with velocities (m/s) using hydraulics to provide suitable shear stress to mobilise sediments to maintain instream habitat diversity preferred by indicator vegetation in a near natural condition (Zero rank), altered distributions but suitable abundances of required habitats for indicator species (Low rank), altered habitat distributions that will not significantly affect riparian vegetation (Mod rank) and altered flows that significantly change substrate characteristics that will result in loss of riparian substrates and morphological features required by indicator vegetation species for lifecycle events. [DISCHARGE_YR]	DATA FROM THIS STUDY

Variable title (BN CODE)	Justification (Incl. indicator and measure (units) and specify rank descriptions, standard Zero, Low, Moderate (Mod) and High, or continuous or categorical etc.)	References
Environment potential for invertebrates (INV_ECO_POT)	Instream aquatic invertebrate communities are influenced by physical and chemical parameters, and in turn as primary processors of organic material, they are key to nutrient cycling in aquatic ecosystems. Emerging adults export nutrients from the aquatic environment into the terrestrial, and most larvae and adults form important parts of riverine, riparian, and terrestrial foodwebs. Aquatic invertebrates in "healthy" aquatic ecosystems perform crucial functions as "free services" to other life form dependant on these systems. La Notte et al. (2017) calculated the financial worth of Europe's sustainable water purification ecosystem service as up to €31 billion per year. Ranks selected for this node are based on Present Ecological State (PES - A, B, C, D, E, F categories) for the aquatic macroinvertebrate community. PES natural to Largely Natural (Zero-low rank), PES Largely Natural to moderately impaired (B/C - C) (Mod rank); PES < C (High rank).	Finn et al. (2011); La Notte et al. (2017); Liquete et al. (2016); Sanpera-Calbert et al. (2009)
Barriers affecting migrations (INV_ECO_BAR)	This node considers the importance of longitudinal river connectivity for amphidromous migrations of macro-invertebrates using Palaemonid indicator species. The larval stages of most freshwater prawn species (Palaemonidae: *Macrobrachium*) requires access to saline water to complete development. With some species hatched larvae drift downstream to saline water, and after metamorphosis, post larvae migrate back to freshwater. With other species ovigerous females migrate to estuaries, where eggs hatch a free-swimming zoeae, progressing through 12 larval stages before migrating into freshwater in post larval stage. The larvae of *Macrobrachium* species currently present in the Limpopo and Luvuvhu, and historically Letaba (last 1960) and Olifants (last 1980) all require salinity of 8 - 12 ppt to devlop (Cort & Schoonbee (1993). Migrational barrier potential ranked are zero, low, moderate and high. No barrier (Zero); temporary barriers which may delay seasonal migrations (Low); partial/seasonal barrier that may hamper migrations during important life cycle phases but do not significant affect population (Moderate); permanent barriers that restrict species migrations (High). [NO_BARRIERS]	Alam et al. (2017); Bauer & Delahoussaye (2008); Bertini et al. (2014); Hart et al. (2001).

Variable title (BN CODE)	Justification (Incl. indicator and measure (units) and specify rank descriptions, standard Zero, Low, Moderate (Mod) and High, or continuous or categorical etc.)	References
Sediment supply (INV_ECO_SSUP)	In the context of geomorphic substrates that provide habitat for macro-invertebrate communities. The potential for the supply of sediment into the rivers has been considered. Sedimentation is a natural process, but increased sediment inputs and deposition associated with upstream and onsite anthropogenic impacts. Sediment input and deposition potentially reduces habitat heterogeneity, smothering available interstitial spaces. Severity impact of sedimentation affects dependant on shape, size, density of particles; potential for microbial colonisation; availability of nutrients; and water flow, velocity, turbulence and temperature. Ranks selected for this node include consideration of condition of catchment and land use activities that may affect supply of sediment that can potentially affect habitat diversity. Measure include an intact catchment area with pristine buffer of sediments from entering the river that supports indicator species (Zero), near-natural conditions that do not affect indicator species (Low), acceptable condition to provide minimal requirements for indicator species (consider abundances on reach scale) (Mod) and unacceptable loss of substrate types that will significantly affect aquatic macroinvertebrate communities. Significant reduction or increase in sediment volume and fine-coarse ratio from upstream or lateral supply associated with runoff from terrestrial areas due to degradation type (degradation intensity) and extent (% catchment degradation). Connectivity and catchment position plays a role too, with distal or poorly connected sources having a smaller impact compared to local or well buffered sources. The shift in sediment supply will directly affect habitat availability within the river associated with river flows that will describe geomorphic/instream habitat characteristics for substrate availability and location for indicator invertebrate species. Ranks selected include degradation condition of catchment, land use activities or upstream supply of sediment that provides potential for habitat diversity to be maintained in natural/pristine condition (Zero), near-natural conditions that do not affect indicator species (Low), acceptable condition to provide minimal requirements for indicator species (consider abundances on reach scale) (Mod) and unacceptable loss of substrate types that will significantly affect invertebrate communities. [LANDUSE_SSUP]	Connolly & Pearson (2007); Cort & Schoonbee (1993); Holmukzi & Biggs (2003); Kreutzweiser et al. (2005); Suren et al. (2005)
Sediment removal flows (INV_ECO_SFLO)	River flows measured as discharge (m3/s) associated with velocities (m/s) using hydraulics to provide suitable shear stress which mobilise sediments, maintaining instream substrate and hydraulic biotope diversity. Indicator aquatic macroinvertebrates for upper (cold water, cobble-boulder taxa e.g., Blepharoceridae, Synlestidae, Baetidae: Demoreptus sp., etc.), mid reach (cool - warm water, cobble-boulder-gravel taxa e.g., Aeshnidae: Pinheyschna subpupillata, Libellulidae: Zygonyx natalensis, Tricorythidae: Tricorythus sp., Heptageniidae: Afronus sp., etc.), lower reach (warm water, gravel-sand-mud (Gomphidae, Unionidae, Corbiculidae and marginal & aquatic vegetation biotopes taxa e.g., Heptageniidae: Compsoneuria sp., Coenagrionidae: Pseudagrion sp., Palaemonidae: Macrobrachium sp. River flows measured as discharge (m^3/s) associated with velocities (m/s) using hydraulics to provide suitable shear stress to mobilise fine and medium sized sediments to maintain instream habitat diversity preferred by indicator invertebrate communities in a near natural condition (Zero rank), altered distributions but suitable abundances of required habitats for indicator species (Low rank), altered habitat distributions that will not significantly affect invertebrate communities (Mod rank) and altered flows that significantly change substrate characteristics that will result in loss of instream substrates and morphological features required by indicator invertebrate species for lifecycle events. [DISCHARGE_YR]	Smith & Stopp (1978)

Variable title (BN CODE)	**Justification (Incl. indicator and measure (units) and specify rank descriptions, standard Zero, Low, Moderate (Mod) and High, or continuous or categorical etc.)**	**References**
Velocity / depth habitat characteristics (INV_ECO_VD)	Presence-absence and abundance of instream velocity-depth habitat (slow-deep, slow-shallow, slow-very shallow, fast-intermediate, fast-shallow and fast-deep) distributions (measure) and substrate type (boulder, cobble, gravel, sand) associated with requirements of indicator aquatic macroinvertebrates. Ranks include distribution and abundances that will support pristine/natural community of indicator species (Zero), occurrence of (but altered) habitat distributions for indicator species (Low), modified velocity-depth habitat distributions for at least one fisheries indicator species while majority of indicator species is provided for (Mod) and significant alteration of velocity-depth habitat characteristics that affects fish community significantly. [DISCHARGE_YR]	Evidence generated in this study
Cover characteristics (INV_ECO_COV)	In the headwaters and mid reaches, substrates such as boulder, cobble and gravel and marginal vegetation provide important cover. In the lower reaches marginal and aquatic vegetation provide cover for the majority of macroinvertebrates, and sand, mud, silt substrates provide cover for filter feederers (Unionidae, Corbiculidae) important cover. [DISCHARGE_YR]	DATA FROM THIS STUDY
Demand/potential for recreation (REC_SPIR_POT)	The availability of river's natural character that represents the environment potential for people to swim and conduct spiritual rituals. Ranks selected for this node include optimal environment (flow and depth potential to support people's appreciation and enjoyment of the water body and spiritual use) (Zero-low rank), moderate environment potential (Mod rank) flow, depth and natural character of river supports most but not all expected parts for spiritual, appreciation, enjoyment (High rank) significant parts of the river's natural character, flow, depth do not support the river's potential for people's enjoyment and spiritual use	DATA FROM THIS STUDY
Velocity / depth habitat characteristics (REC_SPIR_VD)	Distribution and abundance (unit m2) of instream velocity-depth habitat (slow-deep, slow-shallow, slow-very shallow, fast-intermediate, fast-shallow and fast-deep) distributions (measure) associated with requirements for swimming and spiritual water use. Ranks include distribution and abundances of natural character, varied depth and velocity (Zero), occurrence of (but altered) river's natural character for swimming and spiritual use (Low), modified velocity-depth habitat distributions, changing river's natural character for some locations, while majority of areas maintained (Mod) and significant alteration of velocity-depth habitat characteristics with complete change of river's natural character and locations for swimming and spiritual use. [DISCHARGE_YR]	DATA FROM THIS STUDY
Demand/potential for tourism (TOURISM_POT)	The availability of river's natural character that represents the environment potential for people to enjoy tourists attraction and activities(fishing competition, water rafting, bird watching). Ranks selected for this node include optimal environment (flow and depth, water quality) potential to the area's physical environment for tourism (Zero-low rank), moderate environment potential (Mod rank) flow, depth , water quality, natural character of river supports some parts of the river for tourism but not all parts (High rank) significant parts of the river's natural character, flow, depth, water quality support the river's potential for tourism	DATA FROM THIS STUDY

Table 8-2: Example Of The Conditional Probability Table For The Parent Nodes Of The Bayesian Network For The Limpopo E-Flow Study

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
Maintain fisheries for livelihoods (SUB_FISH_END)	Endpoint representing integration of potential for subsistence fisheries (causal leg of risk assessment) and holistic environment including instream and other stressors that affect subsistence fish communities per risk region/site. This node represents the endpoint selected through the visioning process of the study as a part of provisioning services in the study.	Zero	Either oversupply of fish for potential subsistence fishery, or no demand for subsistence fishery associated with no people or subsistence fisheries activities.
		Low	Supply and demand for subsistence fishery matched resulting in sustainable provision of fish that meets livelihoods demand of community.
		Moderate	Provision of fish does not meet demand for subsistence fishery but is suitable to provide critical requirement of community to remain sustainable. This represents "worst" but acceptable condition of fishery for community.
		High	Unacceptable or unsustainable demand for fish or under supply of fish, or unsuitable quality of fish that will negatively affect human health. This rank represents potential for this endpoint not being met as a result of one or many stressors.
Environment for sub.fish (SUB_FISH_ENV)	Endpoint representing integration of instream environment for subsistence fish communities and impacts like barriers and alien fauna affecting fish subsistence fish communities per risk region/site. This node represents the endpoint selected through the visioning process of the study as part of provisioning services in the study.	Zero	Complete environment potential to support subsistence fishery, no impact of barriers and alien fauna and competition
		Low	Sufficient environment potential to support subsistence fishery, low impact of barriers and alien fauna and competition
		Moderate	Moderate environment potential where the environment supports most but not all subsistence fisheries, moderate impact of barriers and alien fauna and competition
		High	Low environment potential where environment support of subsistence fisheries is unsustainable and/or dysfunctional, high impact of barriers and alien fauna and competition
Instream environment for sub.fish (SUB_FISH_INST)	Endpoint representing integration of physical habitat for subsistence fisheries, water quality for subsistence fisheries and cues for life cycles of subsistence fisheries.	Zero	Complete environment potential to support subsistence fishery, physical habitat available, water quality in a good range, lifecycles of subsistence fisheries is undisrupted

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
		Low	Sufficient environment potential to support subsistence fishery, physical habitat available, water quality in a good range, lifecycles of subsistence fisheries is undisrupted
		Moderate	Moderate environment potential where the environment supports most but not all subsistence fisheries, not all physical habitat required are available, water quality in a tolerable range, some part of the lifecycles of subsistence fisheries are disrupted
		High	Low environment potential where environment support of subsistence fisheries is unsustainable and/or dysfunctional, physical habitat required is not available, water quality in a intolerable range, lifecycles of subsistence fisheries is disrupted
Physical habitat for sub.fish (SUB_FISH_HAB)	Endpoint representing integration of geomorphic substrates, velocity depth classes and cover characteristics.	Zero	The physical habitat (velocity depth classes, geomorphic substrates, cover features) available and conditions comparable to pre-anthropogenic activities
		Low	Some alterations to the physical habitat (velocity depth classes, geomorphic substrates, cover features) but suitable availability and conditions present to sustain subsistence fisheries.
		Moderate	Concerning loss to physical habitat (velocity depth classes, geomorphic substrates, cover features) not all expected subsistence fisheries are present.
		High	Critical loss to physical habitat (velocity depth classes, geomorphic substrates, cover features) absences of subsistence fisheries.
Alien fauna competition/predating fish (SUB_FISH_ALI)	Occurrence and abundance (measure and unit) of competing/predacious impact of known alien fauna (fish) on indigenous fishes	Zero	Occurrence and abundance (measure and unit) of competing impact of known alien fauna (fish) on indigenous fishes considered where ranks represents no threat/potential impact. 0 individuals.
		Low	Occurrence of alien (not invasive) species that will not significantly affect life cycle of any indigenous species. 1 individual.

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
		Moderate	Occurrence of alien species (invasive) with potential to affect indigenous populations significantly in low abundances. > 1 individual.
		High	Presence of alien species in high abundances that poses high threat to indigenous populations. Invasive species dominate the site.
Geomorphic substrates (SUB_FISH_GEOM)	Diversity of substrates across a range of geomorphic units (benches, banks, floodplains)	Zero	Habitat and sediment heterogeneity without blanket deposition of fine sediment; no undue incision of active channel and flood features
		Low	Localised scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ localised blanket deposition of fine sediment on inset benches, banks and flood features
		Moderate	Frequent scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ thin blanket deposition of fine sediment on inset benches, banks and flood features
		High	Extensive scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ thick blanket deposition of fine sediment on inset benches, banks and flood features
Maintain plants for livelihoods (SUB_VEG_END)	Endpoint representing demand potential for harvesting plants (causal leg of risk assessment) and supply of plants for harvest per risk region/site. This node represents the endpoint selected through the visioning process of the study as a part of provisioning services in the study.	Zero	Either oversupply of riparian plants for livelihoods, or no demand for riparian plants for livestock grazing
		Low	Supply and demand for riparian plants for livelihoods, matched resulting in sustainable provision that meets demand of people.
		Moderate	riparian plants for livelihoods does not meet demand for subsistence harvesting but is suitable to provide critical requirement.
		High	Unacceptable and unsuitable riparian plants for livelihoods and likely to negatively affect people's health. This rank represents potential for this endpoint not being met.
		Zero	The availability of plants / plant material is in keeping with background (reference) expectations for the risk region.

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
Supply of plants for harvest (SUB_VEG_SUPP)	The combination of available plants /plant material comprising edible and medicinal plants, wood and reeds or large sedges, that can be harvested per risk region.	Low	The availability of plants / plant material is in keeping with current day availability for the risk region.
		Moderate	The availability of plants / plant material has been reduced from current day availability but reduced resource is still available for harvest for the risk region.
		High	The availability of plants / plant material has been reduced from current day availability and is no longer available for harvest for the risk region.
Edible & medicinal plants (SUB_VEG_EDMED)	Endpoint representing edible and medicinal plants expected in the risk region and that are dependent on available riparian habitats for their existence and distribution.	Zero	Riparian habitats are intact and all expected edible and medicinal plants for the risk region are available.
		Low	Riparian habitats are intact and most expected edible and medicinal plants for the risk region are available.
		Moderate	Riparian habitats are altered and only a portion of expected edible and medicinal plants for the risk region are available.
		High	Riparian habitats are altered/dysfunctional and none / few of the expected edible and medicinal plants for the risk region are available.
Wood for fuel/construction (SUB_VEG_WOOD)	Endpoint representing trees and shrubs expected in the risk region and that are dependent on available riparian habitats for their existence and distribution.	Zero	Riparian habitats are intact and all expected woody plants for the risk region are available.
		Low	Riparian habitats are intact and most expected woody plants for the risk region are available.
		Moderate	Riparian habitats are altered and only a portion of expected woody plants for the risk region are available.
		High	Riparian habitats are altered/dysfunctional and none/few of the expected woody plants for the risk region are available.
Riparian habitat for vegetation (SUB_VEG_RIP)	Diversity of riparian habitats across a range of geomorphic features / zones. Habitat diversity key components are substrate and hydrolocal / hydraulic characteristics. Endpoint represents the	Zero	Riparian habitat diversity intact, all expected geomorphic units and substrates are represented for the risk region and hydraulic / hydrological characteristics promote species diversity and abundance.

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
	biophysical template which facilitates plant / vegetation potential responseto environment.	Low	Riparian habitat diversity mostly intact, all expected geomorphic units and substrates are represented for the risk region and hydraulic / hydrological characteristics promote species diversity and abundance.
		Moderate	Riparian habitat diversity reduced, geomorphic unit and substrate diversity reduced and hydraulic / hydrological characteristics promote species dominance with loss of diversity.
		High	Riparian habitat diversity lost, geomorphic unit and substrate diversity reduced and hydraulic / hydrological characteristics promote species dominance with loss of diversity.
Geomorphic substrate (SUB_VEG_GEOM)	Diversity of substrates across a range of geomorphic units (benches, banks, floodplains)	Zero	Habitat and sediment heterogeneity without blanket deposition of fine sediment; no undue incision of active channel
		Low	Localised scour of fine sediment resulting in removal of inset branches and continuous bank erosion/ localised blanket deposition of fine sediment on inset benches, banks and flood features
		Moderate	Frequent scour of fine sediment resulting in removal of inset branches and continuous bank erosion/ thin blanket deposition of fine sediment on inset benches, banks and flood features
		High	Extensive scour of fine sediment resulting in removal of inset branches and continuous bank erosion/ thick blanket deposition of fine sediment on inset benches, banks and flood features
Reeds for fuel/construction (SUB_VEG_REED)	Endpoint representing reeds and large sedges expected in the risk region and that are dependent on available riparian habitats for their existence and distribution.	Zero	Riparian habitats are intact and all expected reeds and sedges for the risk region are available.
		Low	Riparian habitats are intact and most expected reeds and sedges for the risk region are available.
		Moderate	Riparian habitats are altered and only a portion of expected reeds and sedges for the risk region are available.

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
		High	Riparian habitats are altered/dysfunctional and none/few of the expected reeds and sedges for the risk region are available.
Maintain plants for domestic livestock (LIV_VEG_END)	Endpoint representing demand potential for grazing (causal leg of risk assessment, abundance of livestock) and available riparian habitat for livestock. This node represents the endpoint selected through the visioning process of the study as a part of provisioning services in the study.	Zero	Either oversupply of riparian plants for livestock grazing, or no demand for riparian plants for livestock grazing
		Low	Supply and demand for riparian plants for livestock grazing, matched resulting in sustainable provision that meets demand of livestock.
		Moderate	riparian plants for livestock grazing do not meet demand for subsistence livestock but is suitable to provide critical requirement of livestock to live.
		High	Unacceptable and unsuitable riparian plants for livestock grazing and likely to negatively affect livestock health. This rank represents potential for this endpoint not being met.
Riparian habitat for livestock (LIV_VEG_RIP)	Diversity of riparian habitats across a range of geomorphic features / zones that support riparian species suitable for grazing. Habitat diversity key components are substrate and hydrological / hydraulic characteristics.	Zero	Riparian habitat diversity intact, all expected geomorphic units and substrates are represented for the risk region and hydraulic / hydrological characteristics promote species diversity and abundance.
		Low	Riparian habitat diversity mostly intact, all expected geomorphic units and substrates are represented for the risk region and hydraulic / hydrological characteristics promote species diversity and abundance.
		Moderate	Riparian habitat diversity reduced, geomorphic unit and substrate diversity reduced and hydraulic / hydrological characteristics promote species dominance with loss of diversity.
		High	Riparian habitat diversity lost, geomorphic unit and substrate diversity reduced and hydraulic / hydrological characteristics promote species dominance with loss of diversity.
LIV_VEG_SAFE	Based on presence/absence of instream and off stream predators that threaten safety of livestock	Zero	Relates to no predation that threatens safety of livestock
		Low	Relates to low threat due to presence of predators but low abundance and species poses low threat to livestock

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
		Moderate	Relates to moderate threat due to presence of predators but low abundance and species poses threat to juviniles but not adults.
		High	Relates to high threat due to presence of predators that poses threat to livestock.
Environment for flood control (FLO_ATT_ENV)	The riparian zone / habitats and overall vegetation abundance and structure all contribute to reach roughness which attenuates risk to flood damage e.g. function is intact with high vegetation cover, especially reeds and woody component.	Zero	Riparian habitat diversity intact, all expected geomorphic units and substrates are represented for the risk region and hydraulic / hydrological characteristics promote species diversity and abundance.
		Low	Riparian habitat diversity mostly intact, all expected geomorphic units and substrates are represented for the risk region and hydraulic / hydrological characteristics promote species diversity and abundance.
		Moderate	Riparian habitat diversity reduced, geomorphic unit and substrate diversity reduced and hydraulic / hydrological characteristics promote species dominance with loss of diversity.
		High	Riparian habitat diversity lost, geomorphic unit and substrate diversity reduced and hydraulic / hydrological characteristics promote species dominance with loss of diversity.
Geomorphic substrate (RIV_ASS_GEOM)	Diversity of substrates across a range of geomorphic units (benches, banks, floodplains)	Zero	Habitat and sediment heterogeneity without blanket deposition of fine sediment; no undue incision of active channel and flood features
		Low	Localised scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ localised blanket deposition of fine sediment on inset benches, banks and flood features
		Moderate	Frequent scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ thin blanket deposition of fine sediment on inset benches, banks and flood features
		High	Extensive scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ thick blanket deposition of fine sediment on inset benches, banks and flood features

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
Geomorphic substrates (RES_RES_GEOM)	Diversity of substrates across a range of geomorphic units (benches, banks, floodplains)	Zero	Habitat and sediment heterogeneity without blanket deposition of fine sediment; no undue incision of active channel and flood features
		Low	Localised scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ localised blanket deposition of fine sediment on inset benches, banks and flood features
		Moderate	Frequent scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ thin blanket deposition of fine sediment on inset benches, banks and flood features
		High	Extensive scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ thick blanket deposition of fine sediment on inset benches, banks and flood features
Maintain fish communities (FISH_ECO_END)	Endpoint representing integration of potential for fish communities(causal leg of risk assessment) and holistic environment including instream environment for fish communities and other stressors (barriers, disturbance to wildlife) that affect fish communities per risk region/site. This node represents the endpoint selected through the visioning process of the study as a part of supporting services in the study.	Zero	Complete or sufficient environment potential to support expected fish community structure, function and composition
		Low	Sufficient environment potential to support expected fish community structure, function and composition
		Moderate	Moderate environment potential (Mod rank) where the environment supports most but not all expected fish community
		High	Low environment potential (High rank) where environment support of fish communities is unsustainable and/or dysfunctional.
Environmental condition for fish (FISH_ECO_ENV)	Endpoint representing integration of instream environment for fish communities and impacts like barriers and disturbance to wildlife to fish communities per risk region/site. This node represents the endpoint selected through the visioning process of the study as part of supporting services in the study.	Zero	Complete or sufficient environment potential to support expected fish community structure, function and composition
		Low	Sufficient environment potential to support expected fish community structure, function and composition
		Moderate	Moderate environment potential (Mod rank) where the environment supports most but not all expected fish community
		High	Low environment potential (High rank) where environment support of fish communities is unsustainable and/or dysfunctional.

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
Instream environment for fish (FISH_ECO_INS)	Endpoint representing integration of cues for life cycles of indicator fish, physical habitat for indicator fish and water quality for indicator fish.	Zero	Complete environment potential to support fish communities, physical habitat available, water quality in a good range, lifecycles of indicator species is undisrupted
		Low	Sufficient environment potential to support fish communities, physical habitat available, water quality in a good range, lifecycles of indicator species is undisrupted
		Moderate	Moderate environment potential where the environment supports most fish communities, not all physical habitat required are available, water quality in a tolerable range, some part of the lifecycles of indicator fish are disrupted
		High	Low environment potential where environment support of fish communities is unsustainable and/or dysfunctional, physical habitat required is not available, water quality in a intolerable range, lifecycles of indicator species is disrupted
Physical habitat for indicator fish (FISH_ECO_HAB)	Endpoint representing integration of geomorphic substrates, velocity depth classes and cover characteristics.	Zero	The physical habitat (velocity depth classes, geomorphic substrates, cover features) available and conditions comparable to pre-anthropogenic activities
		Low	Some alterations to the physical habitat (velocity depth classes, geomorphic substrates, cover features) but suitable availability and conditions present to sustain fish communities
		Moderate	Concerning loss to physical habitat (velocity depth classes, geomorphic substrates, cover features) not all expected fish species are present.
		High	Critical loss to physical habitat (velocity depth classes, geomorphic substrates, cover features) absences of fish communities.
	Diversity of substrates across a range of geomorphic units (benches, banks, floodplains)	Zero	Habitat and sediment heterogeneity without blanket deposition of fine sediment; no undue incision of active channel and flood features

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
Geomorphic substrates (FISH_ECO_GEOM)		Low	Localised scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ localised blanket deposition of fine sediment on inset benches, banks and flood features
		Moderate	Frequent scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ thin blanket deposition of fine sediment on inset benches, banks and flood features
		High	Extensive scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ thick blanket deposition of fine sediment on inset benches, banks and flood features
Cues for life cycles of indicator fish (FISH_ECO_CUES)	Endpoint represent cues for the life cycles of subsistence fisheries	Zero	There are no changes in cues, or life stages of indicator fish species
		Low	Changes have occurred but it does not impacted the cues or life stages of indicator fish species
		Moderate	Changes in cues have impacted some of the life stages of indicator fish species
		High	Changes in cues has disrupted the life cycles of indicator fish species
Disturbance to wildlife (FISH_ECO_DTW)	Endpoint represent alien fauna on fish	Zero	Occurrence and abundance (measure and unit) of competing impact of known alien fauna (fish) on indigenous fishes considered where ranks represents no threat/potential impact. 0 individuals.
		Low	Occurrence of alien (not invasive) species that will not significantly affect life cycle of any indigenous species. 1 individual.
		Moderate	Occurrence of alien species (invasive) with potential to affect indigenous populations significantly in low abundances. > 1 individual.
		High	Presence of alien species in high abundances that poses high threat to indigenous populations. Invasive species dominate the site.
Alien fauna on fish (FISH_ECO_ALI)	Endpoint representing alien fauna competition and alien fauna predation. (Maybe alien fauna hybridization).	Zero	Occurrence and abundance (measure and unit) of competing impact of known alien fauna (fish) on indigenous fishes considered where ranks represents no threat/potential impact. 0 individuals.

Variable title (BN CODE)	**Description for conditional probability tables (CPTs)**	**Ranks**	**Description of ranks for variable**
		Low	Occurrence of alien (not invasive) species that will not significantly affect life cycle of any indigenous species. 1 individual.
		Moderate	Occurrence of alien species (invasive) with potential to affect indigenous populations significantly in low abundances. > 1 individual.
		High	Presence of alien species in high abundances that poses high threat to indigenous populations. Invasive species dominate the site.
Maintain vegetation communities (VEG_ECO_END)	Endpoint representing integration of environment potential for vegetation (causal leg of risk assessment) and environment condition for vegetation, which represents riverine conditions for vegetation communities (as represented by the interaction of substrate and flow) that may/may not be affected by alien flora.	Zero	The environment has the potential to maintain riparian vegetation communities and the environmental conditions cater for expected community structure, abundance and diversity.
		Low	The environment has the potential to maintain riparian vegetation communities and the environmental conditions mostly cater for expected community structure, abundance and diversity, with low perturbation from expectations.
		Moderate	The environment has some potential to maintain riparian vegetation communities and/or the environmental conditions acceptably cater for expected community structure, abundance and diversity, with moderate perturbation from expectations.
		High	The environment has limited potential to maintain riparian vegetation communities and/or the environmental conditions cater poorly for expected community structure, abundance and diversity, with high levels of perturbation from expectations.
Environment condition for vegetation (VEG_ECO_ENV)	Endpoint representing integration of river environment for vegetation, which represents riverine conditions for vegetation communities (as represented by the interaction of substrate and flow) that may/may not be affected by alien flora.	Zero	The river environment for riparian vegetation is in keeping with background (reference) expectations, and alien vegetation is absent or negligible
		Low	The river environment for riparian vegetation is in keeping with background (near reference) expectations, and alien vegetation is low, or comprised of annuals only.

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
		Moderate	The river environment for riparian vegetation is satisfactory and moderately in keeping with expectations, and alien vegetation is present (annual and perennial), but has low to moderate negative affect on diversity.
		High	The river environment does not support riparian vegetation well, and is not in keeping with expectations, and alien vegetation is dominant (and invasive), and has significantly reduced indigenous diversity.
River environment for vegetation (VEG_ECO_RIV)	The only input is the instream environment for vegetation, suggest amalgamation of the two and call as is (representing instream and riparian) and delete instream node?	Zero	Combination of substrate and flow/depth characteristics required for riparian vegetation exist and are in keeping with background [reference] expectations.
		Low	Combination of substrate and flow/depth characteristics required for riparian vegetation exist and are mostly in keeping with background [reference] expectations.
		Moderate	Perturbations of substrate and/or flow/depth characteristics required for riparian vegetation exist and therefore hinder expected occurrence of riparian vegetation.
		High	An absence of either substrate or flow/depth characteristics required for riparian vegetation, singly or in combination, but do not facilitate riparian vegetation occurrence /persistence.
Instream habitat for aquatic vegetation (VEG_ECO_INS)	Endpoint representing integration of water quality, geomorphic substrates and hydraulic/hydrological preferences. The combination of these three parameters affects microsite characteristics for aquatic and riparian vegetation recruitment (most importantly) and persistence.	Zero	Combination of substrate, water quality and flow/depth characteristics required for aquatic vegetation exist and are in keeping with background [reference] expectations.
		Low	Combination of substrate, water quality and flow/depth characteristics required for aquatic vegetation exist and are mostly in keeping with background [reference] expectations.

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
		Moderate	Perturbations of substrate, water quality or flow/depth characteristics required for aquatic vegetation exist and therefore hinder expected occurrence of aquatic vegetation.
		High	An absence of either substrate, water quality or flow/depth characteristics required for aquatic vegetation, singly or in combination, but do not facilitate aquatic vegetation occurrence.
Geomorphic substrates (VEG_ECO_GEOM)	Diversity of substrates across a range of geomorphic units (benches, banks, floodplains)	Zero	Habitat and sediment heterogeneity without blanket deposition of fine sediment; no undue incision of active channel
		Low	Localised scour of fine sediment resulting in removal of inset branches and continuous bank erosion/ localised blanket deposition of fine sediment on inset benches, banks and flood features
		Moderate	Frequent scour of fine sediment resulting in removal of inset branches and continuous bank erosion/ thin blanket deposition of fine sediment on inset benches, banks and flood features
		High	Extensive scour of fine sediment resulting in removal of inset branches and continuous bank erosion/ thick blanket deposition of fine sediment on inset benches, banks and flood features
Environment condition for invertebrates (INV_ECO_ENV)	The potential for the environment to be suitable for invertebrates in this study is based on knowledge of inst. Env for inverts, barriers and Alien fauna. Conditional relationship. Deterioration of instream env and increase in barriers and inc. in aliens results in increase in risk. Measure available river-stream length (potential habitat) based on historical species distribution data as reference. Compare against current available stream-river length habitats (linked and free flowing rivers). Use % free flowing habitat to set parameters. Express number of manmade barriers in relation to river-stream length to determine severity of fragmentation.	Zero	Free-flowing river (no manmade barriers - measure fluvial distance), influencing migration (i.e., Palaemonidae: *Macrobrachium* sp. in lower reaches), habitat loss (e.g., fluvial habitats, flow modification, over abstraction, etc.), and sources for introductions of alien invasive species (competition, predation, introducing new diseases, parasites). Alien invasive fauna absent or present in very low abundance.
		Low	Free-flowing river habitat (fluvial connectivity) reduced by ≤20% (e.g., distance between 1st barrier and estuary/mouth compared against "reference") - in case of *Macrobrachium* sp.. Upstream barriers/fluvial length, potential habitat reduced by ≤20%. Alien invasive fauna present but in low abundance.

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
		Moderate	Free-flowing river habitat (fluvial connectivity) reduced by 20 - 40% (e.g., distance between 1st barrier and estuary/mouth compared against "reference") - in case of *Macrobrachium* sp.. Upstream barriers/fluvial length, potential habitat reduced by 20 - 40%. Alien invasive fauna present and abundant.
		High	Free-flowing river habitat (fluvial connectivity) reduced by ^{3}40% (e.g., distance between 1st barrier and estuary/mouth compared against "reference") - in case of *Macrobrachium* sp.. Upstream barriers/fluvial length, potential habitat reduced by ^{3}40%. Alien invasive fauna present and very abundant.
Geomorphic substrates (INV_ECO_GEOM)	Diversity of substrates across a range of geomorphic units (benches, banks, floodplains)	Zero	Habitat and sediment heterogeneity without blanket deposition of fine sediment; no undue incision of active channel and flood features
		Low	Localised scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ localised blanket deposition of fine sediment on inset benches, banks and flood features
		Moderate	Frequent scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ thin blanket deposition of fine sediment on inset benches, banks and flood features
		High	Extensive scour of fine sediment resulting in removal of inset benches and continuous bank erosion/ thick blanket deposition of fine sediment on inset benches, banks and flood features
Maintain recreation and spiritual act (REC_SPIR_END)	Endpoint representing integration of river's physical environment for recreation and spiritual activities and holistic environment including instream and other stressors that affect use of river for recreation and spiritual activities per risk region/site. This node represents the endpoint selected through the visioning process of the study as a part of supporting services in the study.	Zero	Water depth and flow heterogenous to maintain a pristine and natural character of the river for recreational water use(people‘s appreciation and enjoyment of the water body) and spiritual use.
		Low	Water depth and flow heterogenous most parts of the river's natural character is maintained for recreational water use(people‘s appreciation and enjoyment of the water body) and spiritual use.
		Moderate	Minimal disturbances which obstruct flow and depth, changing some parts of the river from their natural character for recreational and spiritual use

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
		High	Absence of water flow and shallow water levels through out the seasons, with excessive sedimentation leading to homogenous area with complete change of river's natural character for recreational and spiritual use
Safe environment condition for recreation (REC_SPIR_SAFE)	Endpoint representing integration of physical and social environment affecting recreation per risk region/site. This node represents the endpoint selected through the visioning process of the study as part of supporting services in the study.	Zero	Ultimate safe environment to support recreation with no impact of hazards
		Low	Sufficiently safe environment with potential to support recreation and spiritual rituals with no impact of hazards
		Moderate	Moderately safe environment with potential to support recreation and spiritual activities with moderate hazards
		High	Dangerous environment with limited potential to support recreation and spiritual rituals with high hazards
Access and safely for recreation (REC_SPIR_ACC)	End point representing social and physical barriers present to prevent access to areas for recreational, spiritual activities and safety of users	Zero	Relates to no social and physical barriers present to prevent access to tourist areas with safe environment
		Low	Relates to a few/low present social and physical and barriers with low threat to access tourist areas by interested population.
		Moderate	Relates to moderately present social and physical barriers/threats that inhibit access to recreation sites for interested population
		High	Relates to major and high social threats and physical barriers that discourages access to recreation areas for interested population
Maintain tourism (TOURISM_END)	Endpoint representing integration of potential for tourism(causal leg of risk assessment) and holistic environment including environment for tourism and other stressors which include barriers that affect tourism per risk region/site. This node represents the endpoint	Zero	Either heterogenous and optimal environment for potential tourism or no demand for tourism associated and no people with interest in tourism.
		Low	Environmental conditions for tourism matched demand resulting in sustainable provision of tourist areas to meet demand of people and access

Variable title (BN CODE)	Description for conditional probability tables (CPTs)	Ranks	Description of ranks for variable
	selected through the visioning process of the study as a part of supporting services in the study.	Moderate	environmental conditions for tourism do not meet demand but is suitable to provide critical requirements of people for tourism remain sustainable and acceptable condition of fishery for community.
		High	Unacceptable or unsustainable demand for tourism or river environment not suitable for acceptable tourist environment which will affect their social well being. This rank shows potential for this endpoint not being met as a result of one or many stressors.
Environment condition for tourism (TOURISM_ENV)	Endpoint representing integration of physical environment for tourism and impacts like social barriers affecting tourism per risk region/site. This node represents the endpoint selected through the visioning process of the study as part of supporting services in the study.	Zero	Ultimate environment potential to support tourism with no impact of social barriers and physical environment.
		Low	Sufficient environment potential to support tourism with no impact of social barriers and physical environment.
		Moderate	Moderate environment potential where the physical environment supports tourism with moderate impact of social barriers
		High	Low environment potential where the physical environment supports tourism with high impact of social barriers and unsustainable and/or dysfunctional tourism

9 APPENDIX B

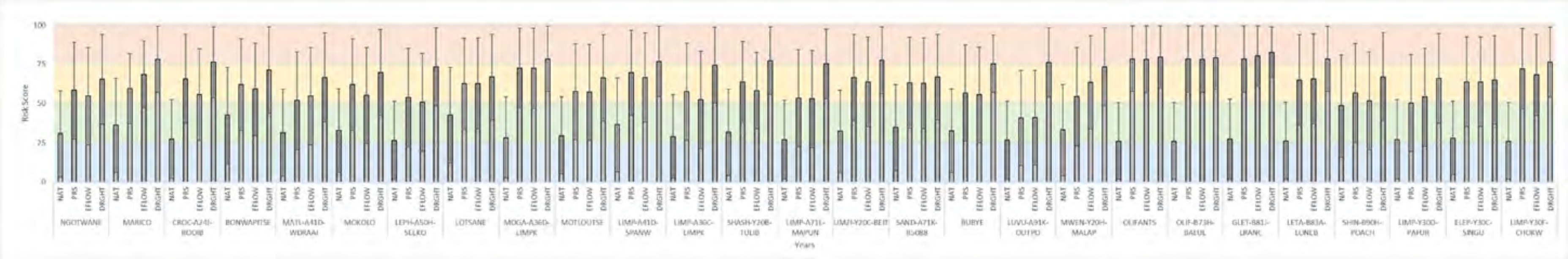

Figure 9-1: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to FISH-ECO-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

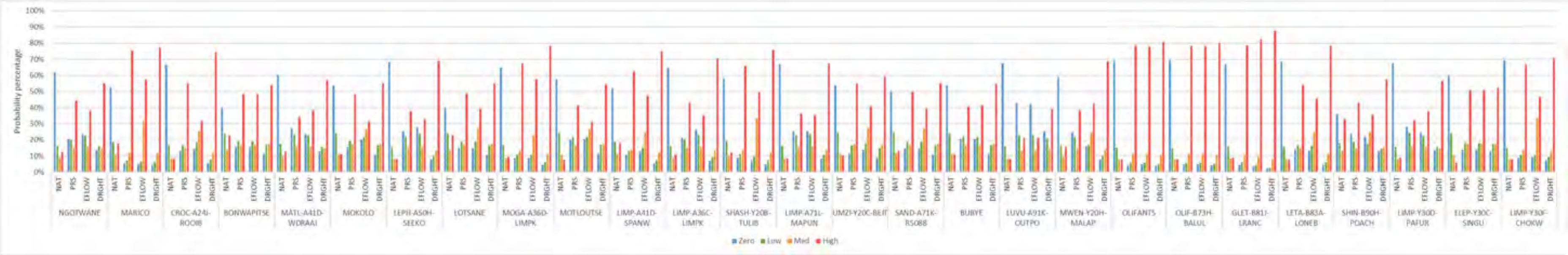

Figure 9-2: Probability of each risk rank occurring to the FISH-ECO-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

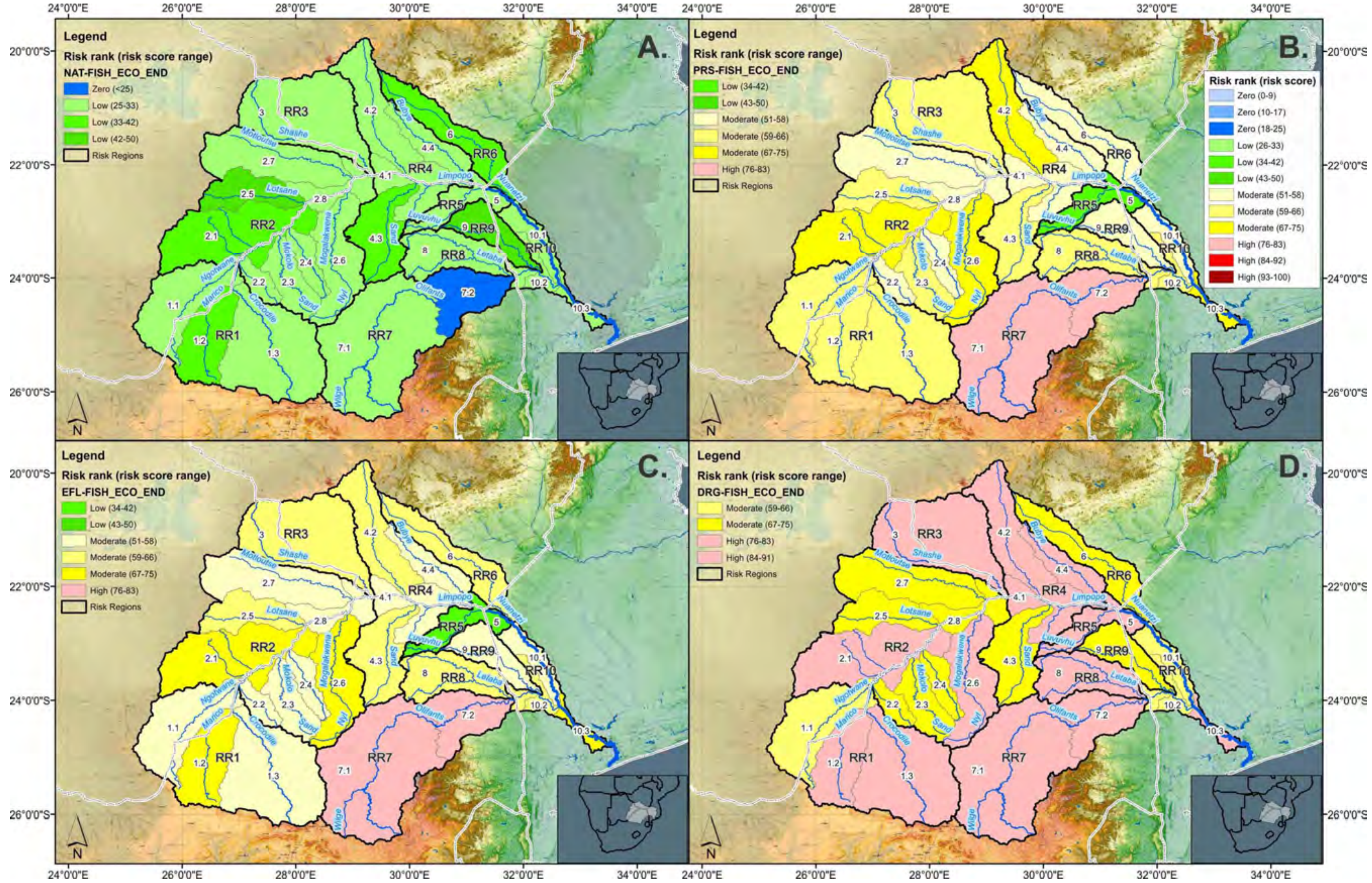

Figure 9-3: Relative risk scores to FISH-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

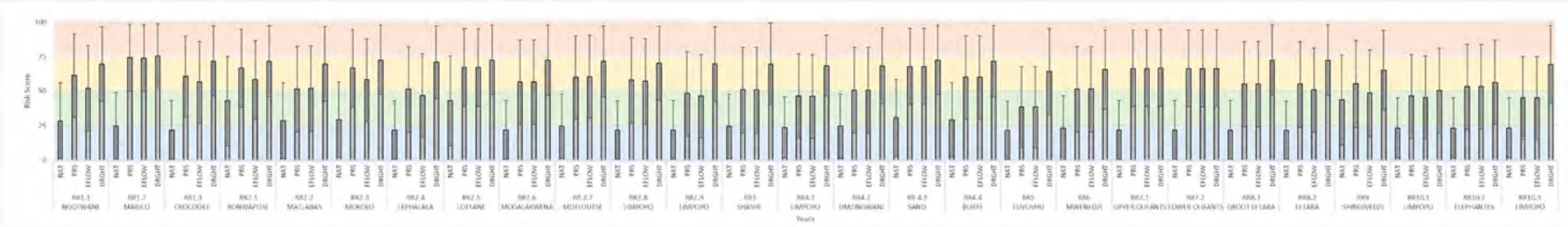

Figure 9-4: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to INV-ECO-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

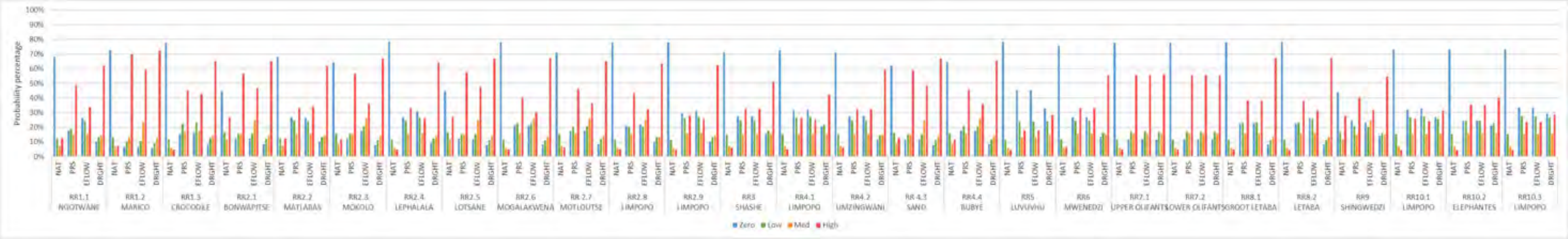

Figure 9-5: Probability of each risk rank occurring to the INV-ECO-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

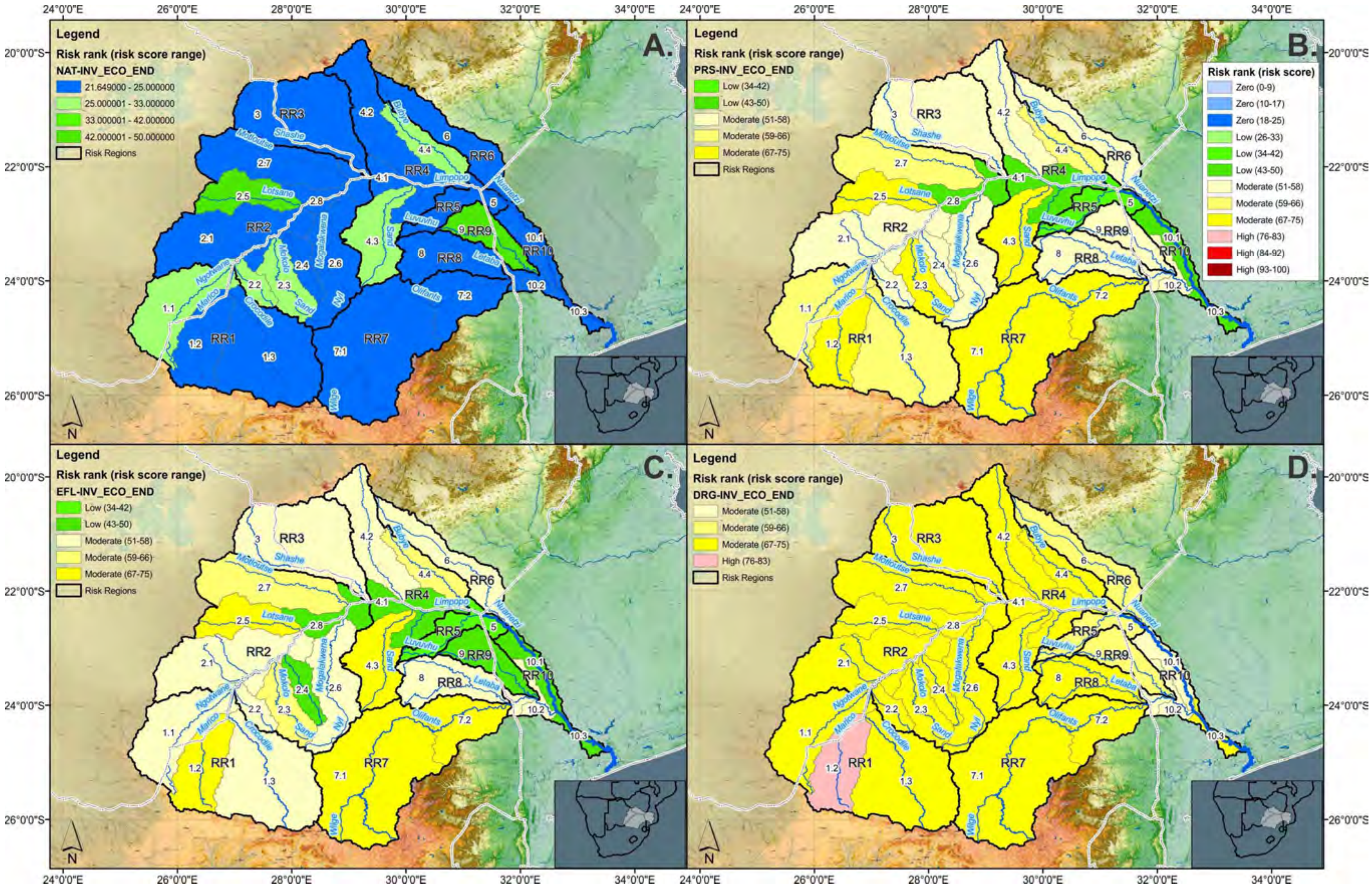

Figure 9-6: Relative risk scores to INV-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

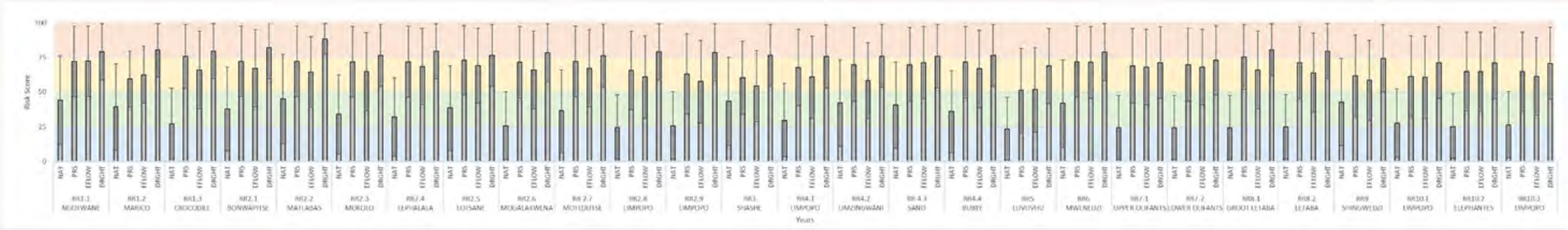

Figure 9-7: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to VEG-ECO-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

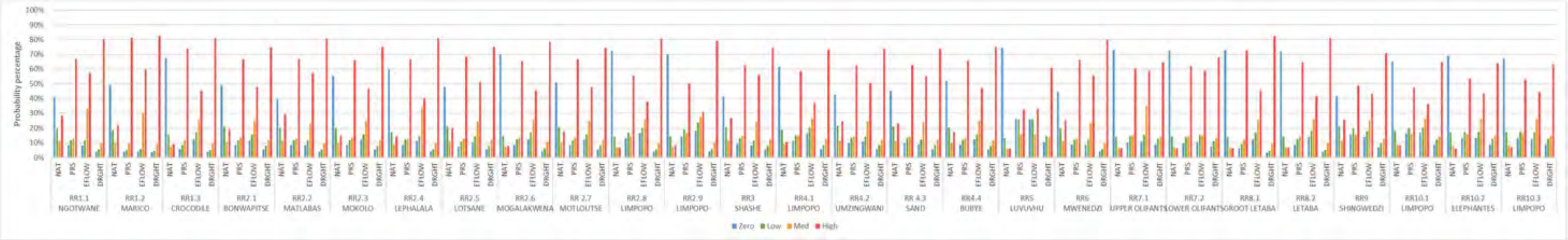

Figure 9-8: Probability of each risk rank occurring to the VEG-ECO-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

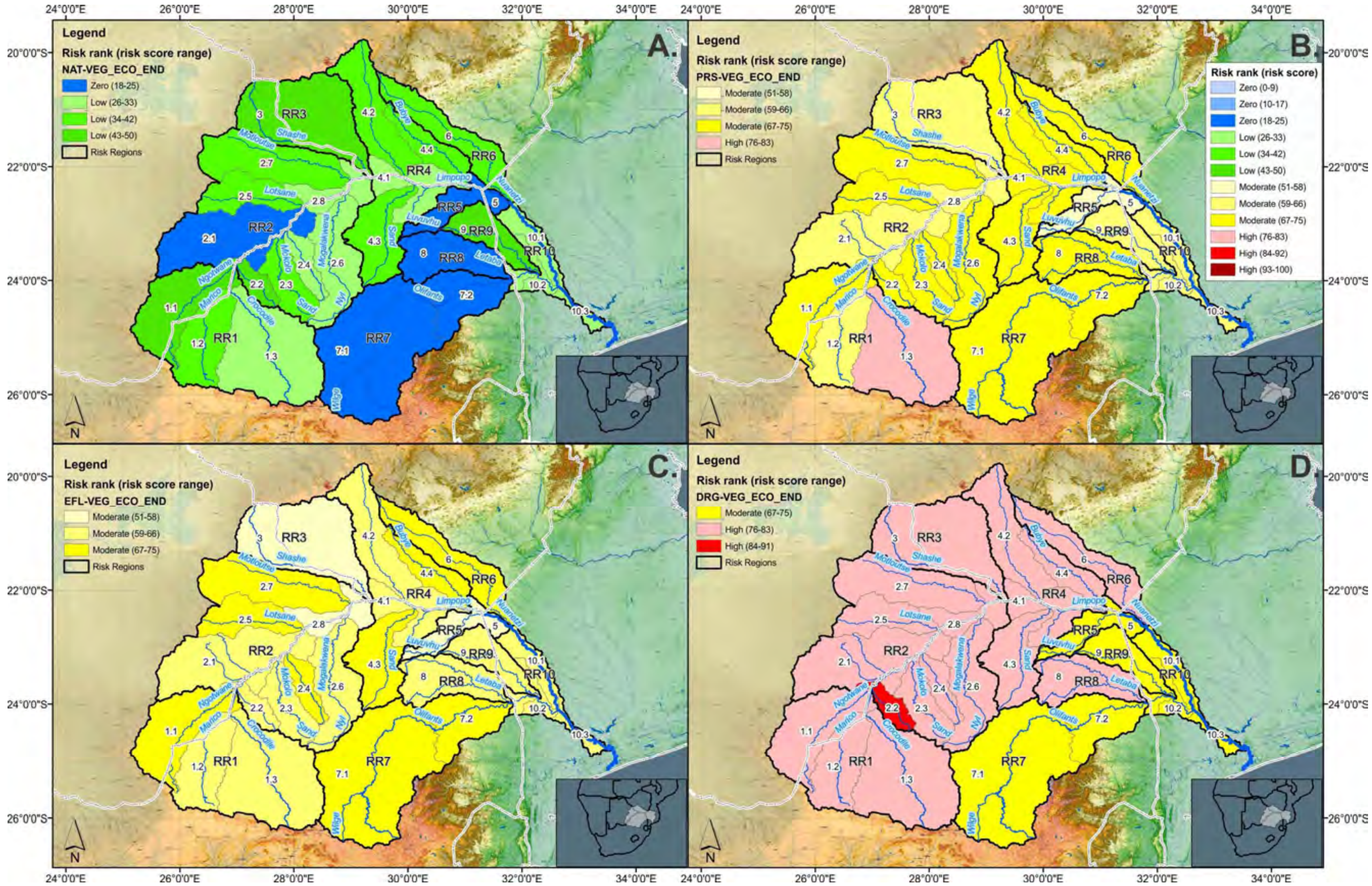

Figure 9-9: Relative risk scores to VEG-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

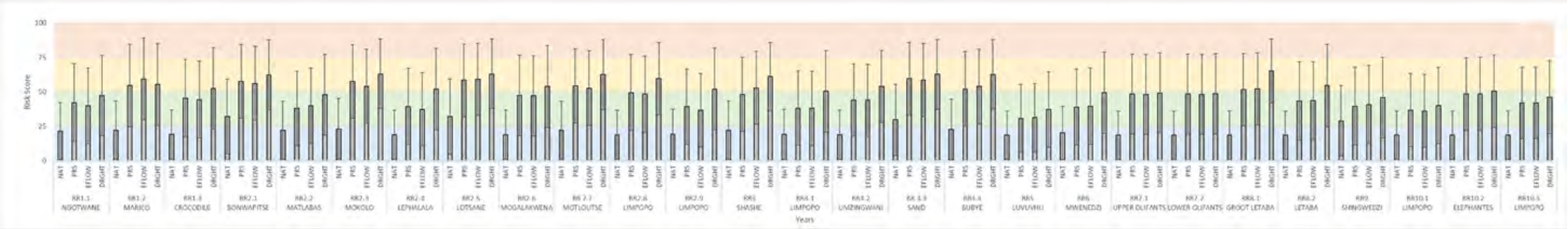

Figure 9-10: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to SUB-FISH-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

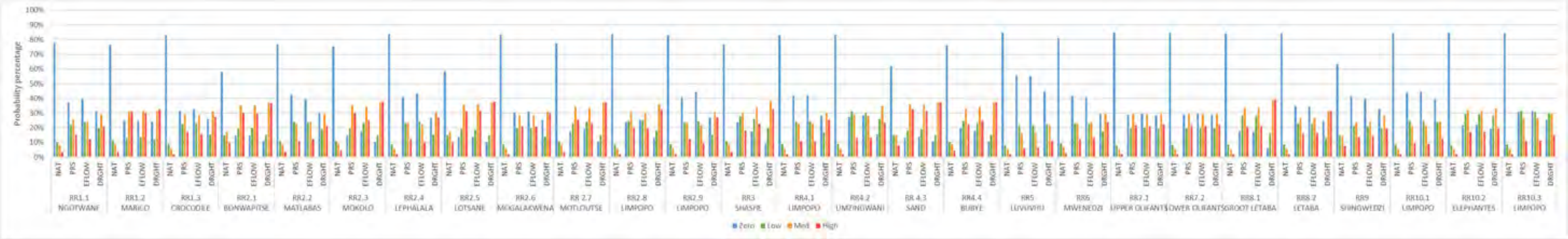

Figure 9-11: Probability of each risk rank occurring to the SUB-FISH-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

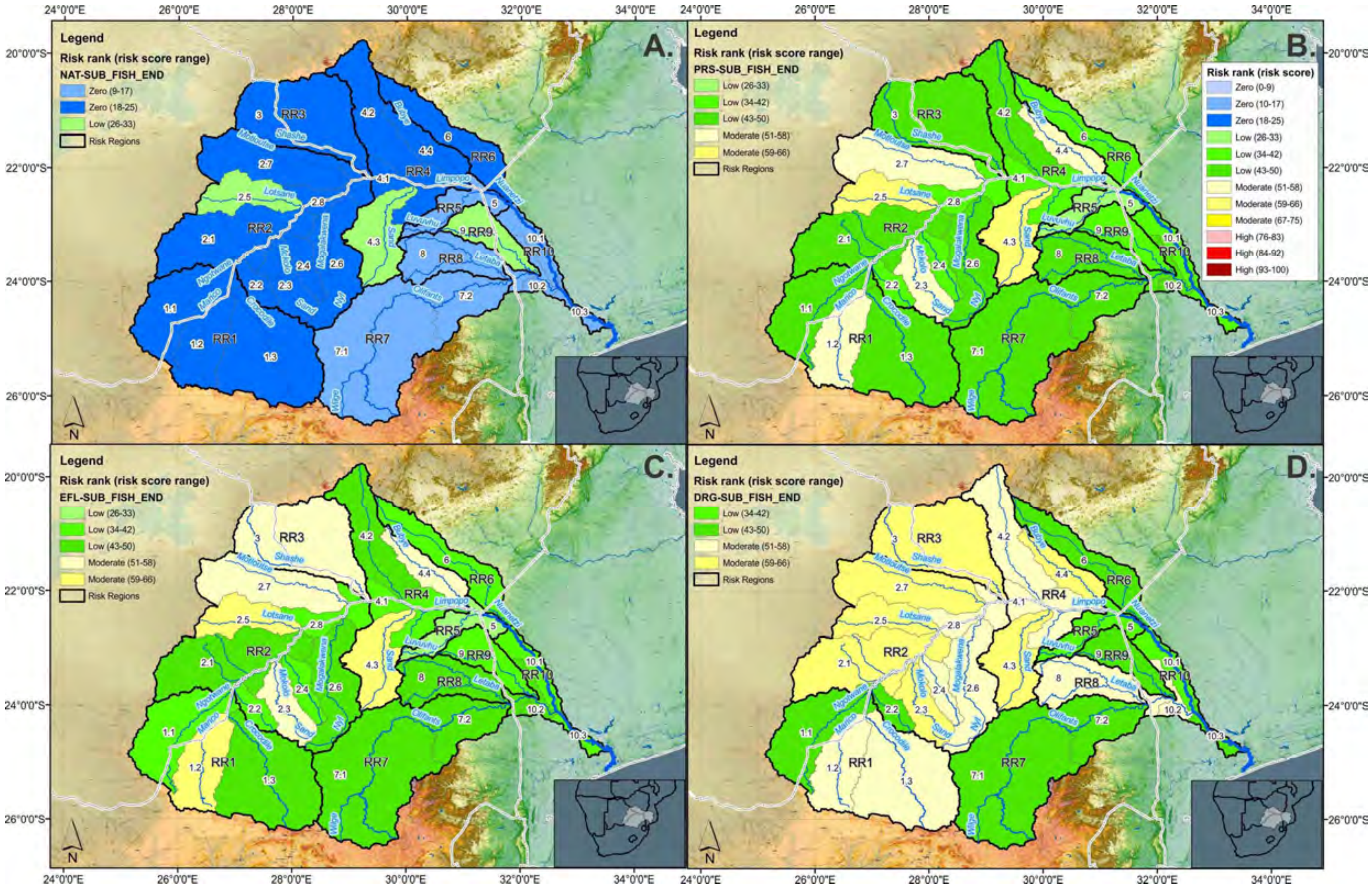

Figure 9-12: Relative risk scores to SUB-FISH-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

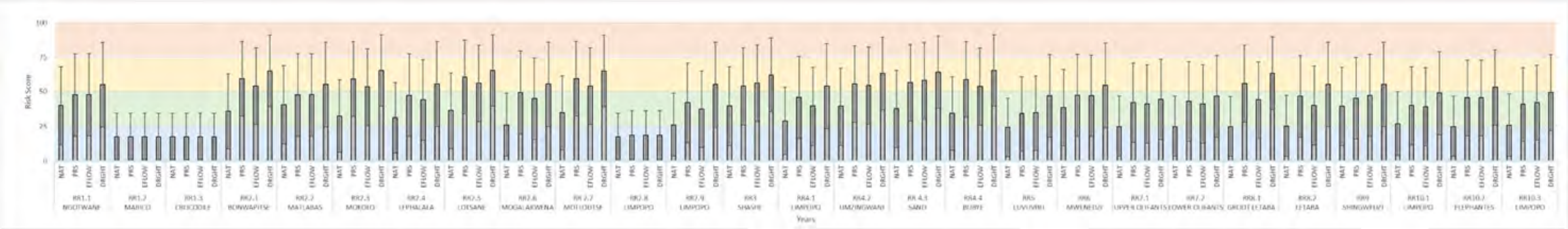

Figure 9-13: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to SUB-VEG-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

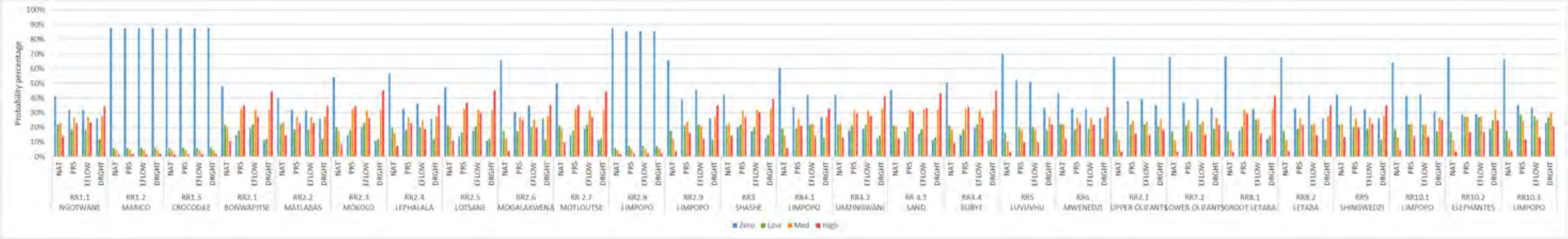

Figure 9-14: Probability of each risk rank occurring to the SUB-VEG-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

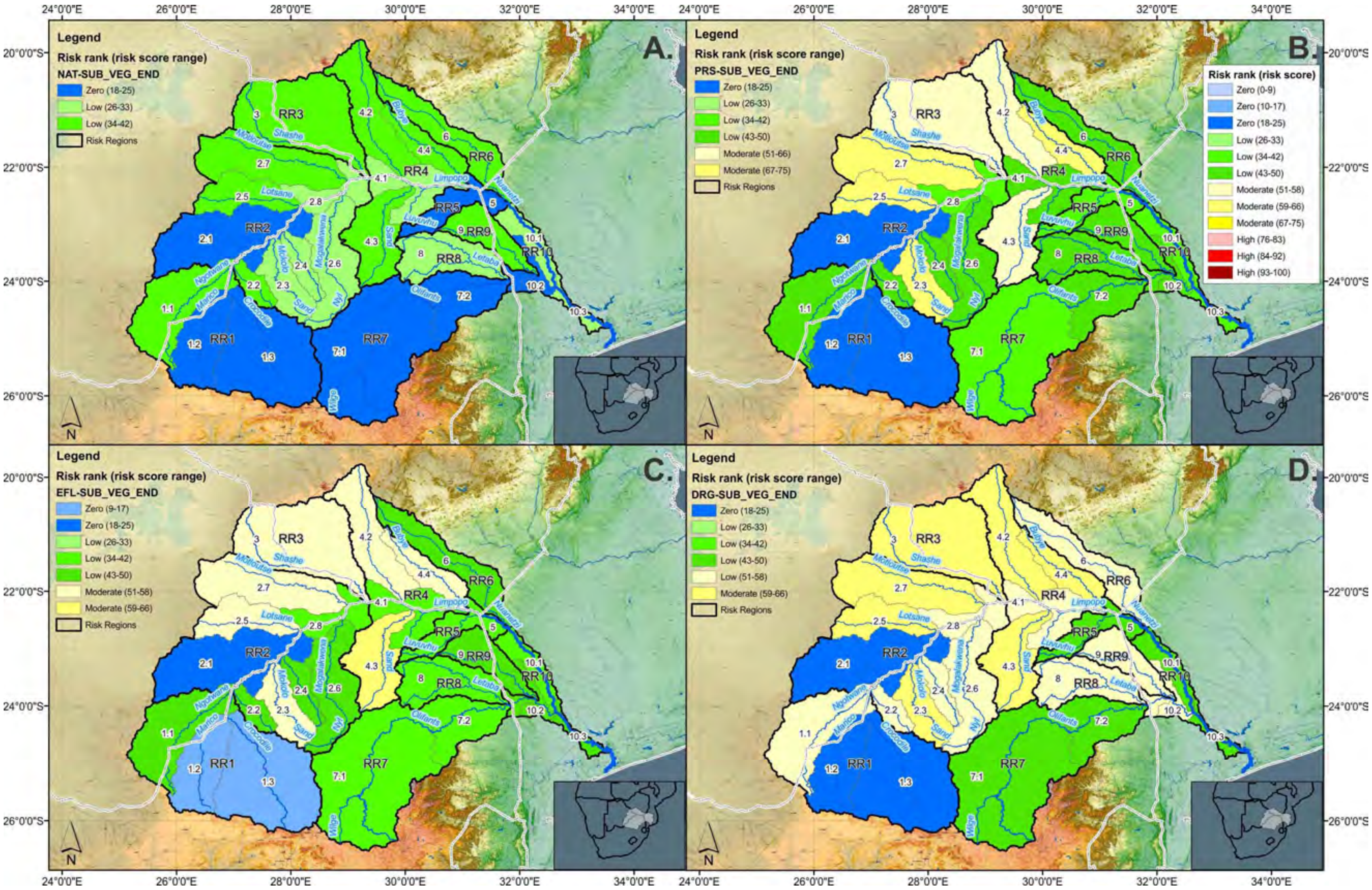

Figure 9-15: Relative risk scores to SUB-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

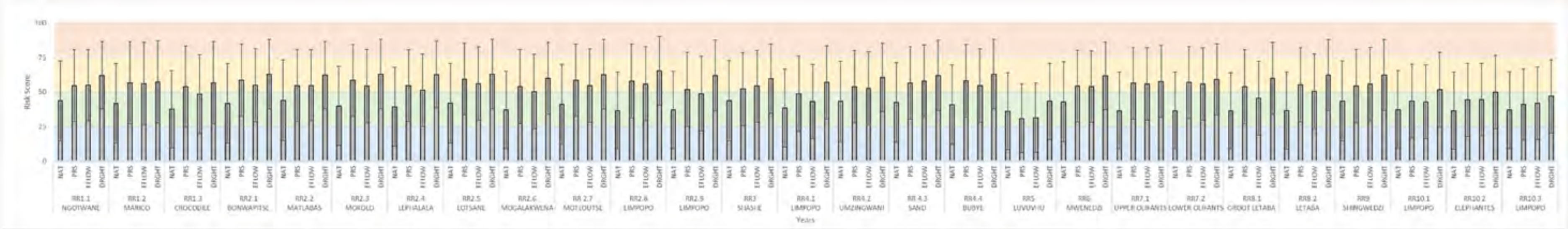

Figure 9-16: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to LIV-VEG-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

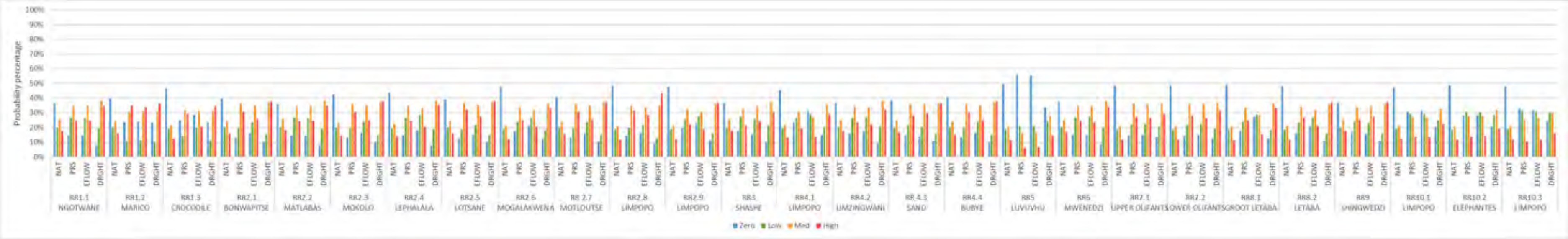

Figure 9-17: Probability of each risk rank occurring to the LIV-VEG-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

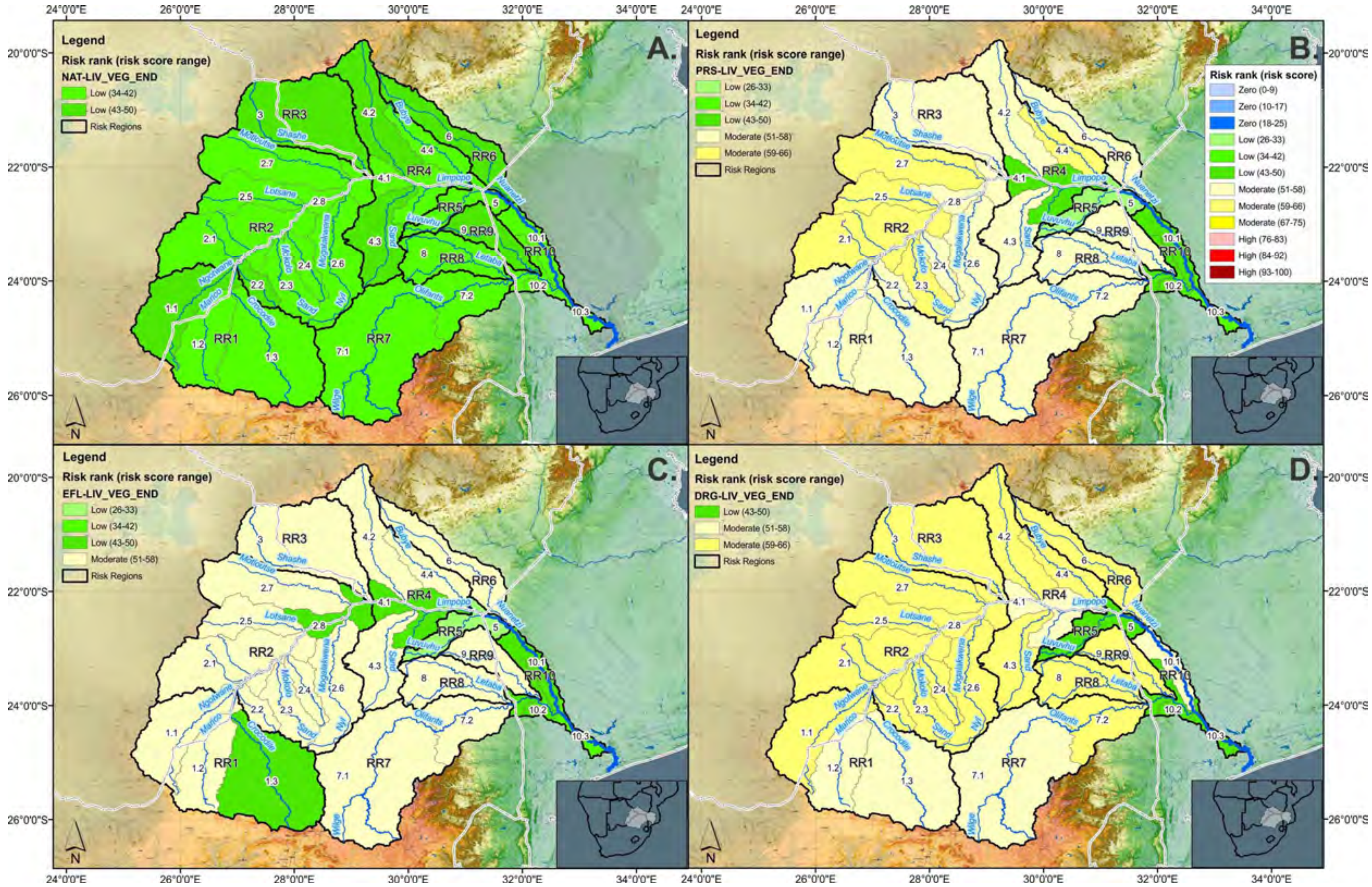

Figure 9-18: Relative risk scores to LIV-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

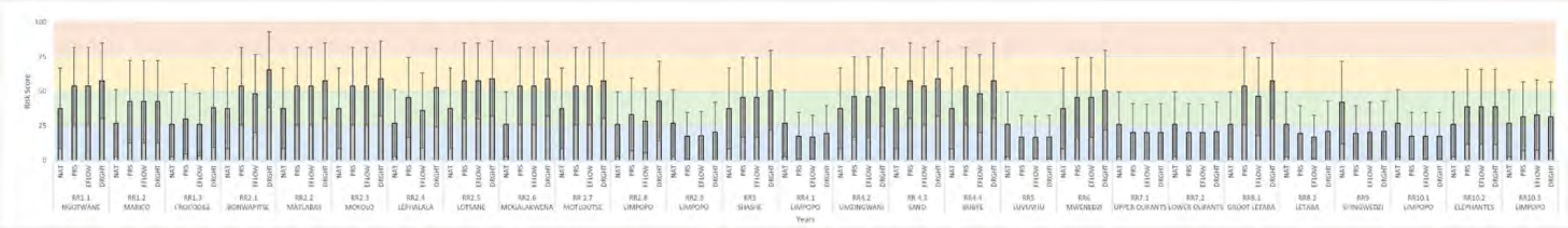

Figure 9-19: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to DOM-WAT-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

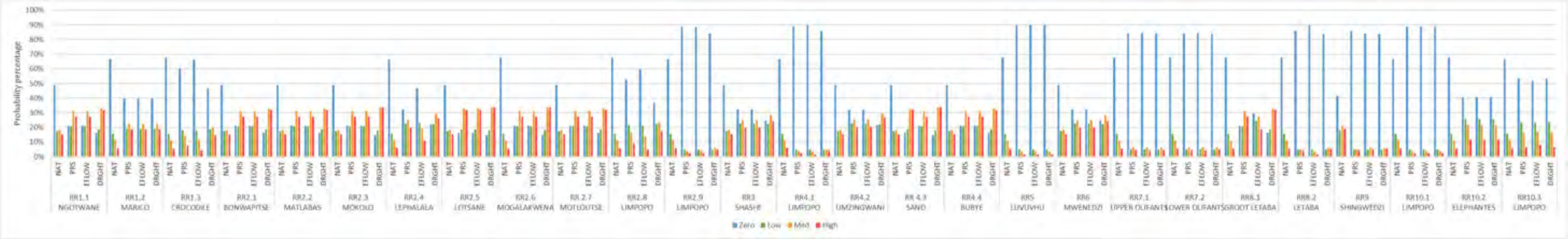

Figure 9-20: Probability of each risk rank occurring to the DOM-WAT-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

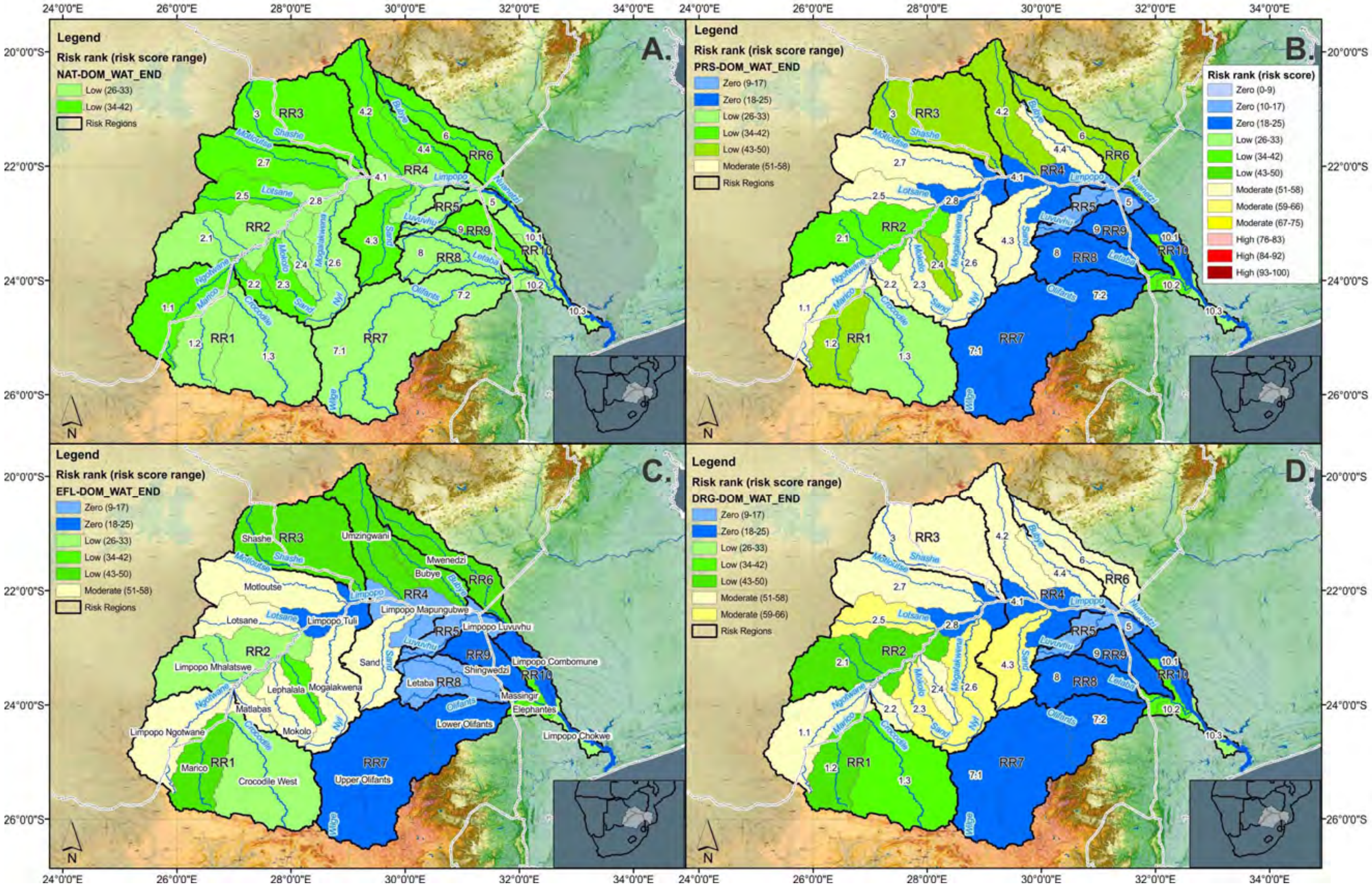

Figure 9-21: Relative risk scores to DOM-WAT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

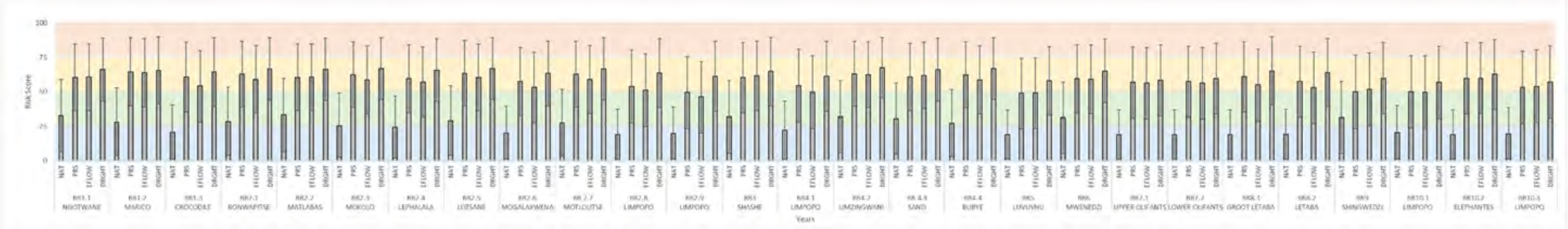

Figure 9-22: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to FLO-ATT-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

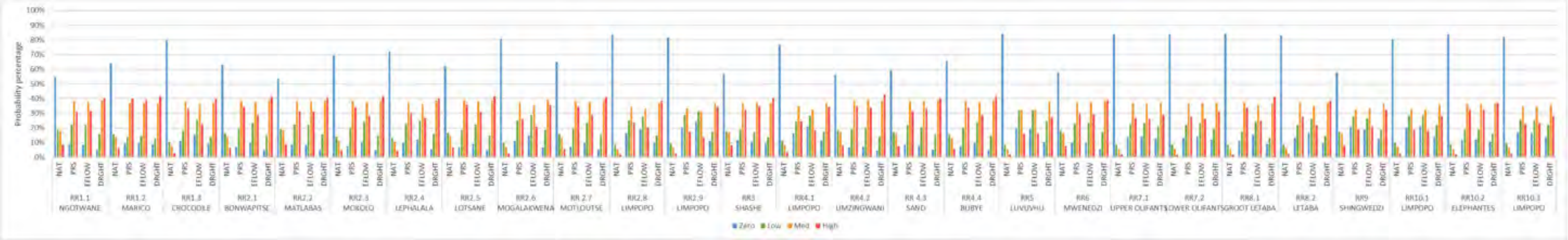

Figure 9-23: Probability of each risk rank occurring to the FLO-ATT-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

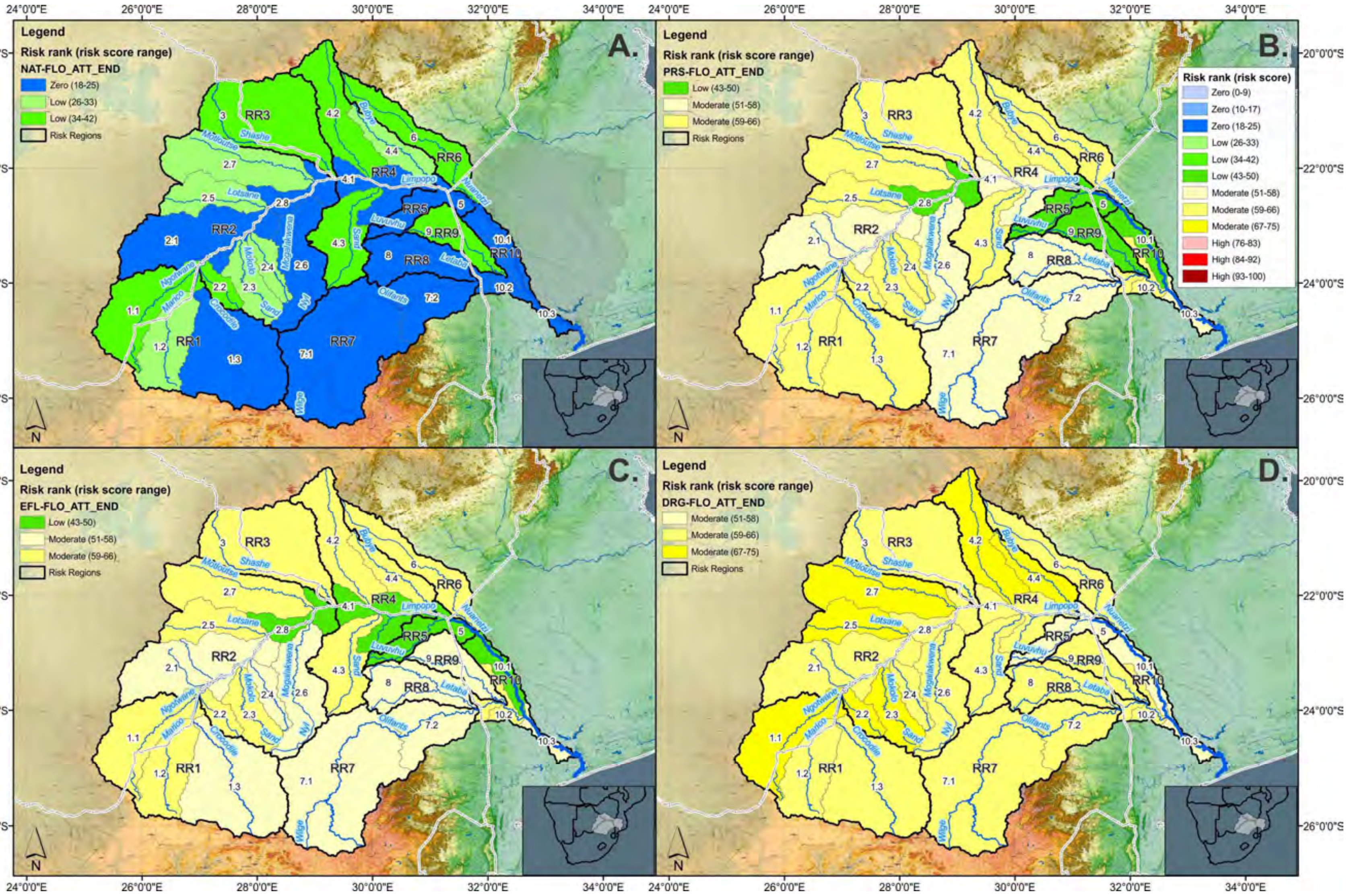

Figure 9-24: Relative risk scores to FLO-ATT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

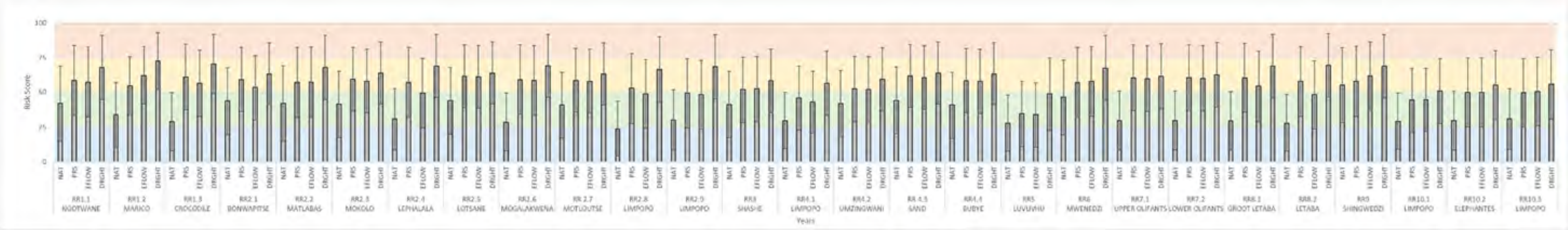

Figure 9-25: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to RIV-ASS-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

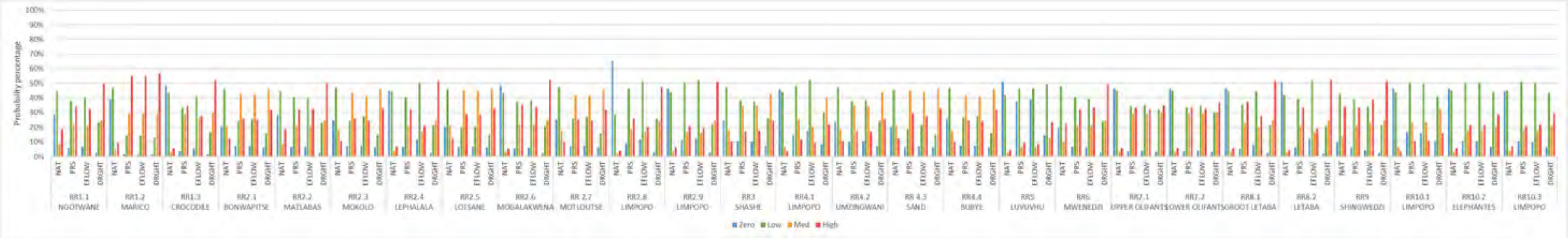

Figure 9-26: Probability of each risk rank occurring to the RIV-ASS-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

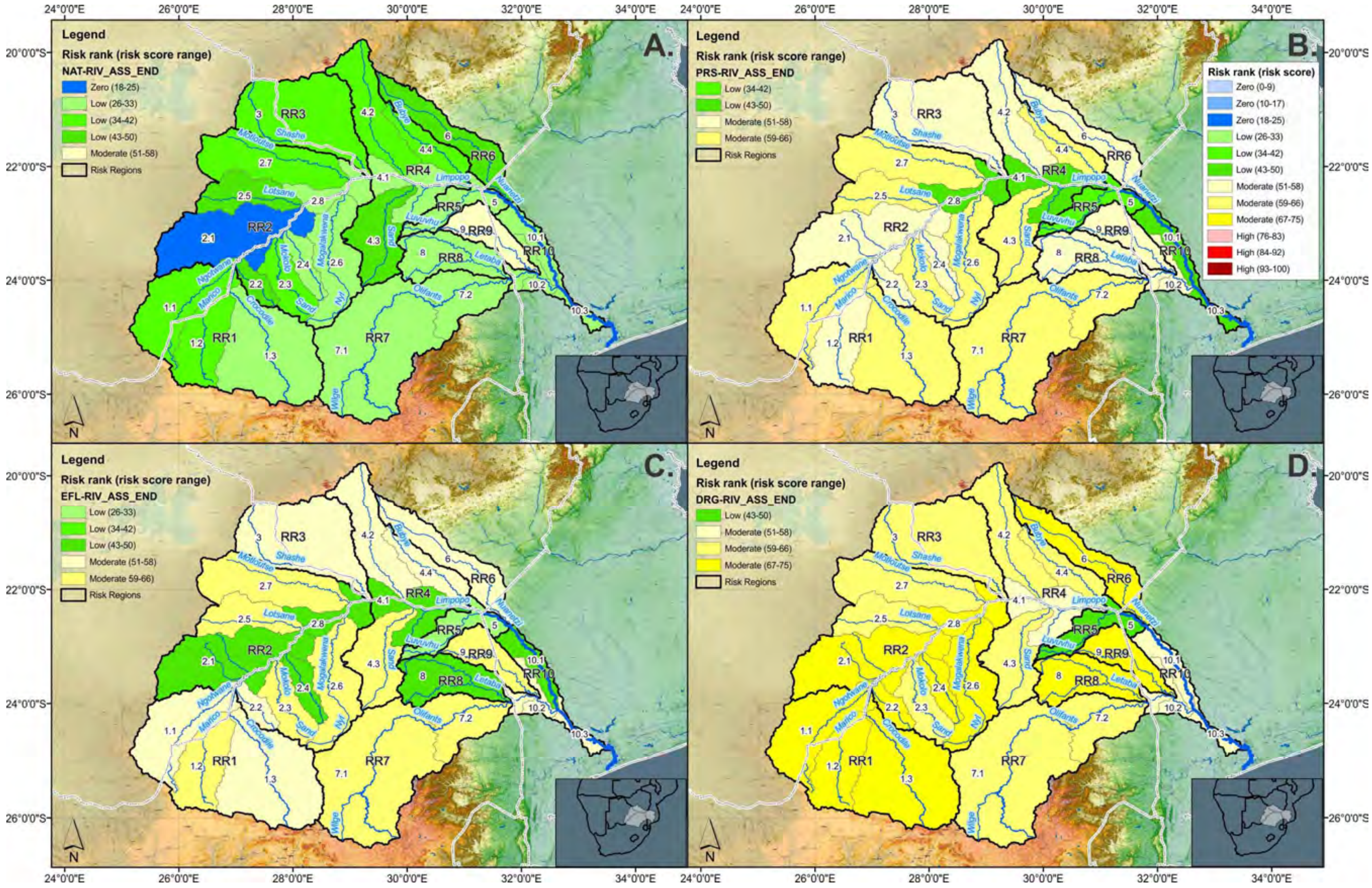

Figure 9-27: Relative risk scores to RIV-ASS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

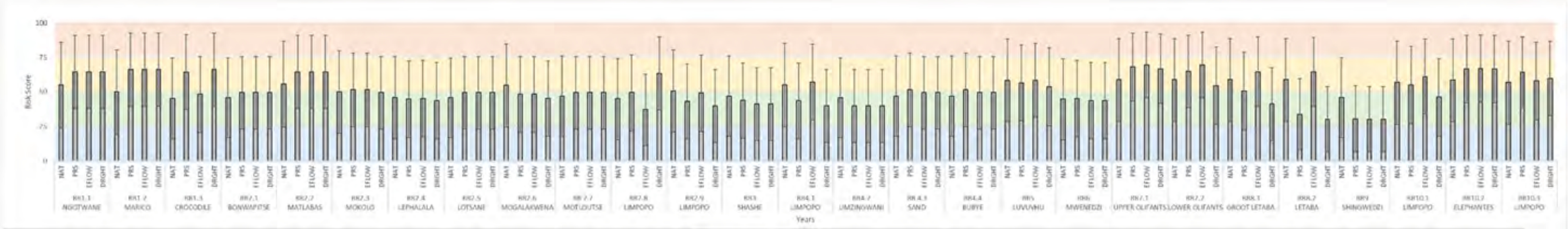

Figure 9-28: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to WAT-DIS-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

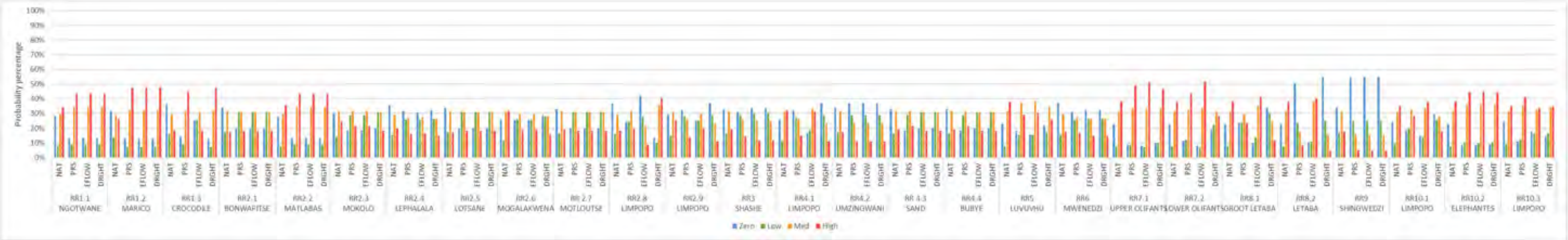

Figure 9-29: Probability of each risk rank occurring to the WAT-DIS-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

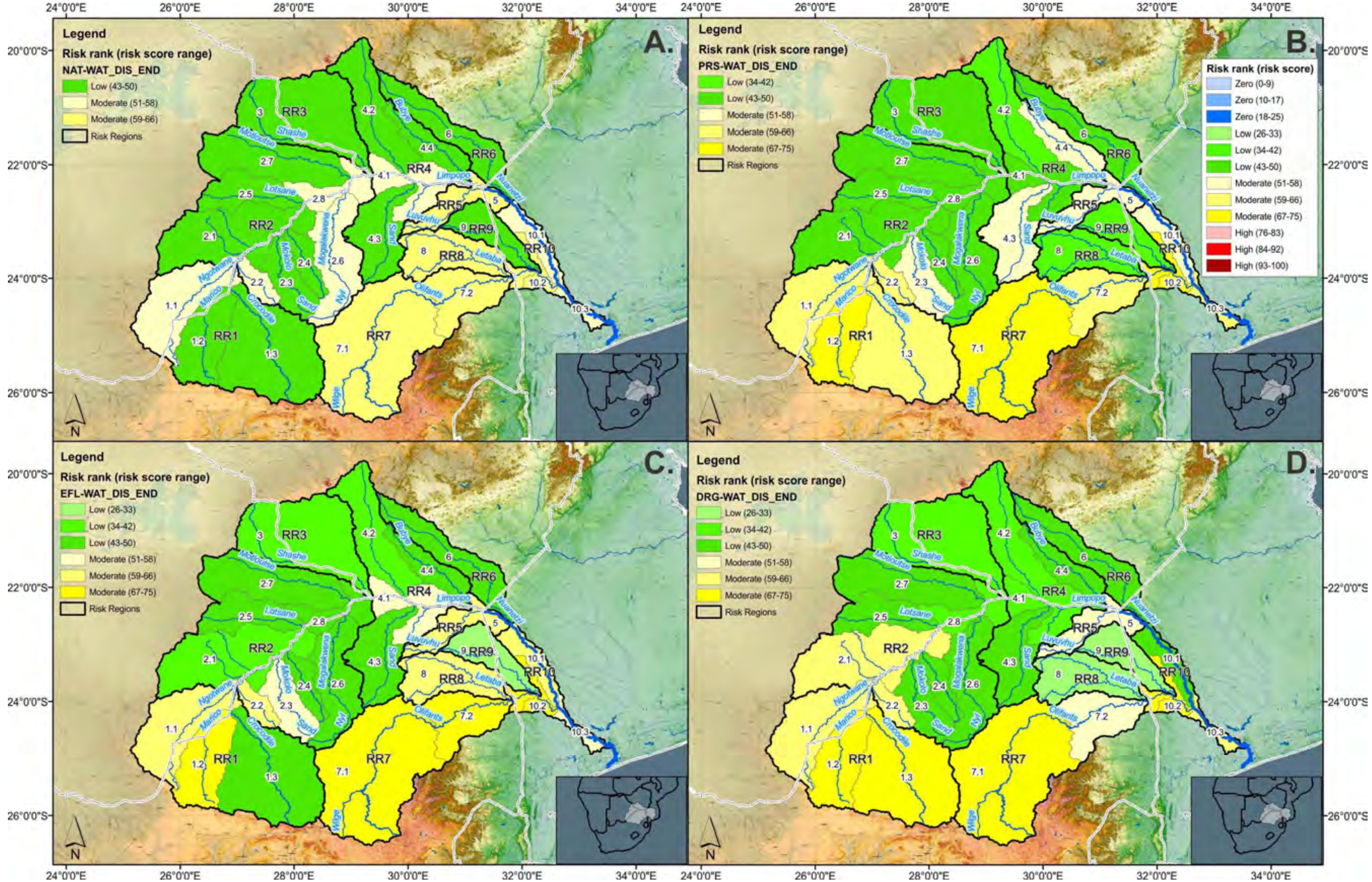

Figure 9-30: Relative risk scores to WAT-DIS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

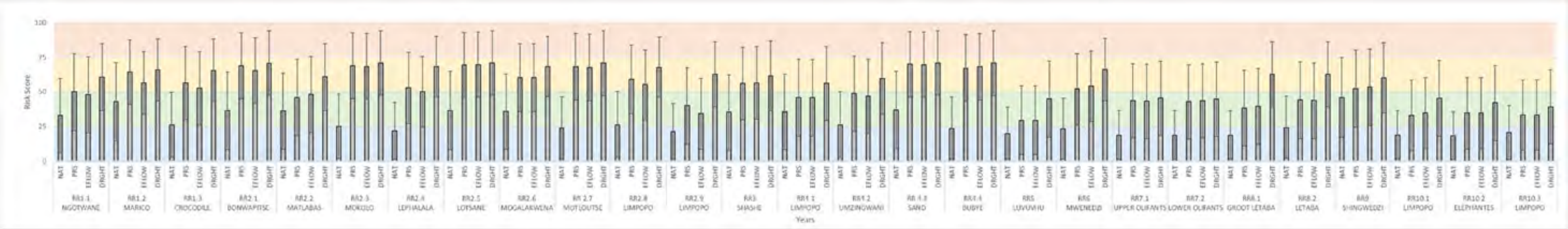

Figure 9-31: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to RES-RES-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

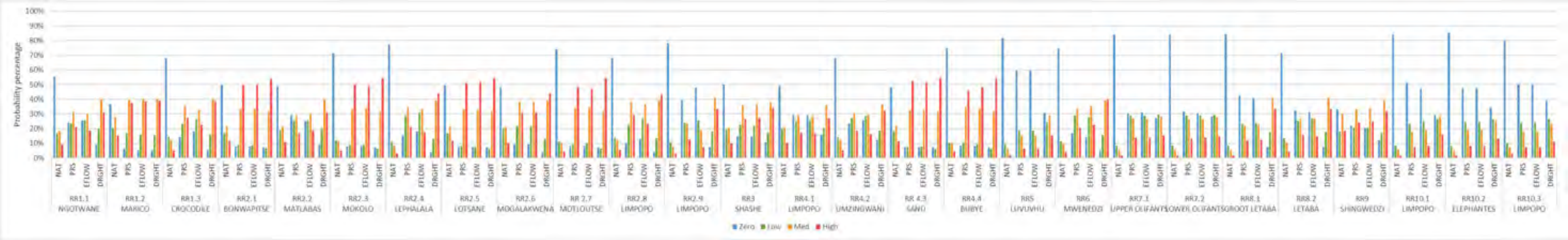

Figure 9-32: Probability of each risk rank occurring to the RES-RES-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

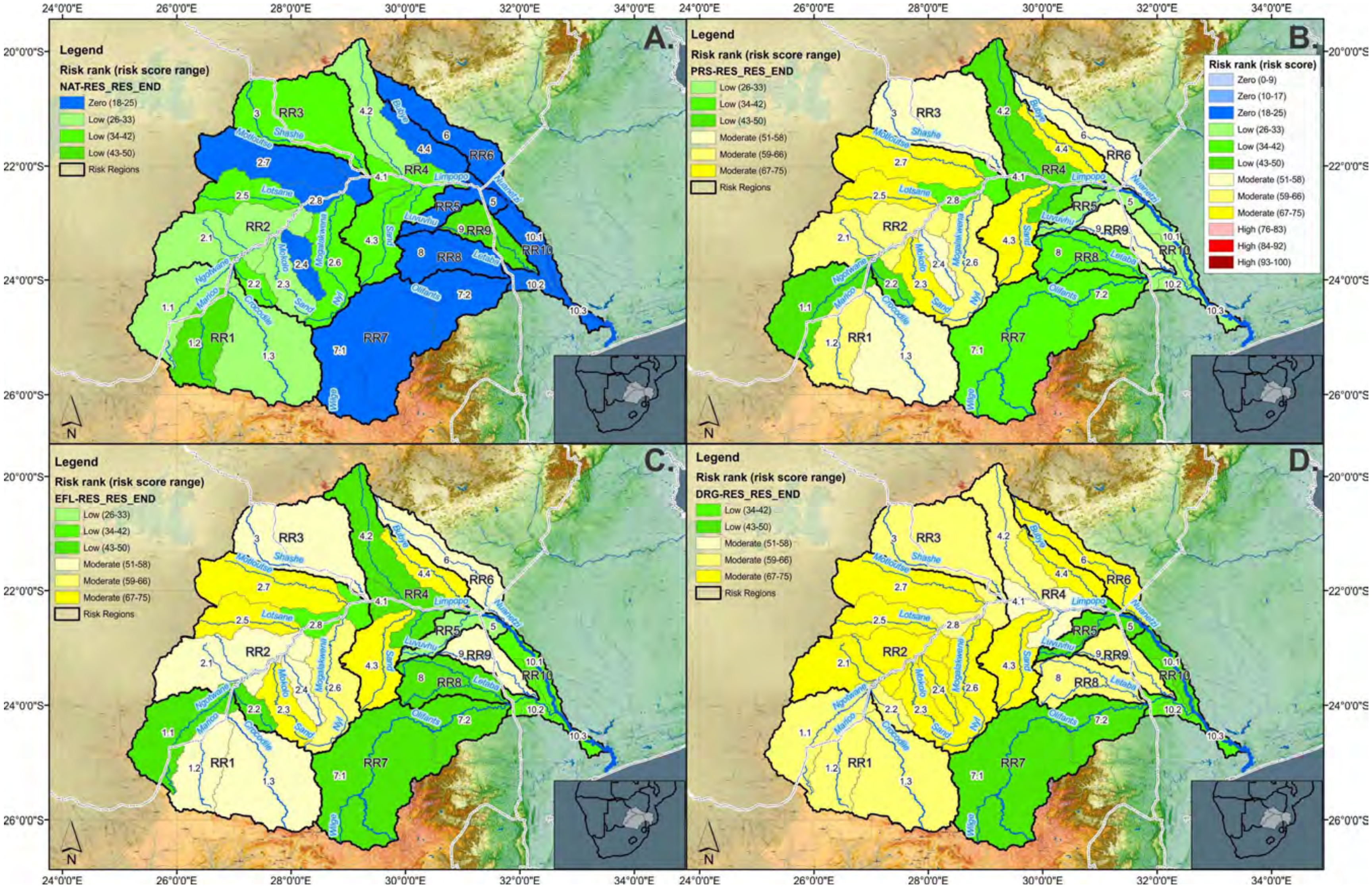

Figure 9-33: Relative risk scores to RES-RES-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

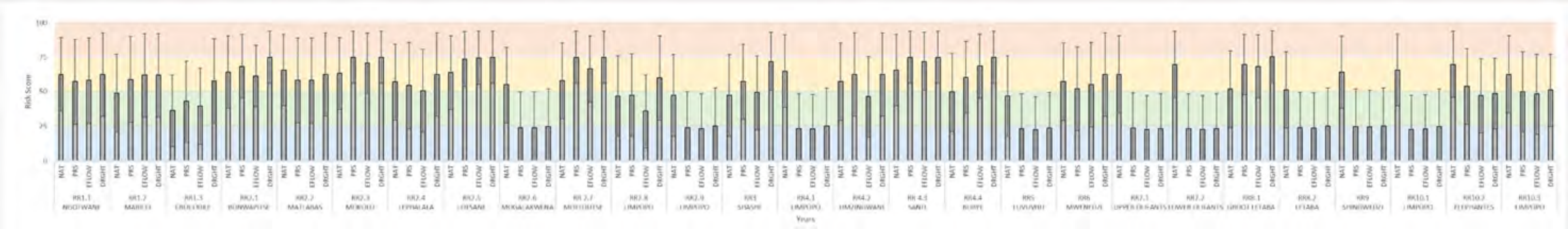

Figure 9-34: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to REC-SPIR-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

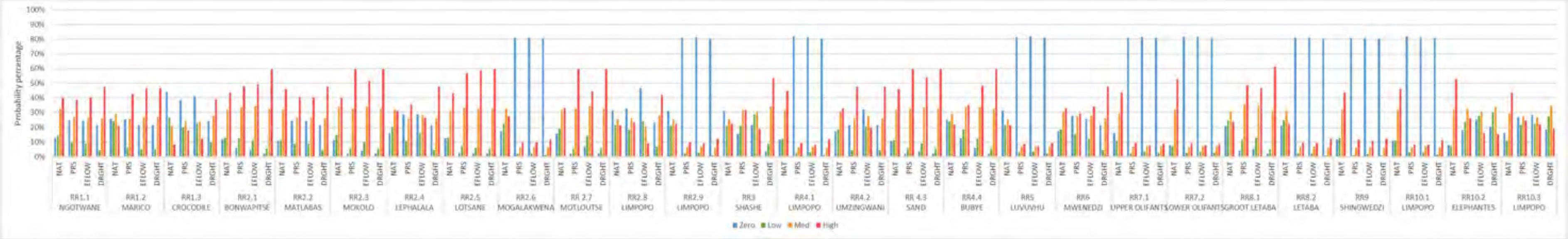

Figure 9-35: Probability of each risk rank occurring to the REC-SPIR-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

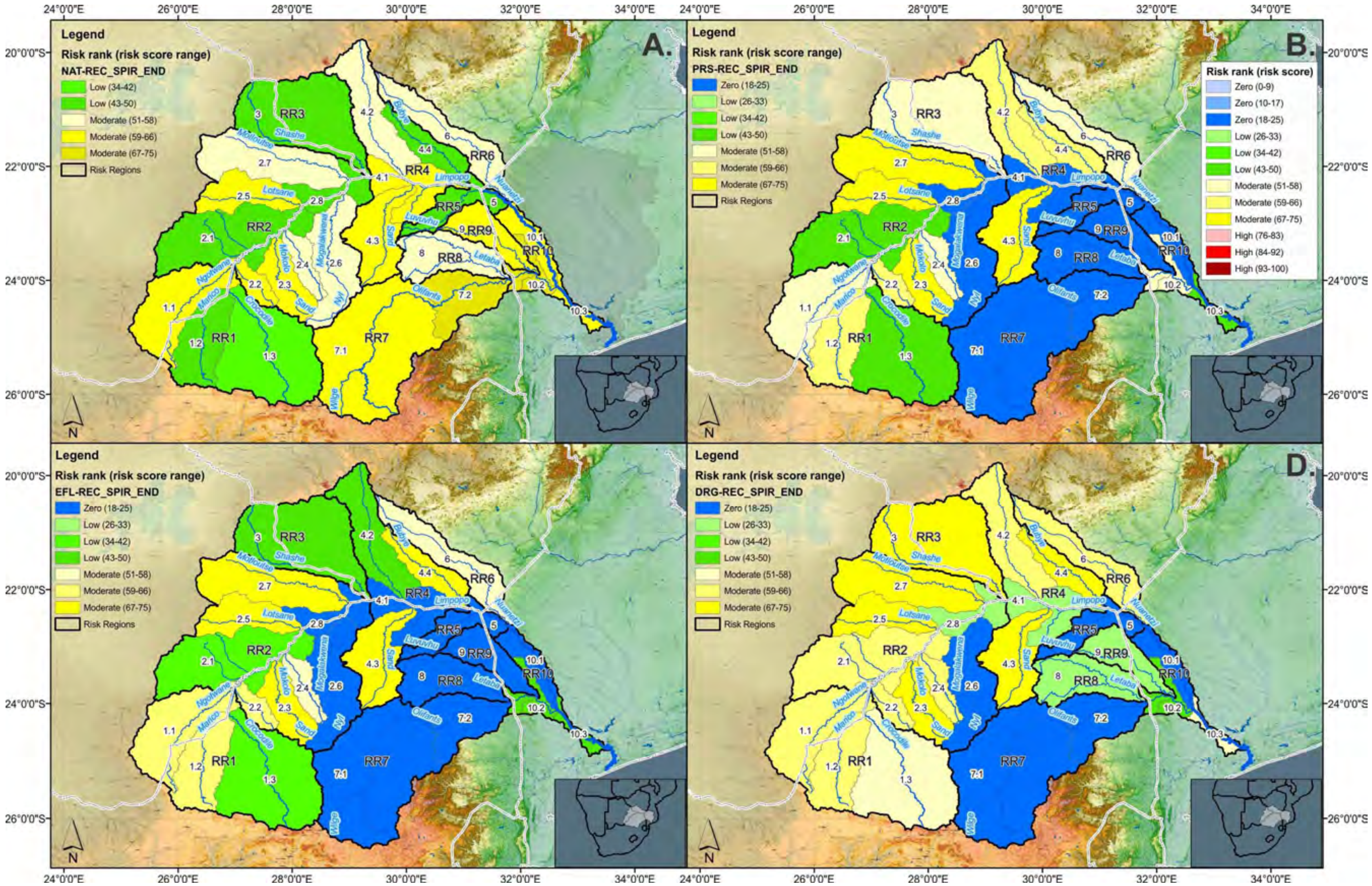

Figure 9-36: Relative risk scores to REC-SPIR-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

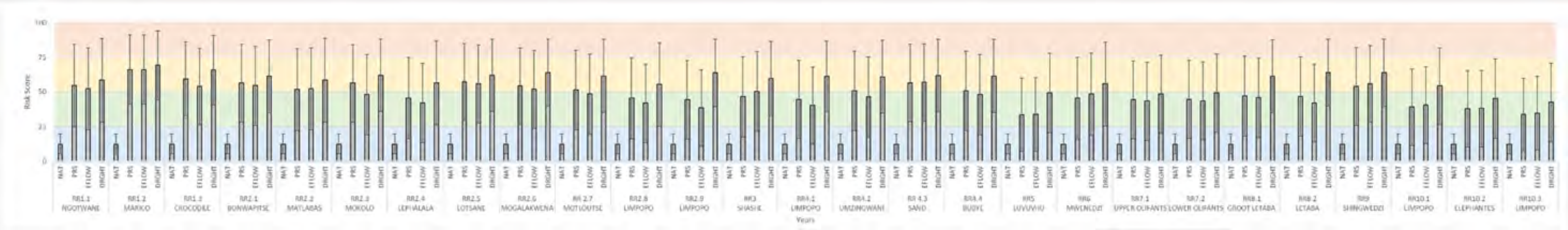

Figure 9-37: Highest likely relative risk scores (0-100) determined from the PROBFLO assessment to TOURISM-END for each scenario (Natural, Present, E-Flow and Drought), including standard deviation representing risk profile (rank ranges, zero 1-25, low 25-50, moderate 50-75, high 75-100) for each risk region considered in the Limpopo River e-flow study.

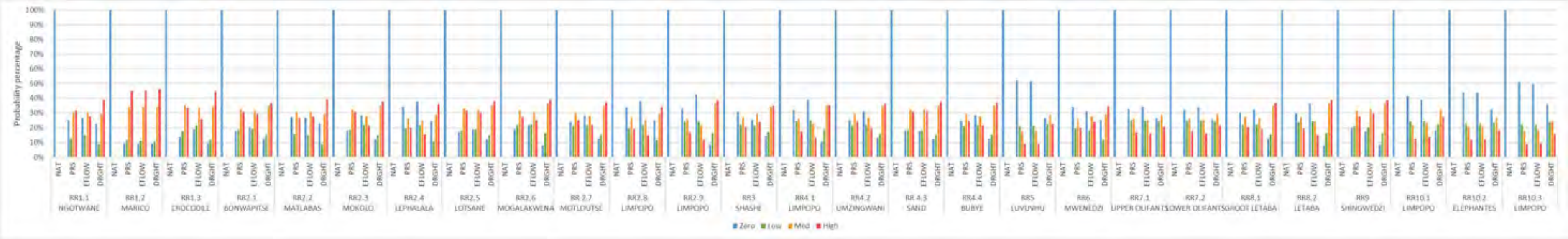

Figure 9-38: Probability of each risk rank occurring to the TOURISM-END established from the PROBFLO assessment for each scenario in each risk region considered in the Limpopo River e-flow study.

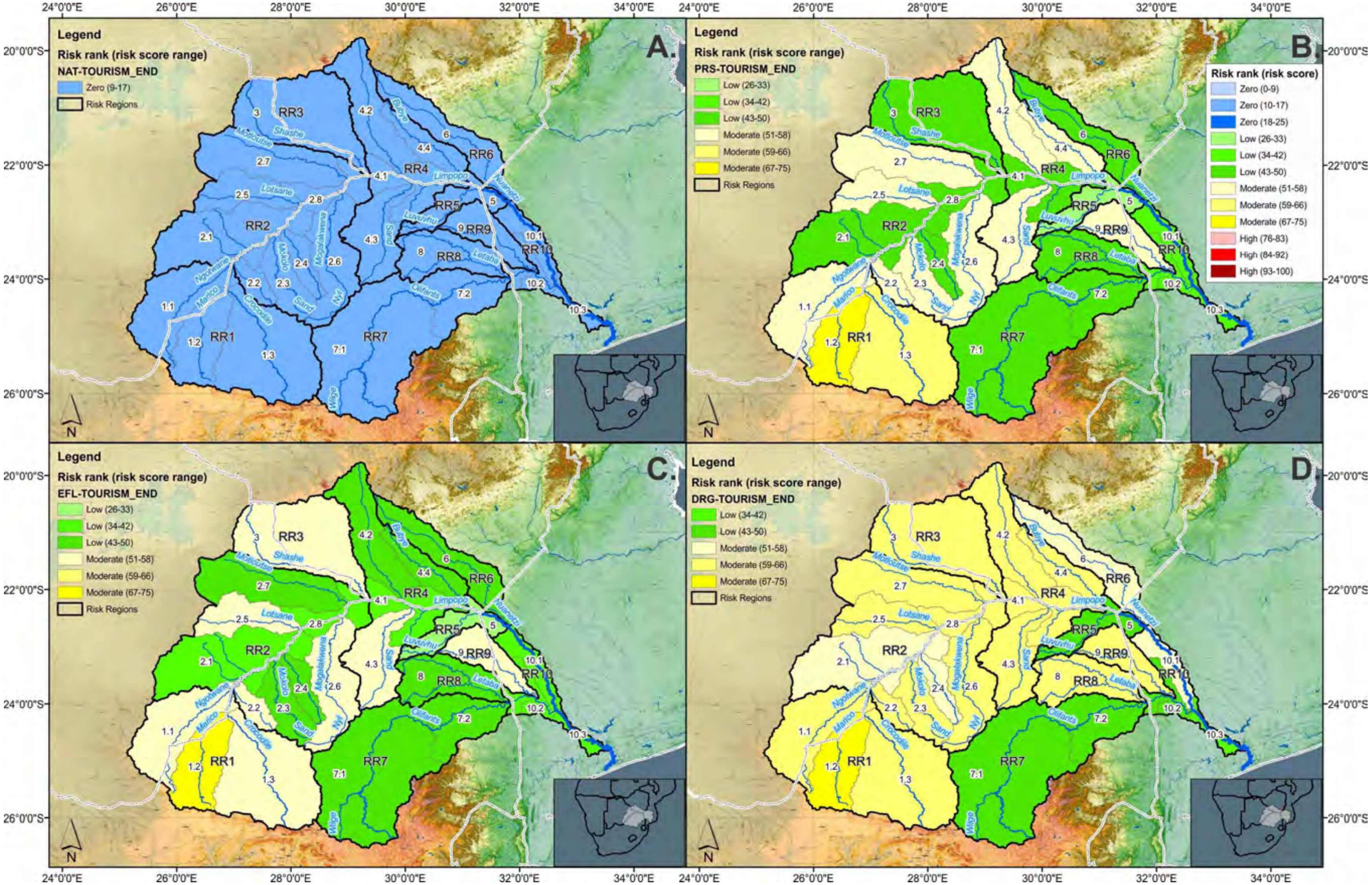

Figure 9-39: Relative risk scores to TOURISM-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

10 APPENDIX C

Table 10-1: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR1.1 Ngotwane River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	10.81	1.28	0.01069	0.542	0.001366
INV_ECO_END	1.453	0.172	0.00155	0.0785	0.0001167
RIV_ASS_END	0.3392	0.04	0.00033	0.0165	0.0000279
RES_RES_END	0.09539	0.0113	0.0001	0.00526	0.0000078
LIV_VEG_END	0.08649	0.0102	0.0001	0.00488	0.0000071
WAT_DIS_END	0.02311	0.00273	0.00003	0.00128	0.0000019
TOURISM_END	0.008875	0.00105	0.00001	0.000471	0.0000007
SUB_VEG_END	0.008732	0.00103	0.00001	0.000493	0.0000007
FLO_ATT_END	0.00601	0.00071	0.00001	0.000338	0.0000005
VEG_ECO_END	0.004412	0.000521	0	0.00025	0.0000004
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-2: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR1.2 Marico River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	5.181	0.586	0.00497	0.259	0.0005721
INV_ECO_END	0.1851	0.0209	0.00029	0.015	0.0000241
RIV_ASS_END	0.1294	0.0146	0.00015	0.00759	0.0000131
RES_RES_END	0.02376	0.00269	0.00004	0.00194	0.000003
LIV_VEG_END	0.02055	0.00232	0.00003	0.00167	0.0000026
WAT_DIS_END	0.007878	0.00089	0.00001	0.000639	0.000001
FLO_ATT_END	0.002295	0.000259	0	0.000188	0.0000003
VEG_ECO_END	0.001104	0.000125	0	9.13E-05	0.0000001
TOURISM_END	0.0003828	4.33E-05	0	3.42E-05	0.0000001
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0
SUB_VEG_END	0	0	0	0	0

Table 10-3: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR1.3 Crocodile River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	8.417	0.967	0.00773	0.395	0.000898
INV_ECO_END	1.525	0.175	0.00201	0.103	0.000148
RIV_ASS_END	0.6106	0.0701	0.00069	0.0351	0.000055
REC_SPIR_END	0.3552	0.0408	0.00046	0.0235	0.0000342
RES_RES_END	0.1278	0.0147	0.00017	0.00872	0.0000128
LIV_VEG_END	0.08865	0.0102	0.00012	0.00607	0.000009
TOURISM_END	0.03201	0.00368	0.00004	0.00213	0.0000031
WAT_DIS_END	0.02177	0.0025	0.00003	0.00146	0.0000022
FLO_ATT_END	0.01362	0.00156	0.00002	0.000927	0.0000014
VEG_ECO_END	0.009562	0.0011	0.00001	0.000647	0.000001
DOM_WAT_END	0	0	0	0	0
SUB_VEG_END	0	0	0	0	0
SUB_VEG_END	0	0	0	0	0

Table 10-4: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR2.1 Bonwapitse River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	1.836	0.284	0.00247	0.135	0.0001399
INV_ECO_END	1.195	0.185	0.00155	0.0852	0.0001395
WAT_DIS_END	0.306	0.0473	0.00041	0.0225	0.0000358
RIV_ASS_END	0.2938	0.0454	0.00038	0.0208	0.0000326
LIV_VEG_END	0.06592	0.0102	0.00009	0.00482	0.0000076
TOURISM_END	0.02913	0.0045	0.00004	0.00208	0.0000032
RES_RES_END	0.01577	0.00244	0.00002	0.00114	0.0000018
SUB_VEG_END	0.007677	0.00119	0.00001	0.000565	0.0000009
FLO_ATT_END	0.004885	0.000755	0.00001	0.000345	0.0000005
VEG_ECO_END	0.002594	0.000401	0	0.000176	0.0000003
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-5: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR2.2 Matlabas River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	10.4	1.22	0.01016	0.515	0.0012792
INV_ECO_END	1.33	0.156	0.00143	0.0724	0.0001073
RIV_ASS_END	0.3158	0.037	0.0003	0.0153	0.0000259
RES_RES_END	0.08738	0.0103	0.0001	0.00488	0.0000072
LIV_VEG_END	0.07908	0.00928	0.00009	0.0045	0.0000065
WAT_DIS_END	0.02168	0.00254	0.00002	0.00121	0.0000018
TOURISM_END	0.008779	0.00103	0.00001	0.000473	0.0000007
SUB_VEG_END	0.007611	0.000893	0.00001	0.000434	0.0000006
FLO_ATT_END	0.005049	0.000592	0.00001	0.000293	0.0000004
VEG_ECO_END	0.003766	0.000442	0	0.000215	0.0000003
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-6: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR2.3 Mokolo River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	1.115	0.175	0.00163	0.0903	0.0000838
INV_ECO_END	0.5052	0.0792	0.00069	0.038	0.0000677
WAT_DIS_END	0.2126	0.0333	0.00029	0.0163	0.0000261
RIV_ASS_END	0.1783	0.0279	0.00024	0.0131	0.0000207
LIV_VEG_END	0.04489	0.00704	0.00006	0.00343	0.0000055
RES_RES_END	0.007171	0.00112	0.00001	0.000561	0.0000009
SUB_VEG_END	0.004757	0.000746	0.00001	0.00036	0.0000006
FLO_ATT_END	0.002789	0.000437	0	0.000216	0.0000003
TOURISM_END	0.001593	0.00025	0	0.000113	0.0000002
VEG_ECO_END	0.001372	0.000215	0	0.000104	0.0000002
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-7: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR2.4 Lephalala River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	5.261	0.6	0.0051	0.261	0.0006066
INV_ECO_END	0.4155	0.0474	0.0005	0.0253	0.0000388
RIV_ASS_END	0.1423	0.0162	0.00014	0.00694	0.000012
WAT_DIS_END	0.06776	0.00772	0.00008	0.00431	0.0000063
LIV_VEG_END	0.04177	0.00476	0.00005	0.00265	0.0000039
RES_RES_END	0.01877	0.00214	0.00002	0.00119	0.0000017
SUB_VEG_END	0.003018	0.000344	0	0.00019	0.0000003
FLO_ATT_END	0.002086	0.000238	0	0.000136	0.0000002
VEG_ECO_END	0.001846	0.00021	0	0.000114	0.0000002
TOURISM_END	0.000726	0.0000828	0.0000000	0.0000424	0.0000001
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-8: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR2.5 Lotsane River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	1.115	0.175	0.00163	0.0903	0.0000838
INV_ECO_END	0.5051	0.0792	0.00069	0.038	0.0000677
WAT_DIS_END	0.2126	0.0333	0.00029	0.0163	0.0000261
RIV_ASS_END	0.1783	0.0279	0.00024	0.0131	0.0000207
LIV_VEG_END	0.04489	0.00704	0.00006	0.00343	0.0000055
RES_RES_END	0.007171	0.00112	0.00001	0.000561	0.0000009
SUB_VEG_END	0.004757	0.000746	0.00001	0.00036	0.0000006
FLO_ATT_END	0.002789	0.000437	0	0.000216	0.0000003
TOURISM_END	0.001593	0.00025	0	0.000113	0.0000002
VEG_ECO_END	0.001377	0.000216	0	0.000104	0.0000002
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-9: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR2.6 Mogalakwena River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	5.075	0.574	0.00474	0.244	0.0005521
INV_ECO_END	0.4041	0.0457	0.00056	0.0288	0.0000455
RIV_ASS_END	0.1118	0.0126	0.00011	0.00578	0.0000102
WAT_DIS_END	0.05724	0.00647	0.00008	0.00425	0.0000065
LIV_VEG_END	0.02464	0.00279	0.00004	0.00182	0.0000028
RES_RES_END	0.01347	0.00152	0.00002	0.001	0.0000015
FLO_ATT_END	0.002618	0.000296	0	0.000189	0.0000003
SUB_VEG_END	0.002282	0.000258	0	0.00017	0.0000003
VEG_ECO_END	0.001741	0.000197	0	0.00013	0.0000002
TOURISM_END	0.000742	0.000084	0.000000	0.000066	0.0000001
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-10: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR2.7 Motloutse River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	1.494	0.232	0.00209	0.115	0.0001129
INV_ECO_END	0.8795	0.137	0.00117	0.0642	0.0001089
WAT_DIS_END	0.2609	0.0406	0.00035	0.0195	0.0000312
RIV_ASS_END	0.2429	0.0378	0.00032	0.0175	0.0000275
LIV_VEG_END	0.05802	0.00902	0.00008	0.00434	0.0000069
TOURISM_END	0.01077	0.00167	0.00001	0.000783	0.0000012
RES_RES_END	0.009769	0.00152	0.00001	0.000718	0.0000011
SUB_VEG_END	0.00714	0.00111	0.00001	0.000534	0.0000008
FLO_ATT_END	0.004255	0.000662	0.00001	0.000322	0.0000005
VEG_ECO_END	0.002088	0.000325	0	0.000164	0.0000003
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-11: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR2.8 Limpopo River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
INV_ECO_END	6.059	0.881	0.00722	0.382	0.0005717
FISH_ECO_END	4.546	0.661	0.00564	0.299	0.0003565
RIV_ASS_END	0.2963	0.0431	0.00034	0.0181	0.0000255
REC_SPIR_END	0.1506	0.0219	0.00017	0.00926	0.0000126
RES_RES_END	0.04829	0.00702	0.00006	0.00302	0.0000044
LIV_VEG_END	0.0285	0.00415	0.00003	0.0018	0.0000027
WAT_DIS_END	0.01797	0.00261	0.00002	0.00114	0.0000017
TOURISM_END	0.008434	0.00123	0.00001	0.000537	0.0000008
FLO_ATT_END	0.004348	0.000633	0.00001	0.000271	0.0000004
VEG_ECO_END	0.002791	0.000406	0	0.000183	0.0000003
DOM_WAT_END	0	0	0	0	0
SUB_VEG_END	0	0	0	0	0

Table 10-12: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR2.9 Limpopo River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	4.744	0.541	0.00461	0.235	0.0005456
INV_ECO_END	0.645	0.0735	0.00076	0.0389	0.0000592
RIV_ASS_END	0.151	0.0172	0.00014	0.00739	0.0000128
WAT_DIS_END	0.1125	0.0128	0.00014	0.00717	0.0000105
LIV_VEG_END	0.02962	0.00338	0.00004	0.00188	0.0000027
RES_RES_END	0.02493	0.00284	0.00003	0.00158	0.0000023
TOURISM_END	0.003866	0.000441	0	0.000239	0.0000004
SUB_VEG_END	0.00335	0.000382	0	0.000207	0.0000003
FLO_ATT_END	0.002945	0.000336	0	0.000187	0.0000003
VEG_ECO_END	0.002372	0.00027	0	0.000153	0.0000002
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-13: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR3 Shashe River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
INV_ECO_END	1.83	0.3	0.00237	0.129	0.0001691
REC_SPIR_END	0.5905	0.0968	0.00077	0.042	0.0000497
WAT_DIS_END	0.2412	0.0395	0.00032	0.0173	0.0000233
FISH_ECO_END	0.1921	0.0315	0.00025	0.0136	0.0000166
RIV_ASS_END	0.1713	0.0281	0.00022	0.0122	0.0000163
LIV_VEG_END	0.1038	0.017	0.00014	0.00741	0.0000099
RES_RES_END	0.07132	0.0117	0.00009	0.0051	0.0000068
TOURISM_END	0.04751	0.00779	0.00006	0.00342	0.0000042
SUB_VEG_END	0.0127	0.00208	0.00002	0.000905	0.0000012
FLO_ATT_END	0.004801	0.000787	0.00001	0.00035	0.0000005
VEG_ECO_END	0.004673	0.000766	0.00001	0.000328	0.0000004
DOM_WAT_END	0	0	0	0	0

Table 10-14: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR4.1 Limpopo River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	6.79	0.777	0.0064	0.325	0.0007782
INV_ECO_END	1.631	0.187	0.00183	0.0932	0.0001425
RIV_ASS_END	0.2925	0.0335	0.00028	0.0142	0.0000244
WAT_DIS_END	0.1583	0.0181	0.00018	0.00937	0.0000139
RES_RES_END	0.1077	0.0123	0.00012	0.00612	0.0000093
LIV_VEG_END	0.06046	0.00692	0.00007	0.00356	0.0000053
TOURISM_END	0.04867	0.00557	0.00005	0.00268	0.0000041
REC_SPIR_END	0.01248	0.00143	0.00001	0.000651	0.0000011
SUB_VEG_END	0.007132	0.000816	0.00001	0.000414	0.0000006
FLO_ATT_END	0.00534	0.000611	0.00001	0.000318	0.0000005
VEG_ECO_END	0.003774	0.000432	0	0.000216	0.0000003
DOM_WAT_END	0	0	0	0	0

Table 10-15: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR4.2 Umzingwani River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
INV_ECO_END	1.405	0.206	0.00161	0.083	0.0001033
WAT_DIS_END	0.5998	0.0881	0.0007	0.0358	0.0000476
RIV_ASS_END	0.3822	0.0561	0.00044	0.0228	0.0000303
LIV_VEG_END	0.209	0.0307	0.00024	0.0124	0.000016
FISH_ECO_END	0.1406	0.0206	0.00016	0.00838	0.0000099
RES_RES_END	0.1296	0.019	0.00015	0.00769	0.00001
SUB_VEG_END	0.02512	0.00369	0.00003	0.00149	0.0000019
FLO_ATT_END	0.01134	0.00167	0.00001	0.000678	0.0000009
VEG_ECO_END	0.007688	0.00113	0.00001	0.000452	0.0000006
TOURISM_END	0.006864	0.00101	0.00001	0.000413	0.0000005
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-16: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR4.3 Sand River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	1.142	0.178	0.00165	0.0912	0.0000856
INV_ECO_END	0.5421	0.0846	0.00073	0.0403	0.0000708
WAT_DIS_END	0.2497	0.0389	0.00034	0.0189	0.0000303
RIV_ASS_END	0.2115	0.033	0.00028	0.0154	0.0000244
LIV_VEG_END	0.06274	0.00979	0.00009	0.00472	0.0000075
SUB_VEG_END	0.009572	0.00149	0.00001	0.000729	0.0000012
RES_RES_END	0.008101	0.00126	0.00001	0.000619	0.000001
FLO_ATT_END	0.005871	0.000916	0.00001	0.000445	0.0000007
VEG_ECO_END	0.003026	0.000472	0	0.000238	0.0000004
TOURISM_END	0.001852	0.000289	0	0.000152	0.0000002
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-17: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR4.4 Bubye River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	1.442	0.225	0.00203	0.112	0.000109
INV_ECO_END	0.8255	0.129	0.0011	0.0606	0.0001034
WAT_DIS_END	0.2488	0.0388	0.00034	0.0187	0.00003
RIV_ASS_END	0.228	0.0355	0.0003	0.0165	0.000026
LIV_VEG_END	0.0521	0.00812	0.00007	0.00389	0.0000062
RES_RES_END	0.009174	0.00143	0.00001	0.000681	0.0000011
TOURISM_END	0.008512	0.00133	0.00001	0.000631	0.000001
SUB_VEG_END	0.00538	0.000838	0.00001	0.000411	0.0000007
FLO_ATT_END	0.003535	0.000551	0	0.00025	0.0000004
VEG_ECO_END	0.001688	0.000263	0	0.00012	0.0000002
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-18: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR5 Luvuvhu River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	12	1.62	0.01399	0.765	0.002437
INV_ECO_END	4.454	0.6	0.00497	0.272	0.0004804
RIV_ASS_END	0.6637	0.0894	0.0007	0.0381	0.0000964
RES_RES_END	0.06847	0.00922	0.00007	0.00392	0.0000098
TOURISM_END	0.05763	0.00776	0.00006	0.0033	0.0000075
LIV_VEG_END	0.04061	0.00547	0.00004	0.00233	0.000006
VEG_ECO_END	0.01181	0.00159	0.00001	0.000673	0.0000017
WAT_DIS_END	0.007814	0.00105	0.00001	0.000451	0.0000012
SUB_VEG_END	0.007073	0.000952	0.00001	0.000404	0.000001
FLO_ATT_END	0.005995	0.000807	0.00001	0.000343	0.0000009
REC_SPIR_END	0.004157	0.00056	0	0.000236	0.0000006
DOM_WAT_END	0	0	0	0	0

Table 10-19: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR6 Mwenedzi River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	6.796	0.779	0.00636	0.323	0.0007934
INV_ECO_END	5.497	0.63	0.00573	0.291	0.0004543
RES_RES_END	0.772	0.0885	0.00081	0.041	0.0000645
RIV_ASS_END	0.3535	0.0405	0.00033	0.0168	0.0000295
WAT_DIS_END	0.1209	0.0139	0.00013	0.00669	0.0000102
TOURISM_END	0.0867	0.00993	0.00009	0.00457	0.0000073
LIV_VEG_END	0.07428	0.00851	0.00008	0.00407	0.0000062
SUB_VEG_END	0.007275	0.000834	0.00001	0.000403	0.0000006
FLO_ATT_END	0.005558	0.000637	0.00001	0.000301	0.0000005
VEG_ECO_END	0.004603	0.000527	0	0.000248	0.0000004
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-20: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR7.1 Upper Olifants River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	8.254	0.979	0.00765	0.387	0.0007691
INV_ECO_END	5.791	0.687	0.0072	0.364	0.0004897
RIV_ASS_END	4.837	0.573	0.00568	0.287	0.0004177
RES_RES_END	4.01	0.475	0.00527	0.266	0.0003746
TOURISM_END	1.988	0.236	0.00258	0.131	0.0001785
LIV_VEG_END	1.482	0.176	0.00193	0.0976	0.0001347
SUB_VEG_END	1.002	0.119	0.00131	0.0664	0.0000928
VEG_ECO_END	0.8494	0.101	0.00111	0.056	0.0000744
FLO_ATT_END	0.4726	0.056	0.00062	0.0314	0.0000426
WAT_DIS_END	0.1234	0.0146	0.00016	0.00802	0.0000109
REC_SPIR_END	0.006952	0.000824	0.00001	0.000461	0.0000006
DOM_WAT_END	0	0	0	0	0

Table 10-21: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR7.2 Lower Olifants River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	9.068	1.07	0.00844	0.427	0.0008559
INV_ECO_END	6.116	0.725	0.00734	0.371	0.0005074
RIV_ASS_END	4.445	0.527	0.00507	0.257	0.0003745
RES_RES_END	4.268	0.506	0.00537	0.271	0.0003847
TOURISM_END	1.981	0.235	0.00247	0.125	0.0001715
LIV_VEG_END	1.222	0.145	0.00152	0.077	0.0001066
WAT_DIS_END	0.9722	0.115	0.00124	0.0626	0.0000853
SUB_VEG_END	0.7194	0.0853	0.0009	0.0456	0.0000635
VEG_ECO_END	0.6415	0.076	0.0008	0.0404	0.0000544
FLO_ATT_END	0.3587	0.0425	0.00045	0.0228	0.0000312
REC_SPIR_END	0.004917	0.000583	0.00001	0.000311	0.0000004
DOM_WAT_END	0	0	0	0	0

Table 10-22: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR8.1 Groot Letaba River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
INV_ECO_END	0.5354	0.0994	0.00079	0.046	0.0000766
WAT_DIS_END	0.126	0.0234	0.00019	0.0111	0.0000177
FISH_ECO_END	0.09893	0.0184	0.00015	0.00842	0.0000127
RIV_ASS_END	0.068	0.0126	0.0001	0.0059	0.0000094
LIV_VEG_END	0.03373	0.00626	0.00005	0.00297	0.0000047
RES_RES_END	0.02328	0.00432	0.00004	0.00206	0.0000033
SUB_VEG_END	0.004182	0.000776	0.00001	0.000353	0.0000006
VEG_ECO_END	0.001642	0.000305	0	0.000143	0.0000002
FLO_ATT_END	0.001466	0.000272	0	0.000134	0.0000002
TOURISM_END	0.001022	0.00019	0	0.000088	0.0000001
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-23: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR8.2 Letaba River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	5.032	0.567	0.00469	0.243	0.0005436
INV_ECO_END	0.3416	0.0385	0.00049	0.0256	0.0000415
WAT_DIS_END	0.1343	0.0151	0.0002	0.0105	0.0000161
RIV_ASS_END	0.09459	0.0107	0.0001	0.00499	0.0000089
LIV_VEG_END	0.01898	0.00214	0.00003	0.00146	0.0000022
RES_RES_END	0.01488	0.00168	0.00002	0.00116	0.0000018
SUB_VEG_END	0.001958	0.000221	0	0.000144	0.0000002
FLO_ATT_END	0.001206	0.000136	0.000000	0.000091	0.0000001
VEG_ECO_END	0.001194	0.000135	0.000000	0.000095	0.0000001
TOURISM_END	0.000844	0.000095	0.000000	0.000062	0.0000001
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-24: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR9 Shinwedzi River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	3.839	0.455	0.00398	0.203	0.0005441
INV_ECO_END	0.6574	0.078	0.00069	0.0349	0.0000532
WAT_DIS_END	0.5688	0.0675	0.0006	0.0306	0.0000483
RIV_ASS_END	0.253	0.03	0.00024	0.0122	0.0000225
LIV_VEG_END	0.06214	0.00737	0.00006	0.00331	0.0000053
RES_RES_END	0.04237	0.00503	0.00004	0.00227	0.0000036
SUB_VEG_END	0.007851	0.000931	0.00001	0.000421	0.0000007
FLO_ATT_END	0.00785	0.000931	0.00001	0.000419	0.0000007
VEG_ECO_END	0.004595	0.000545	0	0.000244	0.0000004
TOURISM_END	0.003632	0.000431	0	0.000195	0.0000003
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0

Table 10-25: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR10.1 Limpopo River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	19.94	2.88	0.02327	1.29	0.0032138
INV_ECO_END	12.83	1.85	0.01568	0.867	0.0012718
RIV_ASS_END	4.508	0.652	0.00532	0.294	0.0004905
RES_RES_END	2.083	0.301	0.00252	0.14	0.0002153
TOURISM_END	1.515	0.219	0.00185	0.102	0.0001582
LIV_VEG_END	1.495	0.216	0.00182	0.101	0.000157
SUB_VEG_END	0.6225	0.09	0.00076	0.0421	0.0000641
VEG_ECO_END	0.5938	0.0858	0.00073	0.0403	0.0000629
FLO_ATT_END	0.3808	0.055	0.00047	0.0261	0.0000391
WAT_DIS_END	0.1133	0.0164	0.00014	0.00766	0.0000123
REC_SPIR_END	0.000449	0.00006	0.00000	0.00003	0.0000001
DOM_WAT_END	0	0	0	0	0

Table 10-26: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR10.2 Elephantes River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
FISH_ECO_END	0.8714	0.262	0.00238	0.263	0.0003886
RES_RES_END	0.8594	0.259	0.00216	0.239	0.0003324
RIV_ASS_END	0.767	0.231	0.00198	0.219	0.000292
VEG_ECO_END	0.6958	0.209	0.00169	0.187	0.0002507
FLO_ATT_END	0.4964	0.149	0.00123	0.136	0.0001842
INV_ECO_END	0.4895	0.147	0.00118	0.131	0.0001693
SUB_VEG_END	0.3753	0.113	0.00094	0.104	0.0001438
LIV_VEG_END	0.1303	0.0392	0.00035	0.0383	0.0000535
WAT_DIS_END	0.02049	0.00616	0.00006	0.00637	0.0000095
DOM_WAT_END	0	0	0	0	0
REC_SPIR_END	0	0	0	0	0
TOURISM_END	0	0	0	0	0

Table 10-27: Sensitivity of Findings for the SUB-FISH-END' to a finding at another node for RR10.3 Limpopo River

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of Beliefs
INV_ECO_END	12.89	1.84	0.01459	0.746	0.0009658
FISH_ECO_END	2.453	0.351	0.00276	0.141	0.0002021
RIV_ASS_END	2.013	0.288	0.00229	0.117	0.0001537
LIV_VEG_END	1.667	0.238	0.00188	0.0962	0.0001268
RES_RES_END	1.657	0.237	0.00187	0.0958	0.000125
TOURISM_END	1.256	0.18	0.00142	0.0724	0.0000938
SUB_VEG_END	0.831	0.119	0.00094	0.0479	0.0000625
VEG_ECO_END	0.2756	0.0394	0.00031	0.0159	0.0000209
FLO_ATT_END	0.2162	0.0309	0.00024	0.0125	0.0000161
WAT_DIS_END	0.2008	0.0287	0.00023	0.0116	0.0000151
REC_SPIR_END	0.02436	0.00348	0.00003	0.00139	0.0000019
DOM_WAT_END	0	0	0	0	0

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