# A SURVEY OF ADULT ODONATA ALONG THE CROCODILE-INKOMATI RIVER MAIN STEM FROM SOURCE TO OCEAN:

## A pilot project to determine the application of the Dragonfly Biotic Index (DBI) as an indicator of river health


[1]


[2]

Gerhard Diedericks, John Simaika and Francois Roux

December 2013

[1]*Crenigomphus hartmanni* (Clubbed Talon-tail)
[2]*Pseudagrion gamblesi* (Great Sprite)

**Status of Report:** Draft

**Corresponding Authors:**

Gerhard Diedericks
Postnet Suite 225
Private Bag X9910
White River
1240
Fax: +27 86 684 7769
Cell: +27 82 337 2312
E-mail: gerhardd@mweb.co.za

Dr John P Simaika
Dept. of Cons. Eco. & Ent.
University of Stellenbosch
Matieland
7602
simaikaj@sun.ac.za

**Date:** September 2013

**Field Work:** Gerhard Diedericks, John Simaika & Francois Roux

# CONTENTS



## LIST OF FIGURES

## LIST OF TABLES



## APPENDICES

## LIST OF ABREVIATIONS

| | | |
|---|---|---|
| ADBI | = | Average Dragonfly Biotic Index (per site) |
| ATO 725 | = | Zambian Mopane Woodland |
| CB | = | Coastal Belt |
| DBI | = | Dragonfly Biotic Index |
| DEWAT | = | Department of Environmental, Water Affairs and Tourism |
| EN | = | Endangered |
| Gm 18 | = | Lydenburg Montane Grassland |
| Gm 21 | = | Lydenburg Thornveld |
| GPS | = | Global Positioning System |
| FOz 5 | = | Scrap Forest Forest |
| ICMA | = | Inkomati Catchment Management Agency |
| IUCN | = | International Union for Conservation of Nature |
| m a.s.l. | = | Meters above sea level |
| Lat. | = | Latitude |
| LC | = | Least Concern |
| Long. | = | Longitude |
| LSB | = | Left Stream Bank |
| MTPA | = | Mpumalanga Tourism and Parks Agency |
| NRHP | = | National River Health Programme |
| NT | = | Near Threatened |
| RCC | = | River Continuum Concept |
| RSB | = | Right Stream Bank |
| SVl 3 | = | Granite Lowveld |
| SVl 4 | = | Delagoa Lowveld |
| SVl 5 | = | Tshokwane-Hlane Basalt Lowveld |
| SVl 9 | = | Legogote Sour Bushveld |

| | | |
|---|---|---|
| VEG | = | Riparian Vegetation Response Assessment Index |
| VEGRAI | = | Vegetation |
| VU | = | Vulnerable |


## ACKNOWLEDGEMENTS

Hereby an expression of our sincere gratitude towards the following persons and institutions for their assistance and contributions:

- Francois Roux from Mpumalanga Tourism and Parks Boardsô Aquatic Division for initiating the study and assistance with logistics and field work;
- The Inkomati Catchment Management Agency (ICMA) for providing the funding for the study, and;
- The land-owners providing access to their properties.

# 1. INTRODUCTION

Continued human population growth coupled with land use intensification, increases the anthropogenic pressures on already threatened aquatic ecosystems (Allan 2004). Freshwater ecosystems are especially vulnerable to the impact of global changes facing declines in water quality and biodiversity due to destruction or degradation of habitat, invasion by alien species, overexploitation, water pollution and flow modification (Dudgeon et al. 2006). In order to influence policy decisions and the management of aquatic ecosystems, monitoring is implemented in an effort to better understand and guide these decisions. Biomonitoring, as opposed to chemical monitoring, has been recognised as a very effective monitoring tool. Biological indicators are used worldwide to determine the ecological health and status of aquatic ecosystems(Barbour et al. 1999; Bonanno & Lo Giudice 2010; Cummins et al. 2008; Davies et al. 1993; Davies & Day 1998; Hughes 2000; Kleynhans et al. 2007; Metcalfe-Smith 1996; Plafkin et al 1989). Globally, Odonata[3] are used as one of the many aquatic indicator groups (Clark & Samways 1996; Foote & Hornung 2005; Hawking & New 2002; Hornung & Rice 2003; Magoba & Samways 2010; Oertli 2010; Sahlén & Ekestubbe 2001; Samways & Taylor 2004; Samways & Sharratt 2010; Simaika & Samways 2009, 2011, 2012). The use of Odonata is mainly centred on their link to the aquatic and terrestrial components of their life stages (Simaika & Samways 2009a;Oertli 2010; Simaika & Samways 2010). Adult Odonata make excellent indicators for several reasons (Samways & Steytler 1996; Chovanec & Waringer 2001):

- They are well-studied, and their taxonomy relatively stable;
- Most are easily identifiable in the field;
- They occupy a spectrum of habitats;
- They are sensitive to changes in water quality and the ecological conditions of their habitats; and,
- Their species assemblages are large enough for assessments.

Natural influences driving the composition and structure of the Odonata communities are (McPeek 2010):

- Hydro-period (e.g. permanence, seasonality);
- Vegetation Structure (e.g. grassland, forest), and;
- Presence or absence of fish.

Anthropogenic influences on the integrity of Odonata habitat are mainly as follows (Foote & Hornung 2005; Kutcher 2011; Magoba & Samways 2010; Samways & Taylor 2004; Samways & Sharratt 2010):

- The surrounding land-use (e.g. industrial, urban, agriculture);
- Fluvial inputs (e.g. nutrients, toxins, sediments);
- Buffer degradation (e.g. width of the buffer zone, degree of weed infestation);
- Over abstraction of water, and;
- Exotic fish species.

[3] Class: Insecta, Order: Odonata ï includes dragonflies and damselflies

The Inkomati Catchment Management Agency (ICMA) is responsible for overseeing the monitoring of the Inkomati Catchment Basin (Sabie, Crocodile and Komati Rivers) and reporting on the health and status of these systems to the Department of Water Affairs (DWA). DWA is the custodian of the countryøs water resource in South Africa. The determination of the present ecological status of the Crocodile River system, using fish and aquatic macro-invertebrates, was scheduled for 2012. The Dragonfly Biotic Index (DBI) was recently developed for South Africa (Simaika & Samways 2009, 2011, 2012), and it was decided to test the application of the DBI on the Crocodile River main stem.

Environmental Biomonitoring Services were approached by the Mpumalanga Tourism and Parks Agency (MTPA) to select monitoring sites and apply the DBI method. Dr John Simaika[4], who developed the DBI method as part of his doctorate was approached to assist. A total of 29 sites were selected from the headwaters of the Crocodile River to below the point where the Inkomati River merges with the Sabie River in Mozambique below the town of Sabia. The 29 sites incorporated elevations ranging from 2,100 to 20 m a.s.l. Adult Odonata were recorded at each of the selected sampling points.

This report therefore aims to present the application and results of the application of the DBI (adult Odonata monitoring) along the main Crocodile River and its extension into Mozambique.

# 2. METHODS

## 2.1 STUDY AREA

The Crocodile River Catchment is located in the eastern portion of the Mpumalanga province of South Africa (Figure 1). The Crocodile River originates at an elevation of 2,260m a.s.l from where it seeps and eventually converges in partial sub-surface stream channels.

The river flows through the town of Dullstroom which is characterised by Trout Farms towards the Kwena Dam near Lydenburg (Mashishing). From the Kwena Dam, the Crocodile River flows east towards Nelspruit and then Malelane and Komatipoort at the South Africa-Mozambique border. The Crocodile River merges with the Komati River, after which the name of the river changes to the Inkomati River. The Inkomati River flows east towards Moamba. From Moamba onwards the river flows through flood-plains towards Sabia and then into Lake Chuali. From Lake Chuali the river meanders northwards and then southwards to the Indian Ocean north of Maputo.

[4] Dr John Simaika, Honorary Researcher, Department of Conservation Ecology & Entomology, Faculty of AgriSciences, Stellenbosch University, South Africa


**Figure 1:** A map of southern Africa, indicating the location of sites along the Crocodile-Inkomati River north of Swaziland.

## 2.2 SITE SELECTION

Sites were selected based on four criteria:

- The location of existing sites;
- Elevation;
- Terrestrial vegetation type, and;
- Ease of access.

Site locations are roughly indicated on a sketch map of the Crocodile-Inkomati River (Figure 2). A table indicating site codes, short site descriptions, GPS points, elevation range and vegetation type of the surrounding land are included below (Table 1).

**CROCODILE-INCOMATI RIVER**

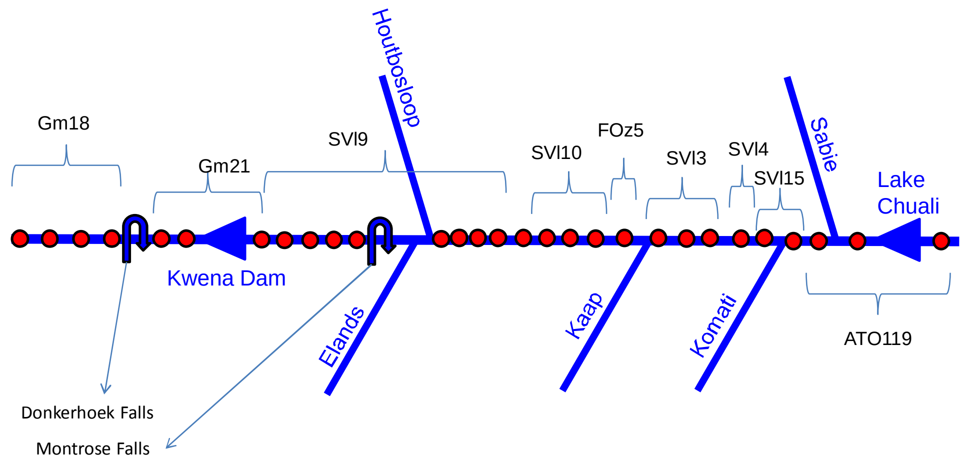



**Figure 2:** A sketch map of the Crocodile-Inkomati River, indicating waterfalls, the Kwena Dam, major tributaries, monitoring points and the codes of the main vegetation types (see Table 1 for explanation of vegetation codes).

The National River Health Programme (NRHP) has adopted the following standard for numbering sites (Dallas 2005):

- Secondary Catchment Code (e.g. X2);
- 1st four letters of river name (e.g. CROC), and;
- 1st five letters of location (e.g. VERLO).

For example, X2CROC-VERLO represents a site on the Crocodile River at Verloren Vallei Nature Reserve.

**Table 1:** A list of the sites sampled from headwaters to ocean, indicating the NRHP site code, site name, GPS location, elevation range,the Kleynhans et al. (2005) aquatic ecoregions, and Mucina&Rutherfordôs (2006)vegetation types. The Mucina & Rutherford (2006) vegetation types excludes Mozambique, so for sites in Mozambique the WWFôs Terrestrial Ecoregions were used.

| SITE CODE | SITE NAME | GPS (dd mm ss.s)[5] | | ELEVATION | AQUATIC ECOREGIONS | | MUCINA AND RUTHERFORD'S VEGETATION TYPES | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Lat. (S) | Long. (E) | (m a.s.l.) | Level I | Level II | Biome | Bioregion | Vegetation Type |
| X2CROC-VERLO | Verlorenvalei | 25° 20ô59.4ò | 30° 06ô35.7ò | 2,080 ï 2,100 | 9. Eastern Bankenveld | 9.02 | Grassland | Mesic Highveld Grassland | Gm 18: Lydenburg Montane Grassland |
| X2CROC-EHOEK | Elandshoek | 25° 22ô27.5ò | 30° 06ô31.7ò | 2,020 ï 2,040 | | | | | |
| X2CROC-VALYS | Valyspruit | 25° 29ô38.6ò | 30° 08ô36.7ò | 1,840 ï 1,860 | | | | | |
| X2CROC-ROODE | Roodekrans | 25° 30ô10.8ò | 30° 11ô12.2ò | 1,700 ï 1,720 | | | | | |
| X2CROC-DHOEK | Donkerhoek | 25° 28ô01.6ò | 30° 13ô47.0ò | 1,320 ï 1,340 | | | | | Gm 21: Lydenburg Thornveld |
| X2CROC-GOEDE | Goedehoop | 25° 24ô34.8ò | 30° 18ô57.9ò | 1,200 ï 1,220 | | 9.04 | | | |
| X2CROC-DOORN | Doornhoek | 25° 23ô23.7ò | 30° 24ô23.4ò | 1,100 ï 1,120 | 10. Northern Escarpment Mountains | 10.01 | | | |
| X2CROC-BEHRE | Behrens | 25° 22ô11.5ò | 30° 30ô02.2ò | 990 ï 1,000 | | | Savanna | Lowveld | SVI 9: Legogote Sour Bushveld |
| X2CROC-RIETV | Rietvlei | 25° 23ô17.3ò | 30° 33ô56.5ò | 920 - 940 | | 10.02 | | | |
| X2CROC-INDEM | Die Rots | 25° 25ô35.1ò | 30° 38ô09.7ò | 860 - 880 | | | | | |
| X2CROC-MONTR | Montrose | 25° 26ô55.3ò | 30° 42ô36.6ò | 780 - 800 | | | | | |
| X2CROC-RIVUL | Rivulets | 25° 25ô48.6ò | 30° 45ô26.8ò | 720 - 740 | 4. North Eastern Highlands | 4.04 | | | |
| X2CROC-STRKS | Sterkstroom | 25° 26ô28.6ò | 30° 53ô27.7ò | 660 - 680 | | | | | |
| X2CROC-HALLS | Halls | 25° 26ô53.6ò | 30° 56ô59.1ò | 640 - 660 | | | | | |
| X2CROC-BOTAN | Botanical Gardens | 25° 26ô38.4ò | 30° 58ô27.7ò | 600 - 620 | | | | | |
| X2CROC-KHAMA | Khamagugu | 25° 27ô03.7ò | 31° 01ô00.1ò | 560 - 580 | | | | | SVI 10: Pretoriuskop Sour Bushveld |
| X2CROC-KINGS | Kingstonvale | 25° 27ô30.4ò | 31° 03ô33.0ò | 540 - 560 | | | | | |
| X2CROC-DNELS | Kanyamazane | 25° 30ô07.1ò | 31° 11ô00.1ò | 460 - 480 | | | | | |
| X2CROC-WELT1 | Crocodile Gorge | 25° 31ô12.7ò | 31° 14ô19.7ò | 380 - 400 | 3. Lowveld | 3.07 | Forest | Zonal & Intrazonal Forest | FOz 5: Scrap Forest |
| X2CROC-KAAPM | Kaapmuiden | 25° 32ô12.0ò | 31° 18ô41.5ò | 320 - 340 | | | Savanna | Lowveld | SVI 3: Granite Lowveld |
| X2CROC-RIVER | Malelane | 25° 27ô38.5ò | 31° 32ô06.4ò | 280 - 300 | | | | | |
| X2CROC-MAROE | Maroela | 25° 22ô55.9ò | 31° 44ô41.9ò | 200 - 220 | | | | | |
| X2CROC-CBRDG | Crocodile Bridge | 25° 21ô44.0ò | 31° 53ô37.9ò | 140 - 160 | | 3.06 | | | SVI 5: Tshokwane-Hlane Basalt Lowveld |
| X2CROC-TENBO | Tenbosch Weir | 25° 21ô47.8ò | 31° 57ô23.6ò | 120 - 140 | 12. Lebombo Uplands | 12.01 | | | |
| X2CROC-NKONG | Nkongoma | 25° 23ô31.8ò | 31° 58ô37.0ò | 120 - 140 | | | | | SVI 15:Northern Lebombo Bushveld |
| X4INCO-KOMAT | Komati Confluence | 25° 26ô11.7ò | 31° 58ô56.9ò | 100 - 120 | | | | | |
| X4INCO-MOAMB | Moamba | 25° 33ô51.6ò | 32° 15ô16.0ò | 60 - 80 | Zambian Mopane Woodland | | Savanna | Lowveld | ATO 725: Zambian Mopane Woodland |
| X4INCO-SABIA | Sabia | 25° 19ô32.6ò | 32° 15ô17.2ò | 40 - 60 | | | Savanna | Lowveld | ATO 725: Zambian Mopane Woodland |
| X4INCO-LCHUA | Lake Chuali | 25° 04ô07.2ò | 32° 55ô18.9ò | 0 - 20 | Eastern Coastal Belt | | Indian Ocean Coastal Belt | | ATO 119: Maputaland Coastal Belt |

[5]MapDatum: WGS84

## 2.3 DRAGONFLY BIOTIC INDEX (DBI)

The dependence of the aquatic and terrestrial life stages of Odonata on aquatic and terrestrial ecosystems has led to their worldwide use as indicators of habitat quality(Clark & Samways 1996; Chovanec & Waringer 2001; Sahlén & Ekestubbe 2001; Hawking & New 2002; Hornung & Rice 2003; Schindler et al. 2003; Samways & Taylor 2004; Oppel 2005; Simaika & Samways 2008; Simaika & Samways 2009a; Oertli 2010; Samways et al. 2010). However, the use of adult dragonflies, rather than their aquatic larval stages, has only recently gained momentum, with only two indication methods currently in existence. One such method, now already being implemented globally, is the Dragonfly Biotic Index (DBI), developed by Simaika & Samways (2009) to provide a measure of ecological habitat integrity. South African adult Odonata species are assigned a score of 0 to 9, which is a weighted measure based on a speciesô geographic distribution, threat status and the sensitivity of the species to disturbance (Simaika & Samways 2009). An index score of 0 indicates a common species which may even thrive in anthropogenically changed habitats, while a species with a score of 9 is geographically restricted and highly sensitive to habitat change.

An hour is spent walking the stream and riparian zone at each site. Species encountered are identified through visual observation. Those species that are difficult to identify without having them in the hand are captured with a sweep net, and are either inspected with a hand lens or collected for identification under a microscope. The species recorded are listed per site, and their species-specific DBI scores added. The total DBI score is then divided by the number of species, which provides an average score per site or average DBI (ADBI also termed DBI/Site (Simaika and Samways 2012).

Although for the DBI only the presence of a species is required for assigning the total DBI and DBI/Site score, abundance data were also collected. Species abundances were estimated using abundance categories from A-D, represented as follows:

- A = 1;
- B = 2 ï 9;
- C = 10 ï 14, and;
- D = >15.

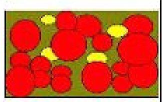
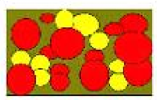
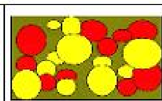
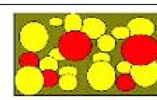
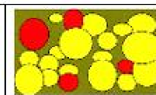
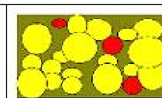
The abundance of each adult Odonata species is expected to be affected by anthropogenic influences on the riparian (Remsburg et al. 2008), terrestrial and aquatic habitats and water quality per site. There are however several natural variations(e.g. predation and competition) that will affect the abundance of a species, and many more data sets are required to properly interpret abundance ratings. Current abundance data were therefore not used in the interpretation of these data sets.

## 2.4 CONDITION OF RIPARIAN ZONES

The dependence of most adult Odonata species on the riparian zone and associated terrestrial vegetation is one of the traits that makes them excellent indicators. It is therefore expected that anthropogenic disturbances within these core zones will influence the abundance, composition and diversity of adult Odonata. Anthropogenic disturbances were therefore determined by measuring (on Google Earth) undisturbed distances from the edge of the river to the riparian zone within each river segment surveyed during the application of the DBI. Five transects were measured perpendicular to the riverõs edge, 20 m apart. Measurements on both stream banks were included.

Invasive weed species were identified, and the degree of weed infestation estimated using the visual assessment approach documented in the Riparian Vegetation Response Assessment Index (VEGRAI).

**Table 2:** Approach to estimating the degree of weed infestation of the riparian zone at the selected sampling points (Kleynhans et al. 2007). The yellow circles represent natural vegetation and the red circles invasive alien plants.

| INVASION BY EXOTICS | | | | | | |
|---|---|---|---|---|---|---|
| Replacement by exotics |  |  |  |  |  |  |
| COVER of exotics | 100-80% | 80 - 60% | 60-40% | 40-20% | 20-10% | <10% |

## 2.5 DATA INTERPRETATION

Sampling sites were grouped (Table 1) based on their location within aquatic ecoregions (Kleynhans et al. 2005) and terrestrial vegetation types (Mucina & Rutherford 2006). A total of 31 aquatic ecoregions have been identified in southern Africa (Kleynhans et al. 2005), of which five are represented along the Crocodile River. The Mucina & Rutherford (2006) vegetation map is classified into 435 vegetation types, of which nine are represented on the main Crocodile River. Adult Odonata are recorded for each ecoregion and vegetation type, with the assumption that as the size of each dataset increase, the associations of species to specific zones (if any), will become clearer.

Because this was a first assessment of this nature, and because there were no previous monitoring data, it was vitally important to access all historical records of Odonata distribution and habitat requiremens of individual species in order to generate a suite of species that are ñexpected to occurò within the different vegetation types and elevation gradients. Expected community composition was compared against observed community composition.

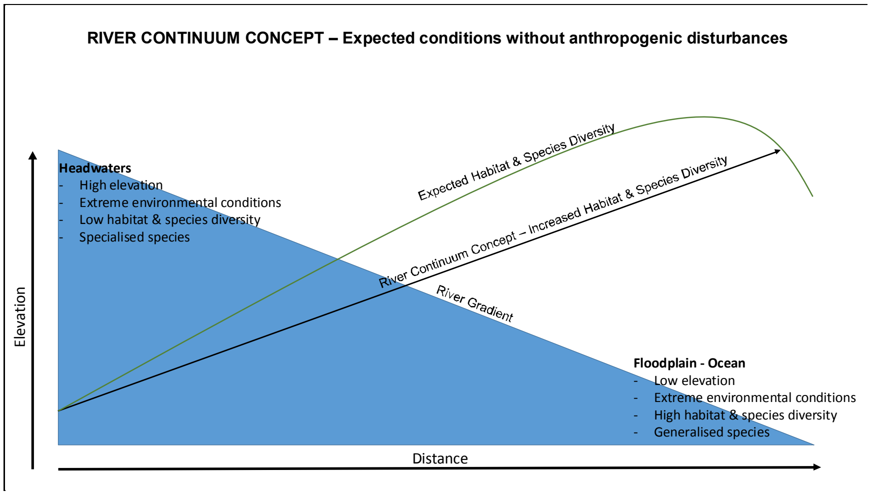



**Figure 3:** A schematic illustration of expected increases in habitat and species diversity without anthropogenic disturbances in a river from its headwaters to the ocean.

The river continuum concept (RCC) predicts changes of physical and biological conditions along a lotic ecosystem from source to sea (Vannote et al. 1980). Changes in habitat (aquatic and terrestrial) and environmental conditions along the continuum are expected towards the ocean up to a point. A decrease in Odonata diversity is expected close to the ocean linked to the oceanic influence (e.g. very few Odonata species are tolerant to salt water). This concept was applied in the interpretation of Odonata species diversity, and graphs illustrating the weighted moving average of species recorded per site to compare against expected results.

Riparian zones were assessed based on the undisturbed width of the riparian and buffer zones and the degree of weed infestation was estimated. The negative impacts associated with each invasive plant species recorded were summarised in order to highlight threats to critical ecosystems.

## 2.6 ASSUMPTIONS AND LIMITATIONS

The assumptions and limitations of the study are briefly discussed as follows:

<u>Field Survey Period</u>

The field survey was limited to one visit per site and took place from the beginning of November 2012 to the end of March 2013. This is limiting in that this baseline data was restricted to one site visit only, and that the flight periods of different species differ and are furthermore dependent on microhabitat and population dynamics.

Sequence of sampling

The study was initiated at the headwaters and culminated close to the ocean. This was not ideal. The sampling should have started in the lower lying areas and then move towards the headwaters, because the lower lying areas take longer logistically due to the fact that these sites are in Mozambique. Also, several adult species are active throughout the year at lower elevations, but less so at high elevations.

Data Availabilityand Expected Species Lists

Actual species records for the catchment are fairly limited. For this reason the list of species expected to occur was drawn up. This was supplemented with known and predicted species associated with vegetation type and micro-climates at the different sampling points. The danger with expected species lists is that they do not take into account natural abiotic influences. Community structures are also naturally influenced by intra-guild predation, interference competition, cannibalism, and interactions with other species (e.g. fish and birds). A high number of species may therefore be expected to occur at a site, but even though habitat is suitable they may not all be present at the same time.

Invasive Plant Species

Alien invasive plant species were identified and recorded per sampling site together with their degree of infestation in the riparian zone. It would have added great value to the data to record the distribution of these infestations in the riparian zone too. For example, there may be a dense infestation of weeds at the edge of the river but this is less dense further away. A high infestation in the immediate vicinity of the river is expected to affect the adult odonata community more than it would further away. These differences were unfortunately not noted. Also, some weed species are allopathic which alters the species composition and structure of the riparian zone.

# 3. RESULTS

The DBI results are presented as well as the condition of the riparian zone in terms of weed infestation and buffer zone width.

## 3.1 ADULT ODONATA

A total of 80 species were recorded along the 29 sampling points on the Crocodile-Inkomati River from an elevation of 2,100 to 20 m a.s.l. This represents 49.4% of all species known to occur in South Africa. Of the 118 species expected to occur, 32.2% were not encountered. A table with the sites visited, the total DBI score (× DBI), number of species, and average DBI score per site (ADBI) are included below (Table 3) and the results illustrated graphically (Figure 4). A species accumulation chart, indicating species that were expected per site compared to those observed are shown inFigure 17.

**Table 3: A list of the sites sampled and the DBI results for each site. The vegetation type (VEG TYPE) refers to the Mucina & Rutherford (2006) vegetation classification.**

| NRHP SITE CODE | SITE NAME | VEG TYPE | SITE DBI | | | VEG TYPE DBI | | |
|---|---|---|---|---|---|---|---|---|
| | | | ∑ DBI | NO. SP. | ADBI | ∑ DBI | NO. SP. | ADBI |
| X2CROC-VERLO | Verlorenvalei | Gm 18 | 24 | 7 | 3.4 | 39 | 16 | 2.4 |
| X2CROC-EHOEK | Elandshoek | | 20 | 8 | 2.5 | | | |
| X2CROC-VALYS | Valyspruit | | 29 | 12 | 2.4 | | | |
| X2CROC-ROODE | Roodekrans | | 19 | 10 | 1.9 | | | |
| X2CROC-DHOEK | Donkerhoek | Gm 21 | 21 | 12 | 1.8 | 37 | 21 | 1.8 |
| X2CROC-GOEDE | Goedehoop | | 18 | 10 | 1.8 | | | |
| X2CROC-DOORN | Doornhoek | | 19 | 12 | 1.6 | | | |
| X2CROC-BEHRE | Behrens | SVl 9 | 21 | 14 | 1.5 | 60 | 34 | 1.8 |
| X2CROC-RIETV | Rietvlei | | 23 | 13 | 1.8 | | | |
| X2CROC-INDEM | Die Rots | | 17 | 10 | 1.7 | | | |
| X2CROC-MONTR | Montrose | | 40 | 24 | 1.7 | | | |
| X2CROC-RIVUL | Rivulets | | 22 | 14 | 1.6 | | | |
| X2CROC-STRKS | Sterkstroom | | 15 | 9 | 1.7 | | | |
| X2CROC-HALLS | Halls | | 26 | 16 | 1.6 | | | |
| X2CROC-BOTAN | Botanical Gardens | | 48 | 26 | 1.8 | 62 | 31 | 2.0 |
| X2CROC-KHAMA | Khamagugu | SVl 10 | 17 | 9 | 1.9 | | | |
| X2CROC-KINGS | Kingstonvale | | 25 | 11 | 2.3 | | | |
| X2CROC-DNELS | Kanyamazane | | 25 | 11 | 2.3 | | | |
| X2CROC-WELT1 | Crocodile Gorge | FOz 5 | 66 | 30 | 2.2 | 66 | 30 | 2.2 |
| X2CROC-KAAPM | Kaapmuiden | SVl 3 | 36 | 17 | 2.1 | 81 | 36 | 2.3 |
| X2CROC-RIVER | Malelane | | 46 | 20 | 2.3 | | | |
| X2CROC-MAROE | Maroela | | 32 | 16 | 2.0 | | | |
| X2CROC-CBRDG | Crocodile Bridge | | 27 | 15 | 1.8 | | | |
| X2CROC-TENBO | Tenbosch Weir | | 14 | 7 | 2.0 | | | |
| X2CROC-NKONG | Nkongoma | SVl 5 | 34 | 22 | 1.5 | 44 | 27 | 1.6 |
| X4INCO-KOMAT | Komatipoort | | 37 | 24 | 1.5 | | | |
| X4INCO-MOAMB | Moamba | ATO 725 | 11 | 9 | 1.2 | 18 | 12 | 1.5 |
| X4INCO-SABIA | Sabia | | 14 | 8 | 1.8 | | | |
| X4INCO-LCHUA | Lake Chuali | CB 1 | 26 | 17 | 1.5 | 26 | 17 | 1.5 |

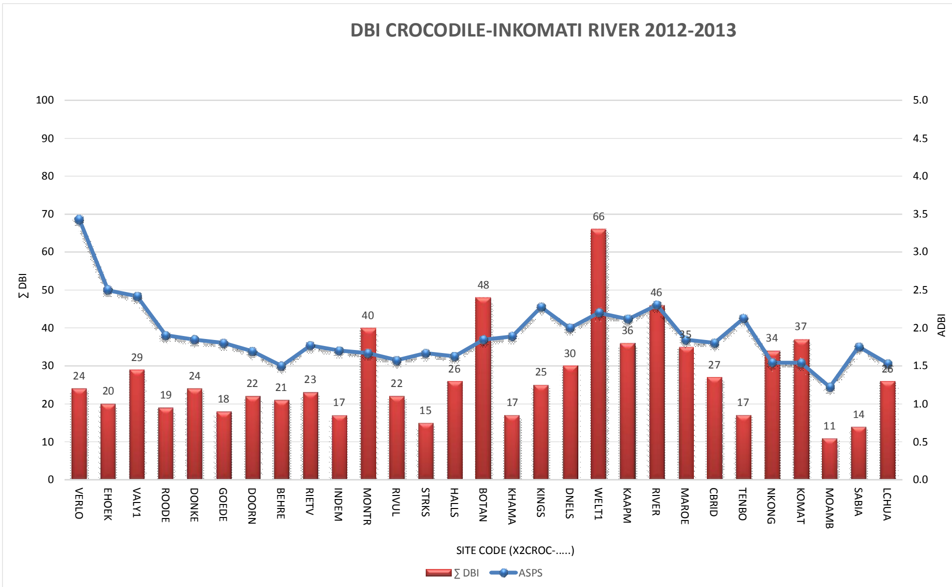



**Figure 4:** Graphical illustration of the total DBI scores and average DBI score per species achieved at each site from the headwaters (Verlorenvalei) to Lake Chuali. The prefix of the NRHP site code (X2CROC-) was excluded from the graph to provide more space.

In general, adult Odonata species diversity was low at the headwaters, increasing longitudinally downstream, with several śspikesọ which tend to indicate increases in species diversity. Very low total DBI scores were recorded at the Sterkstroom (660 ï 680 m a.s.l.), Kamagugu (560 ï 580 m a.s.l.), Tenbosch Weir (120 ï 140 m a.s.l.) and Moamba(60 ï 80 m a.s.l.) sites. High diversity was recorded at the Montrose (780 ï 800 m a.s.l.), Botanical Gardens (600 ï 620 m a.s.l.), Crocodile Gorge(380 ï 400 m a.s.l.) and Malelane(280 ï 300 m a.s.l.) sites. The highest ADBI was recorded at headwater sites Verlorenvalei (2,080 ï 2,100 m a.s.l.), Elandshoek(2,020 ï 2,040 m a.s.l.) and Valyspruit (1,840 ï 1,860 m a.s.l.).

Threatened species were recorded in the Crocodile Gorge, Malelane, Crocodile Bridge and the Inkomati River below Lake Chuali.

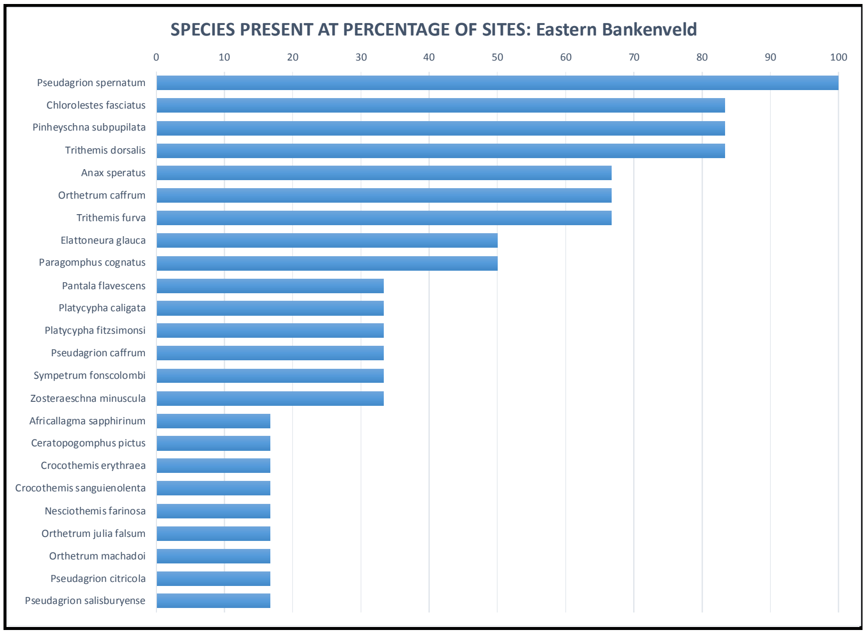



**Figure 5:** The number of sites within the Eastern Bankenveld aquatic ecoregion(Table 1) at which species were recorded, expressed as a percentage.

The species *Pseudagrion spernatum* was recorded at all six sampling sites, with the species *Chlorolestes fasciatus*, *Pinheyschna subpupillata*, *Trithemis dorsalis*recorded at >80% (five of the six) sites. The species *Africallagma sapphirinum*, *Ceratogomphus pictus, Crocothemis erythraea, C. sanguinolenta, Nesciothemis farinosa, Orthetrum julia, O. machadoi, Pseudagrion cirticola* and *P. salisburyense* were only encountered at one of the six sampling sites in the Eastern Bankenveld aquatic ecoregion.

No threatened species were recorded, however, the following range-restricted endemic species were observed:

- *Africallagma sapphirinum* ï South African endemic;
- *Chlorlestes fasciatus* ï restricted range in the catchment;
- *Orthetrum caffrum* ï range in catchment during survey period restricted to upland grasslands;
- *O. machadoi* ï range in catchment during survey period restricted to upland grassland;
- *Platycypha fitzsimonsi* ï Localised species only recorded in the headwaters upstream from Donkerhoek Falls;
- *Pseudagrion caffrum* ï South African endemic restricted to the headwater grasslands, and;
- *P.citricola* ï South African endemic restricted to grasslands in upper catchment.

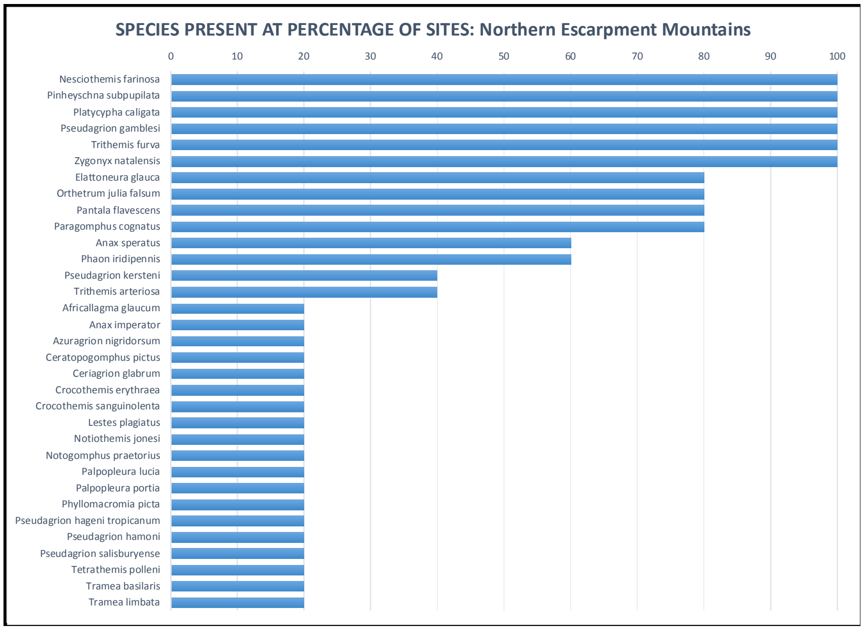



**Figure 6:** The number of sites within the Northern Escarpment Mountains aquatic ecoregion at which species were recorded, expressed as a percentage.

Of the 33 species recorded in this aquatic ecoregion, 12 species were recorded at more than 50% of the sampling sites, and 19 were only recorded at one of the five sampling sites located within the ecoregion. Species recorded at all five sampling points located within the Northern Escarpment Mountains aquatic ecoregion included *Nesciothemis farinosa, Pinheyschna subpupillata, Platycypha caligata, Pseudagrion gamblesi, Trithemis furva* and *Zygonyx natalensis*.

No threatened species were recorded, however, the following migratory species were observed:

- *Crocothemis erythraea* ï facultative migration;
- *Pantala flavescens* ï obligate migration;
- *Phyllomacromia picta* ï facultative migration;
- *Tramea basilaris* ï obligate migration, and;
- *T.limbata* ï obligate migration.

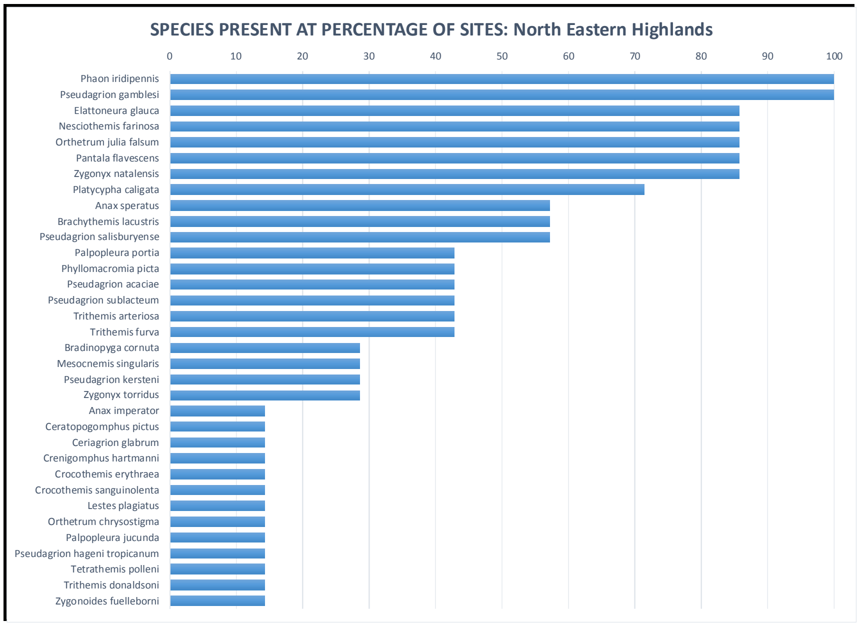



**Figure 7:** The number of sites within the North Eastern Highlands aquatic ecoregion at which species were recorded, expressed as a percentage.

Of the 34 species recorded in this aquatic ecoregion, 11 species were recorded at more than 50% of the sampling sites, and 13 were only recorded at one of the seven sampling sites located within the ecoregion. Species recorded at all seven sampling points located within the North Eastern Highlands aquatic ecoregion included *Phaon iridipennis* and *Pseudagrion gamblesi*.

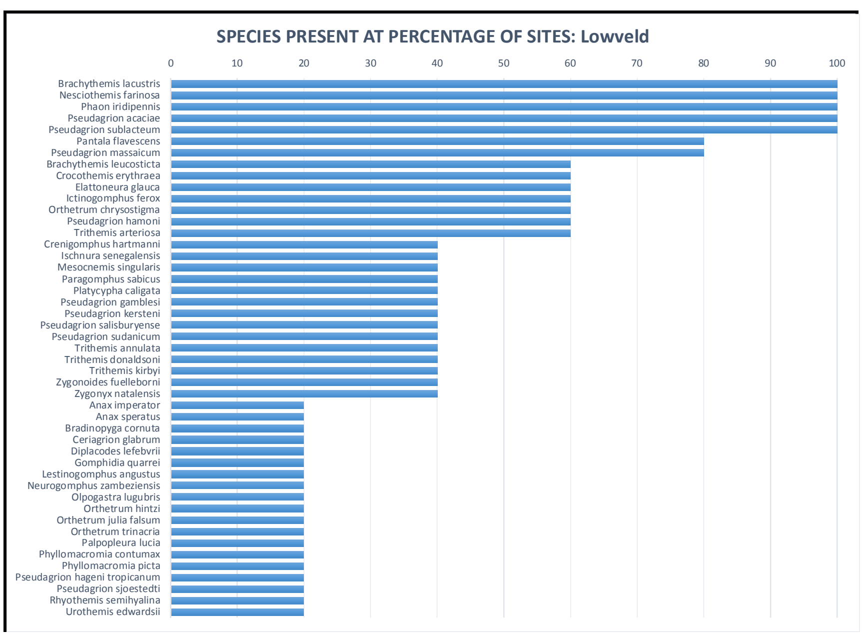



**Figure 8:** The number of sites within the Lowveld aquatic ecoregion at which species were recorded, expressed as a percentage.

Of the 47 species recorded in this aquatic ecoregion, 14 species were recorded at more than 50% of the sampling sites, and 19 were only recorded at one of the five sampling sites located within the ecoregion. Species recorded at all five sampling points located within the Lowveld aquatic ecoregion included *Brachythemis lacustris, Nesciothemis farinosa, Phaon iridipennis, Pseudagrion acaciae* and *P.sublacteum*.

Five of the adult Odonata species recorded in the Lowveld aquatic ecoregion are listed on South Africa's National Red List as Near Threatened (NT), Vulnerable (VU), and Endangered (EN) (Samways 1999). These are:

- *Lestinogomphus angustus* Martin, 1911 [Spined Fairy-tail] ï NT;
- *Gomphidia quarrei* (Schouteden, 1934) [Quarre's Finger-tail] ï VU;
- *Neurogomphus zambeziensis* Cammaerts, 2004 [Zambezi Siphon-tail] - VU;
- *Olpogastra lugubris* Karsch, 1895 [Slender Bottle-tail] ï VU, and;
- *Pseudagrion sjoestedti* Förster, 1906 [Rufous Sprite] ï EN.

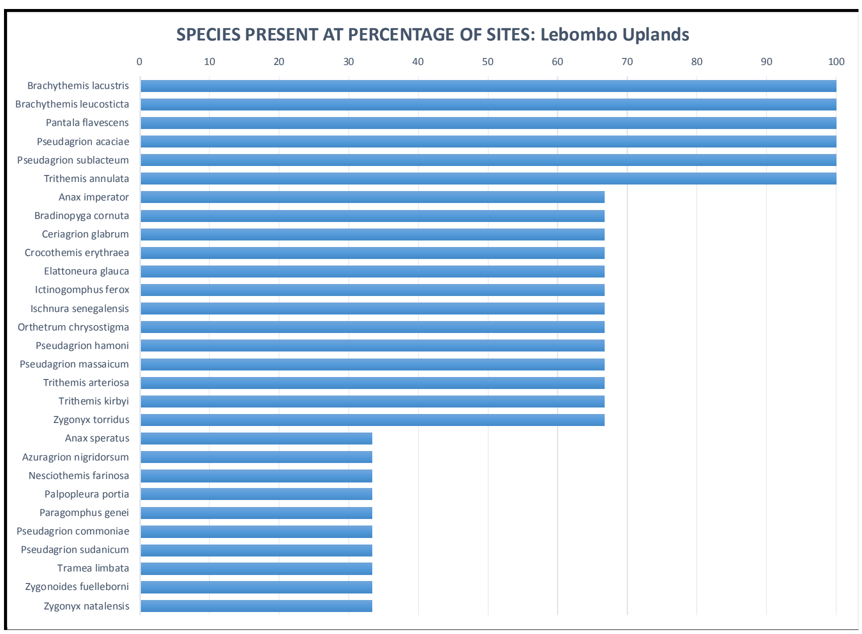



**Figure 9:** The number of sites within the Lebombo Uplands aquatic ecoregion at which species were recorded, expressed as a percentage.

Of the 29 species recorded in this aquatic ecoregion, 19 species were recorded at more than 50% of the sampling sites, and 10 were only recorded at one of the three sampling sites located within the ecoregion. Species recorded at all three sampling points located within the Lowveld aquatic ecoregion included *Brachythemis lacustris, B. leucosticta, Pantala flavescens, Pseudagrion acaciae* and *P.sublacteum*.

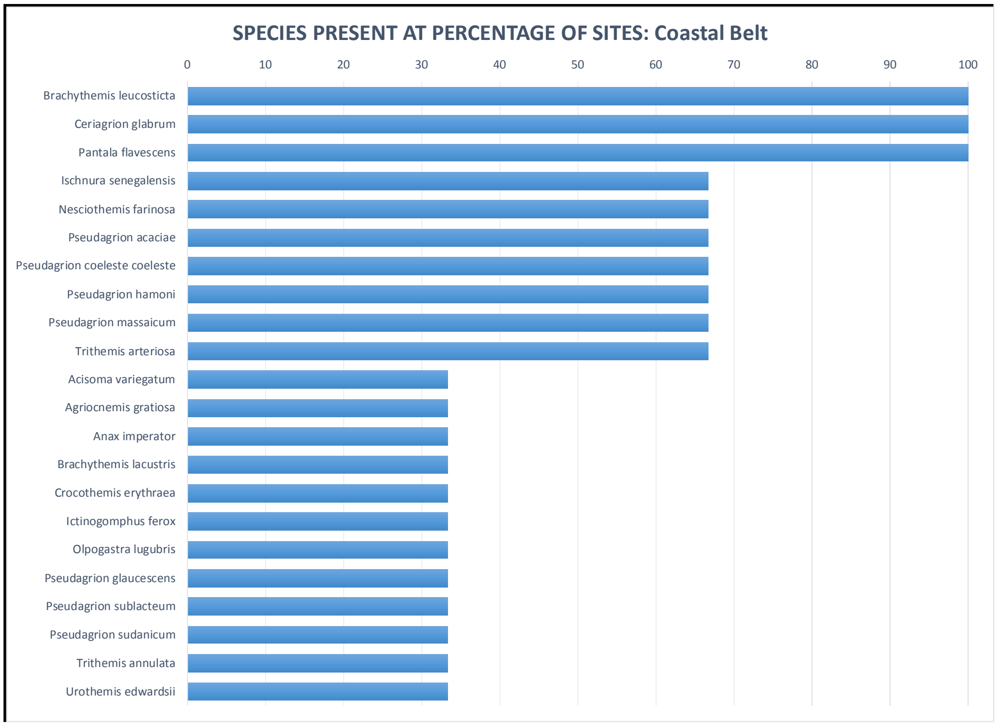



**Figure 10:** All three sites located within Mozambique were grouped into the Coastal Belt aquatic ecoregion. The presence of adult Odonata species at each of these three sites were expressed as a percentage.

Of the 22 species recorded in this aquatic ecoregion, 10 species were recorded at more than 50% of the sampling sites, and 12 were only recorded at one of the three sampling sites. Species recorded at all three sampling points located within the Coastal Belt aquatic ecoregion included *Brachythemis leucosticta, Ceriagrion glabrum* and *Pantala flavescens.*

Three of the adult Odonata species recorded in the Coastal Belt aquatic ecoregion (Mozambique) are listed on South Africa's National Red List as Vulnerable (VU). These are:

- *Agriocnemis gratiosa* Gerstäcker, 1891 [Gracious Wisp];
- *Olpogastra lugubris* Karsch, 1895 [Slender Bottle-tail], and;
- *Pseudagrion coeleste coeleste* Longfield, 1947 [Catshead Sprite].

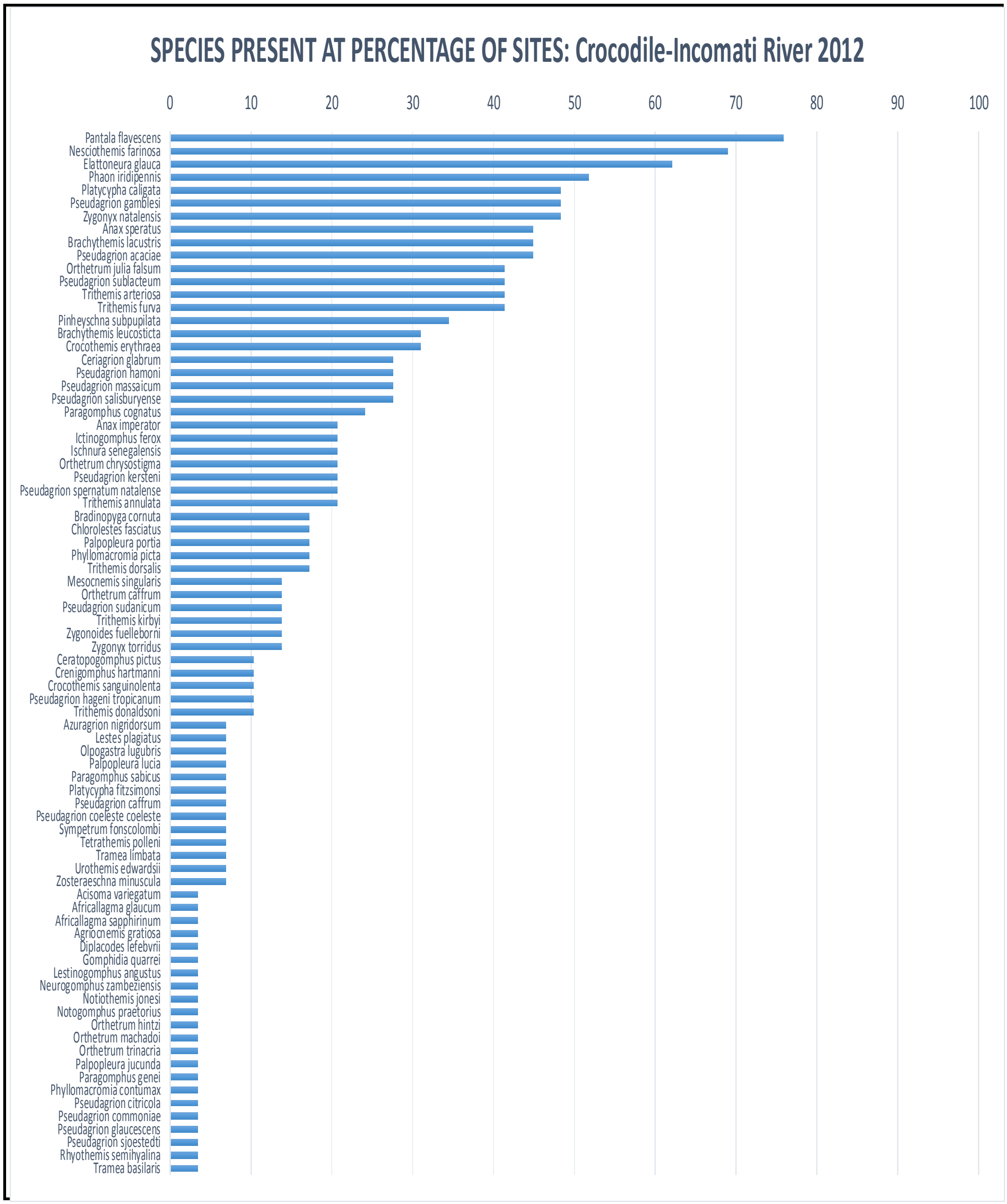



**Figure 11:** A summary indicating all adult Odonata species presented as a percentage of sites sampled along the Crocodile-Inkomati River in 2012.

The global species *Pantala flavescens* was the most ubiquitous, recorded at >75% of the sites sampled, followed by *Nesciothemis farinosa* (69%), *Elattoneura glauca* (62%) and *Phaon iridipennis* (52%).

The vast majority of species were represented at less than 50% of the sites, and about half of those remaining species present at only 15% of the sites. This pattern is most likely indicative of high species turnover (i.e. changes in community composition) along the river continuum.

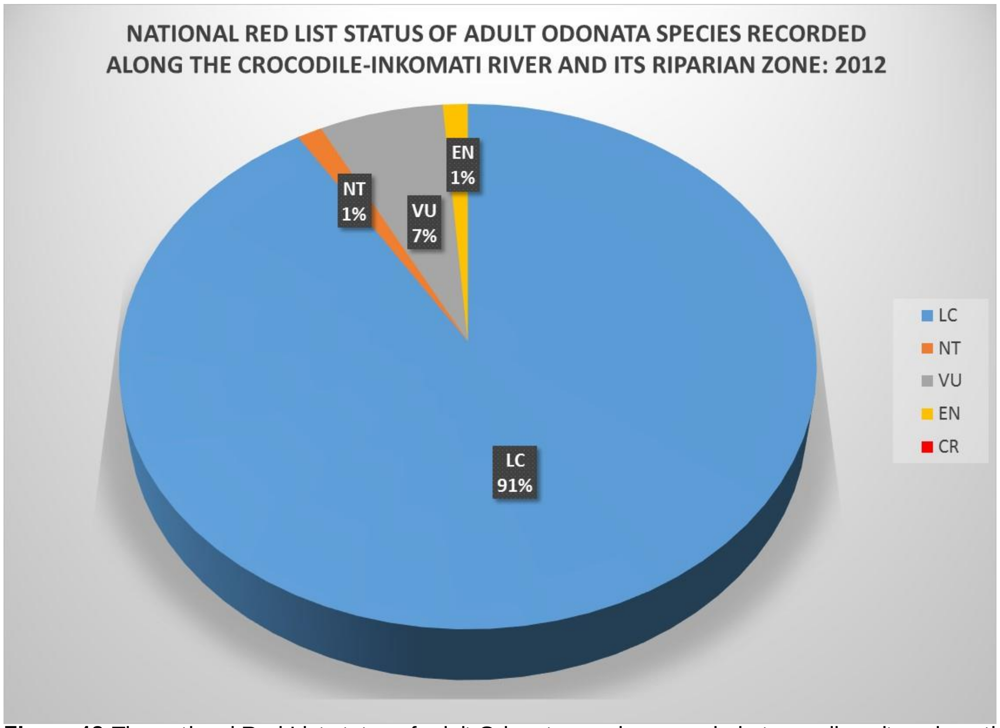


**Figure 12:** The national Red List status of adult Odonata species recorded at sampling sites along the Crocodile-Inkomati River in 2012.

Odonata species included on South Africaøs National Red Data List recorded during the Crocodile-Inkomati survey in 2012 included:

- *Agriocnemis gratiosa* Gerstäcker, 1891 [Gracious Wisp] - VU;
- *Gomphidia quarrei* (Schouteden, 1934) [Quarreøs Finger-tail] ï VU;
- *Lestinogomphus angustus* Martin, 1911 [Spined Fairy-tail] ï NT;
- *Neurogomphus zambeziensis* Cammaerts, 2004 [Zambezi Siphon-tail] - VU;
- *Olpogastra lugubris* Karsch, 1895 [Slender Bottle-tail] - VU;
- *Pseudagrion coeleste coeleste* Longfield, 1947 [Catshead Sprite] ï VU, and;
- *Pseudagrion sjoestedti* Förster, 1906 [Rufous Sprite] ï EN.

Globally, all these species are listed on the IUCN Red Data List as Least Concern (LC).

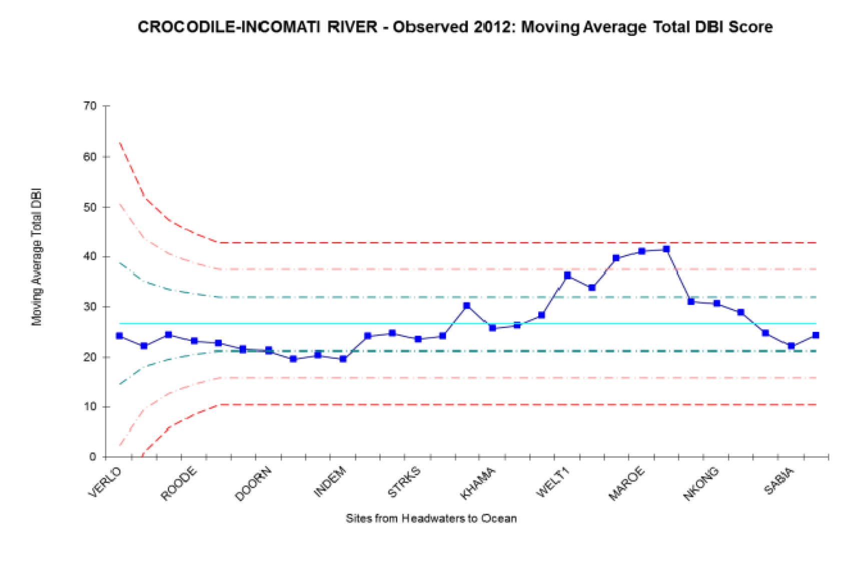



**Figure 13:** The moving average of the total DBI score for sites from Verlorenvalei (headwaters) to Lake Chuali (coastal floodplains).The central light blue line represents the average of all the total DBI scores (27.3), while the dotted blue line represents the moving average.The three dotted lines represent sigma -1, -2 and -3 respectively.

The highest total DBI scores were recorded in the Lowveld region of the Crocodile River and the lowest scores downstream from Kwena Dam. Low total DBI scores were also recorded in the headwaters and coastal plains.

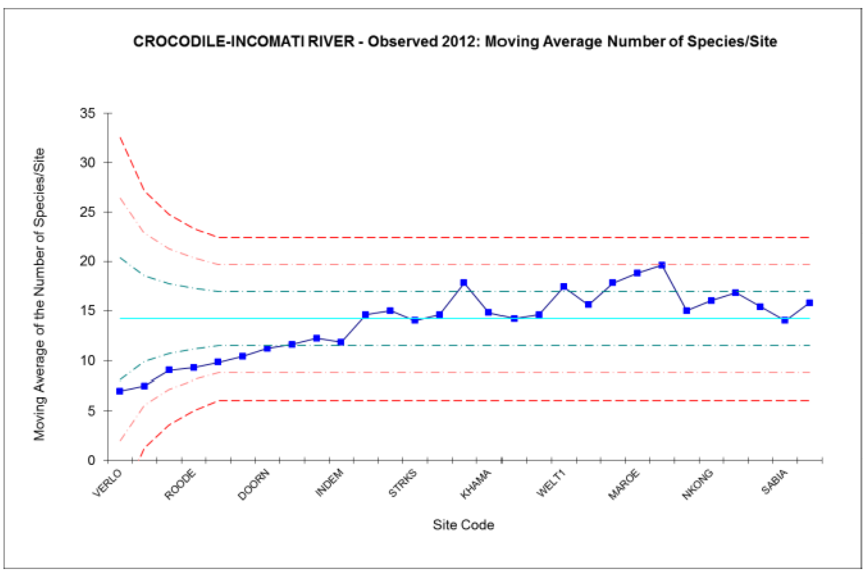
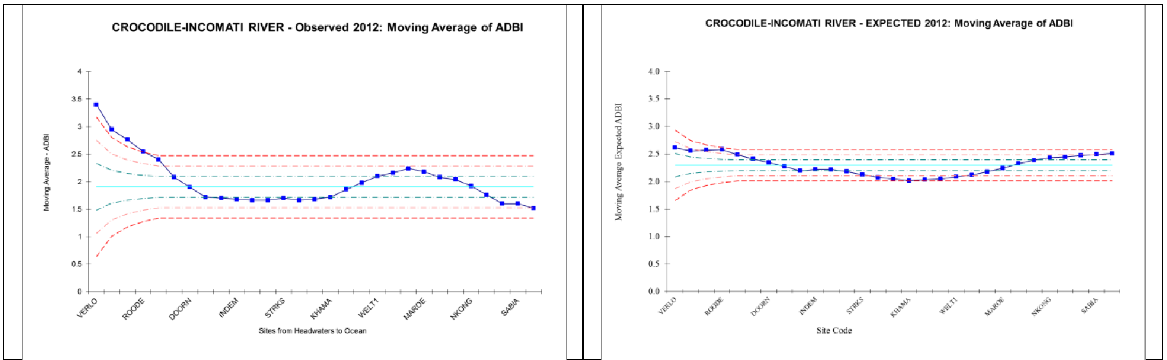



**Figure 14:** The moving average of the number of species recorded per site from Verlorenvalei (headwaters) to Lake Chuale (coastal floodplains). The central light blue line represents the average of the number of species recorded at all the sites (14.7), while the dotted blue line represents the moving average. The three dotted lines represent sigma -1, -2 and -3 respectively.

The moving average of the species diversity (species richness) on a longitudinal scale indicated the lowest diversity at the headwaters, increasing steadily from Montrose Falls onwards reaching its peak at sites bordering the Kruger National Park, and decreasing considerably from the Tenbosch Weir towards the coastal zone.

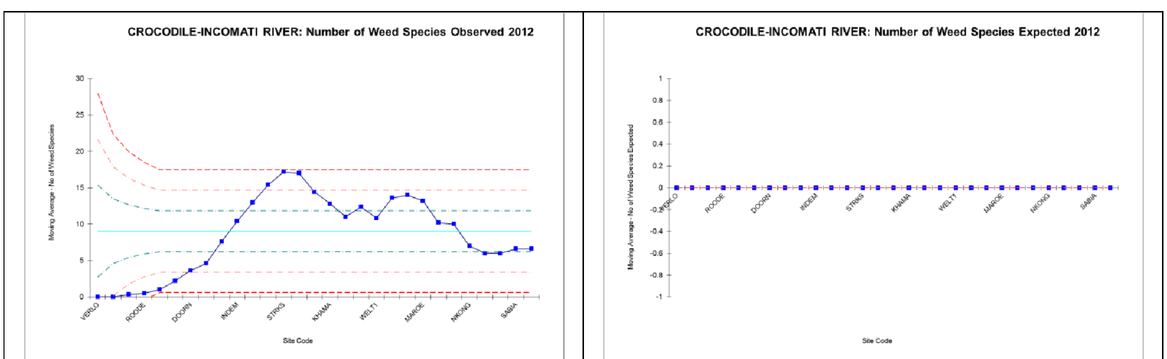



| Observed | Expected |
|---|---|

**Figure 15:** The moving average of the Average DBI (ADBI) score for sites from Verlorenvalei (headwaters) to Lake Chuale (coastal floodplains). The central light blue line represents the average of the number of species recorded at all the sites (1.9), while the dotted blue line represents the moving average. The three dotted lines represent sigma -1, -2 and -3 respectively.

The moving average ADBI provides an indication of the dominance and presence of species with relatively high DBI scores. Sensitive species dominate the headwaters, with a rapid decline towards Nelspruit and downstream from Nelspruit, increasing from The Crocodile Gorge towards the Kruger National Park, diminishing again towards the coastal zone.

The expected species indicates the dominance of sensitive species in the headwaters and coastal zones, with lower values in the middle reaches.




| Observed | Expected |
|---|---|

**Figure 16:** The moving average of exotic weed species observed per sampling point (left) to the species expected to occur.

Weed species diversity increases rapidly below the Donkerhoek Falls, peaking above Nelspruit with a slight decrease in species diversity downstream from Nelspruit.

Under natural conditions no invasive weed species are expected to occur, explaining the straight line illustrated in the graph on the right.

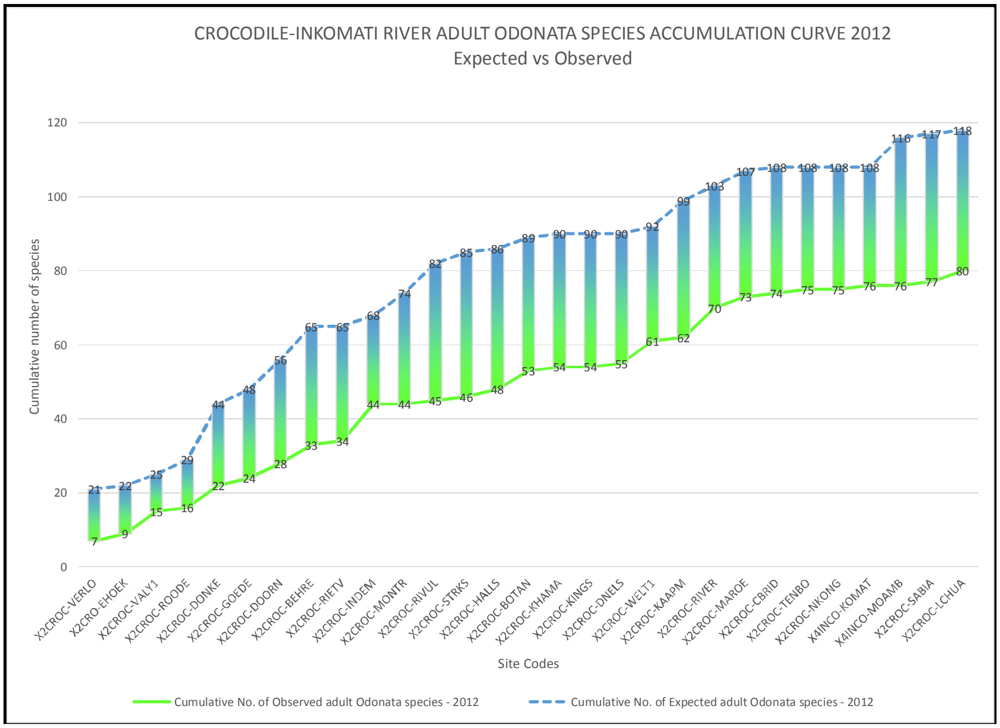



**Figure 17:** An illustration of the cumulative increase in species numbers per sampling point from headwaters to ocean of those species expected (blue) to occur against those observed (green). A total of 80 species were observed and 118 species were expected.

The expected species curve (Figure 17) indicates increases in species diversity between some sampling points which can be linked to bio-geographical changes in the landscape. Higher species richness at waterfalls could be attributed to rapid elevation changes and increased biotope diversity, especially where tributaries meet (e.g. Botanical Gardens). Sites where increased species richness were expected are:

- Roodewal and Donkerhoek: The Donkerhoek Waterfall is located between the two sites, from the upper reaches in the Steenkampsberg to the floodplains above Kwena Dam;
- Goedehoop to Behrens: The Goedehoop site (grassland dominated) is located upstream from the Kwena Dam and with the river below the dam regulated. The riparian vegetation below the dam is dominated by woody species and large portions of the river is shaded;
- Die Rots to Sterkspruit: These sites are located above and below the Montrose Falls;
- Crocodile Gorge ï Maroela: From the Crocodile gorge into the Lowveld;
- Komati-Crocodile Confluence ï Lake Chuali: River flows into the Inkomati Floodplains after leaving Komatipoort.

The observed species accumulation roughly follows this trend, with notable increases at the Donkerhoek, Die Rots, the Crocodile Gorge and Malelane sites.

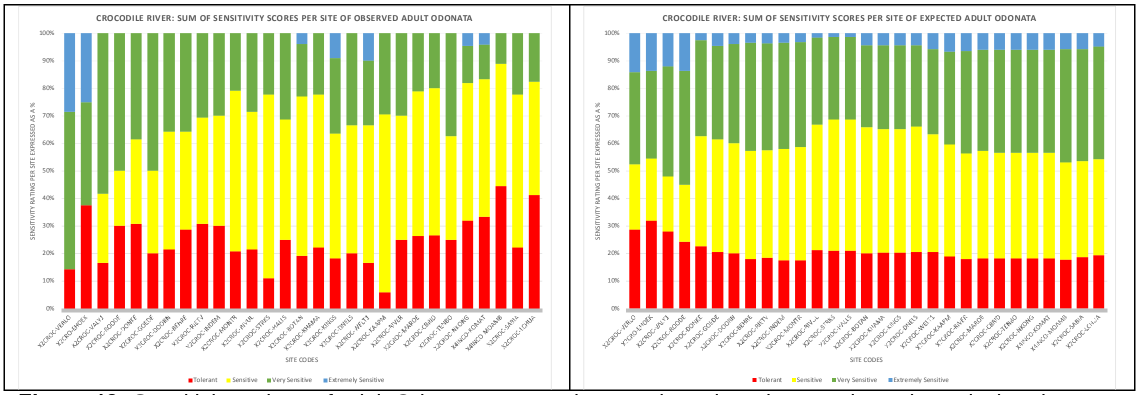



**Figure 18:** Sensitivity ratings of adult Odonata per species per site to invasive weed species calculated per sampling station. Odonata species observed are illustrated on the left and species expected on the right.

The DBI incorporates the sensitivity of a species to habitat changes, mainly in terms of exotic plant infestations. Expected species indicate a dominance of species sensitive to weed infestation at sites within the grassland vegetation types, decreasing slightly in the middle reaches and then increasing slightly towards the coastal plains. Observed species indicate a dominance at the sites located in the grassland dominated headwaters with a steady decline towards the coastal plains.

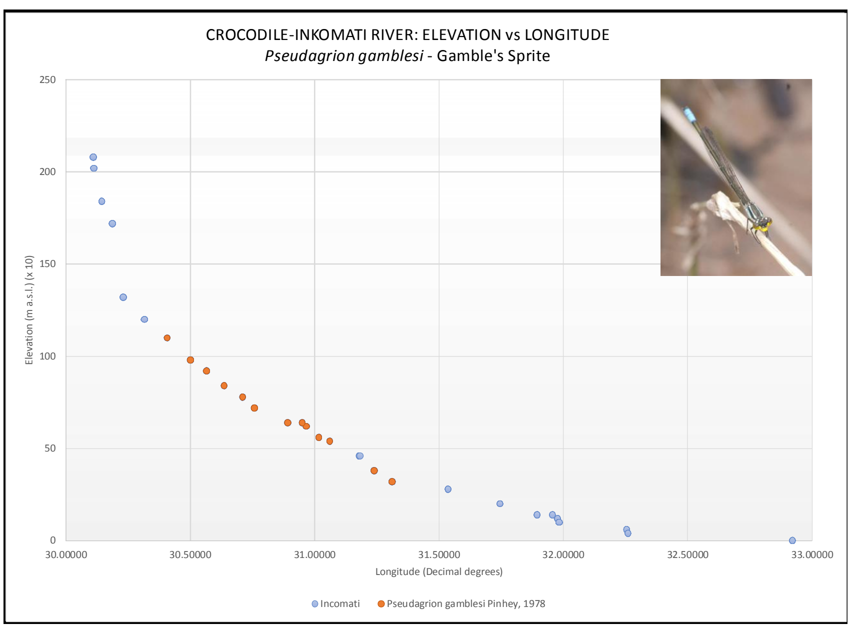



**Figure 19:** The sites sampled (blue) were plotted based on elevation and longitude, which roughly represents the river gradient. Sites at which the species *Pseudagrion gamblesi* were noted, are indicated as orange dots.

The species was only recorded at sites sampled on the Crocodile main stem within a specific stretch of the river. The environmental variables required for the success of the species are contained within these boundaries, and alterations could result in a shift in species distribution. Similarly there were species only restricted to the headwaters or coastal plains.

South African endemic species are restricted to the upper reaches of the river, further highlighting the important contribution of headwater streams to the countriesô endemic biodiversity (Figure 20).

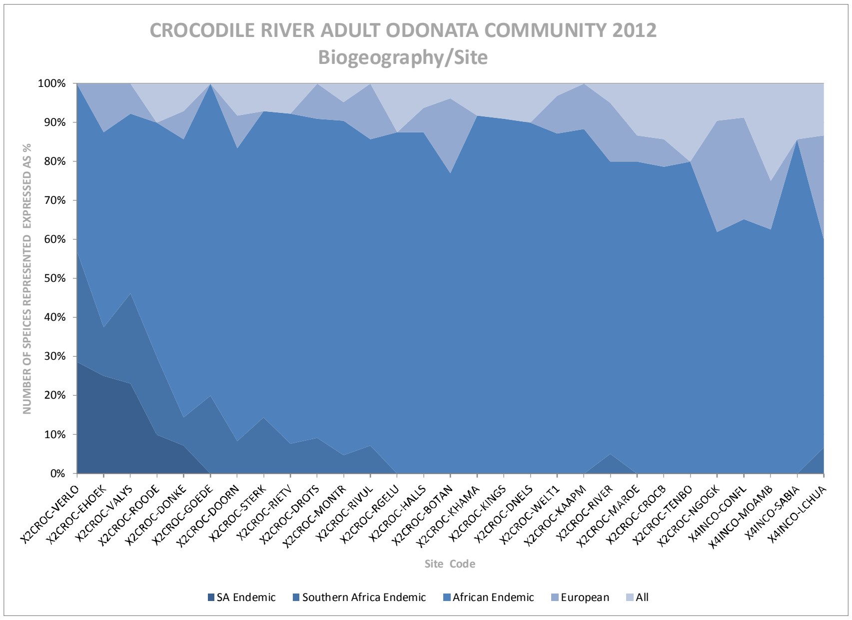



**Figure 20:** An illustration of the community composition per sampling point from headwaters to ocean, focusing on the bio-geographical status of each species.

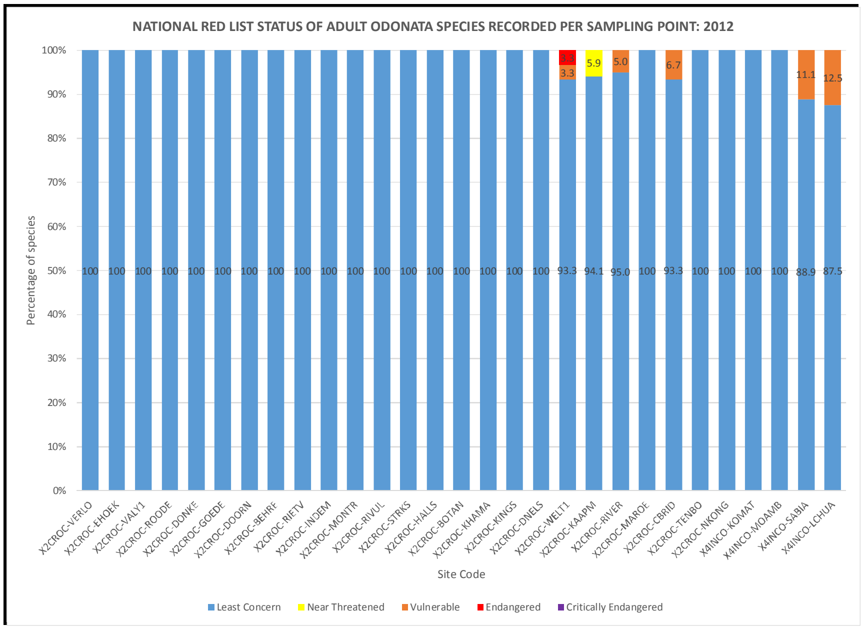



**Figure 21:** The occurrence and composition of adult Odonata species at sites sampled on the Crocodile-Inkomati River in 2012, based on their national red list status.

In the sampled areas most odonate species are listed as Least Concern (LC). However, several species are on the National Red List, categorised as Near Threatened (NT), Vulnerable (VU) and Endangered (EN). Threatened species were recorded at the following sites:

- Crocodile Gorge ï VU & EN;
- Kaapmuiden ï NT;
- Malelane ï VU;
- Crocodile Bridgeï VU;
- Sabia ï VU, and;
- Lake Chuali ï VU.

As shown in Figure 21(above), these Red Listed species were in encountered in the lowland floodplain of the river. This is in contrast to the range-restricted endemic species, which were found only in the headwaters. These findings highlight the fact that patterns of endemism and threat are not congruent along the river continuum.

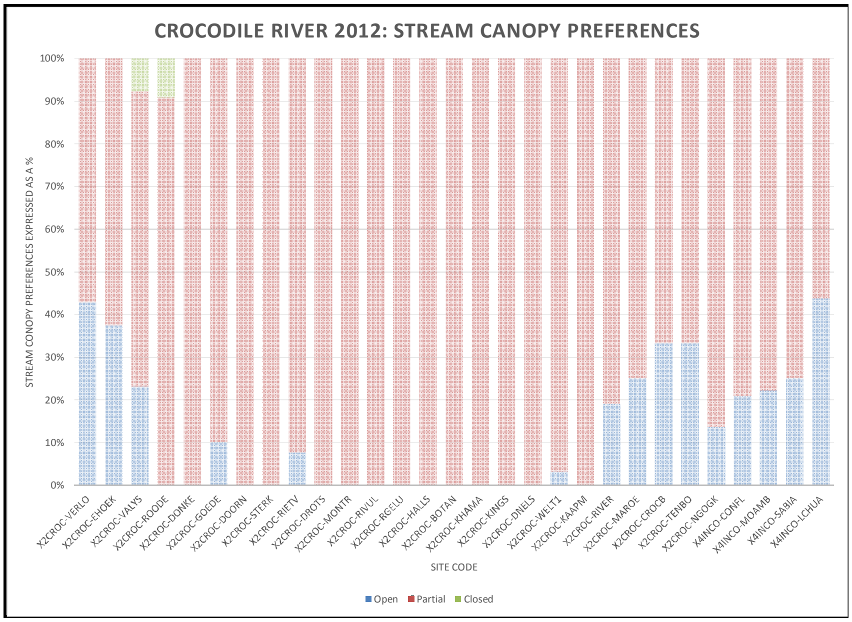



**Figure 22:** A graphical illustration of adult Odonata species distribution based on preferences for open, partially open and closed stream canopies.

Species encountered at each sampling point with preferences for open and closed stream canopies were summarised. Species preferring open stream canopies (grasslands) dominate the headwaters and the lower longitudinal areas of the Crocodile River, and are absent from the middle reaches.

## 3.2 RIPARIAN ZONE

Anthropogenic riparian disturbances are listed per sampling site, with the degree of weed infestation and status of the stream canopy also indicated. Overall, riparian zone disturbance increases longitudinally from the Highveld Mountains towards the Lowveld.

The riparian zones in the upper reaches of the catchment generally have low invasive plant infestations, with relatively undisturbed terrestrial habitats stretching far beyond 200 meters from the edge of the water. The upper catchment is, however characterised by many trout dams and weirs on the main river channel and tributaries. A total of 400 dams and weirs were counted in quaternary catchment X21A, which is the upper catchment of the Crocodile River from Verloren Vallei to the Donkerhoek Waterfalls (Steenkampsberg).

Downstream from the Steenkampsberg, agricultural land-use increases, with livestock grazing and vegetable farming above the Kwena Dam. Agricultural crops are planted to the edge of the river, less than 5 m from the bank in several areas. Pesticides and fertilisers are applied to many of these crops, which further increases pressure on the receiving aquatic ecosystems.

The Kwena Dam further influences the physical and chemical characteristics of the water and riparian vegetation, with a significant increase in woody plant species downstream from the dam. Agricultural activities intensify further downstream from the dam, peaking in the Schoemanskloof Valley. For most of the river reach, large areas are cultivated to the edge of the Crocodile River. Pesticide applications have also been noted in this area, but not during the time of the assessment.

High intensity crop farming is also characteristic downstream from Montrose Falls towards the Kruger National Park. The portion of the Crocodile River forming the Kruger National Park boundary is characterised by large natural riparian and terrestrial buffer zones on the Kruger National Park side (left stream bank facing downstream) and intensive agricultural crops (mostly sugarcane) on the right bank.

In Mozambique, agricultural activities are intensifying, with large portions of the floodplain already drained by man-made channels. During the site visits in 2013, subsistence farming was still the most dominant activity in riparian zones.

**Table 4:** The distance before anthropogenic disturbance of the riparian zone measured (on Google Earth) at five transects perpendicular to the river, 20 m apart on each stream bank in the area surveyed. The LSB represents the left stream bank facing downstream, and the RSB the right. Degree of weed infestation was estimated using Table 2 as a guideline. Stream canopy cover was categorised as open, partially open-closed, and closed.

| SITE CODE | RIPARIAN ZONE DISTURBANCE (m) | | DEGREE OF WEEDS | STREAM CANOPY | | | NOTES |
|---|---|---|---|---|---|---|---|
| | LSB | RSB | (%) | Open | Part | Closed | |
| VERLO | >200 | >200 | <10% | x | | | In Verloren Vallei Nature Reserve |
| EHOEK | >200 | >200 | <10% | x | | | Trout dams in vicinity (up- and downstream) |
| VALY1 | >200 | 55 - >200 | <10% | x | | | Trout dams in vicinity (up- and downstream) |
| ROODE | >200 | >200 | <10% | x | | | 400 dams & weirs in upper catchment |
| DONKE | >200 | 50 ï 195 | 10 ï 20% | | x | | Downstream from waterfall |
| GOEDE | 5 - 185 | 10 ï 60 | 20 ï 40% | x | | | Irrigated crops in upper catchment |
| DOORN | >200 | >200 | 20 ï 40% | | | x | Woody plants dominant below dam |
| BEHRE | 5 - >200 | 20 - >200 | 60 ï 80% | | | x | Woody plants dominant |
| RIETV | 10 ï 35 | 100 - >200 | 40 ï 60% | | x | | Crops in riparian zone & beyond |
| INDEM | 10 -45 | 95 ï 175 | 40 ï 60% | | x | | Crops planted to edge of river |
| MONTR | >200 | 20 ï 130 | 60 ï 80% | | x | | Upstream from waterfall |
| RIVUL | 20 ï 55 | >200 | 60 ï 80% | | x | | Intensive vegetable farming |
| STRKS | 60 ï 133 | 65 - >200 | 60 ï 80% | | x | | Vegetation clearing for housing/plots |
| HALLS | 55 ï 85 | 20 ï 55 | 40 ï 60% | | x | | Crops |
| BOTAN | 35 - >200 | >200 | 40 ï 60% | | x | | National gardens |
| KHAMA | 125 ï 165 | 45 - >200 | 40 ï 60% | | x | | Close to urban area |
| KINGS | 50 - 150 | 50 - >200 | 60 ï 80% | | x | | Agricultural crops (citrus) |
| DNELS | 45 ï >200 | >200 | 40 ï 60% | | x | | High quantities of domestic waste |
| WELT1 | >200 | >200 | 20 ï 40% | | x | | Water hyacinth in pool areas |
| KAAPM | 115 - >200 | 90 - >200 | 40 ï 60% | | x | | Subsistence farming & citrus crops |
| RIVER | >200 | 60 - >200 | 40 ï 60% | | x | | Tourism development |
| MAROE | >200 | >200 | 40 ï 60% | | x | | Private & National Park |
| CRBRID | 75 - >200 | 60 - >200 | 40 ï 60% | | x | | Agriculture & National Park |
| TENBO | >200 | 65 - >200 | 40 ï 60% | | x | | Agriculture & National Park |
| NKONG | >200 | >200 | 40 ï 60% | | x | | Agriculture & National Park |
| KOMAT | >200 | >200 | 40 ï 60% | | x | | Downstream from Komatipoort |
| MOAMB | >200 | >200 | 20 ï 40% | x | | | Car-Truck wash point |
| SABIA | 30 - 50 | >200 | 40 ï 60% | | x | | Densely vegetated (thickets) at edges |
| LCHUA | 5 - 70 | 10 - 90 | 40 ï 60% | x | | | Subsistence farming in floodplains |

Weed species recognised were recorded per site and summarised per vegetation type. The invasive weed species at the Crocodile Gorge site (WELT1) was mainly restricted to water hyacinth covering pool areas. The riparian vegetation itself was relatively weed free.

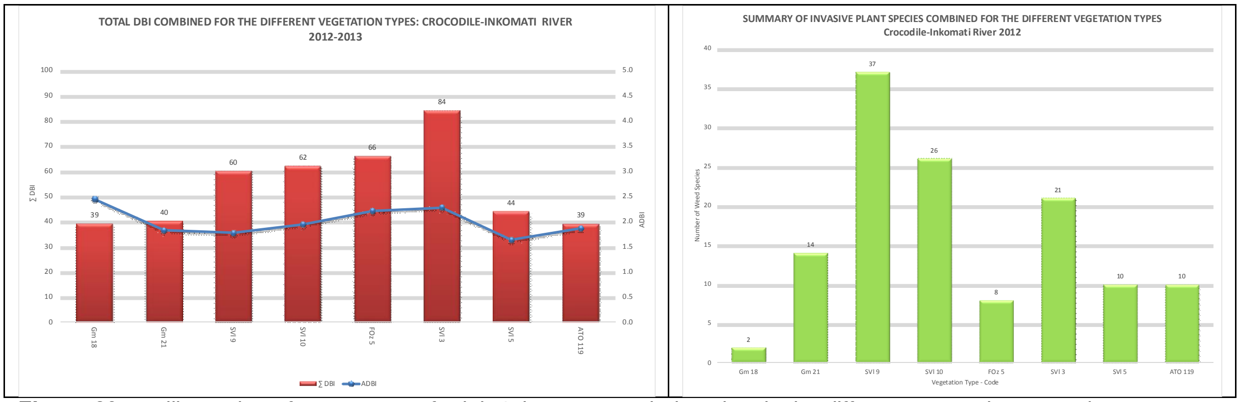



**Figure 23:** An illustration of a summary of adult Odonata recorded at sites in the different vegetation types (on the left) and the number of invasive plant species (on the right) listed from headwaters to ocean.

In Figure 23 the highest invasive plant species distribution (on right) coincides with a low Average DBI (on the left). The Forest Scrub vegetation type (FOz 5) is represented by only one site in the Crocodile Gorge and SVl 5 and ATO 119 by two and three sites respectively.

The summary of the total DBI of recorded adult Odonata (graph on left) follows the trend expected based on the River Continuum Concept (Figure 3). Based on the graph, the headwaters (Gm 18) stand out as an area with the highest ADBI and the Granite Lowveld (SVl 3) as the area with the highest diversity. The lowest diversity and ADBI were recorded at vegetation type SVl 5.

The highest diversity of invasive weed species was recorded in order of magnitude as follows: Lebombo Sour Bushveld (SVl 9), the Pretoriuskop Sour Bushveld (SVl 10) and the Granite Lowveld (SVl 3). The lowest diversity and abundance of invasive weeds was recorded in the Lydenburg Montane Grassland (Gm 18).

The graph that follows below (Figure 24) illustrates the weed species present in the different vegetation types, highlighting which weed species were most frequently recorded at sites.

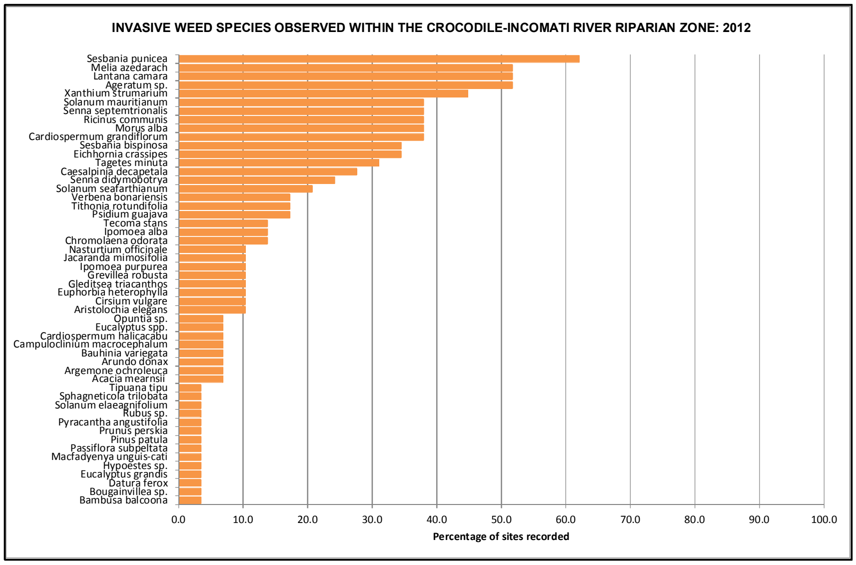



**Figure 24:** Invasive plant species observed in 2012 within the riparian zones of sites sampled along the Crocodile-Inkomati River main stem. Abundances of each species are not reflected in these graphs.

The weed species *Sesbania punicea* was the most dominant, present at 62% of the 29 sites visited, followed by *Melia azedarach*, *Lantana camara* and *Ageratus* species.

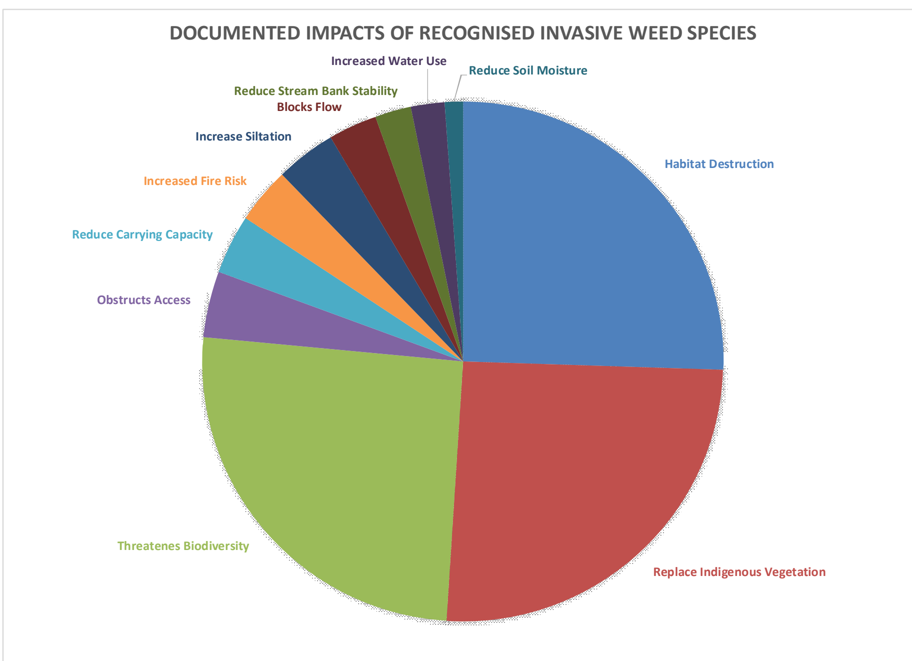



**Figure 25:** A graphical summary of the documented impacts listed per species recorded in the riparian zone of the Crocodile River in 2012. The graph illustrates impacts based on species present, but does not incorporate the abundance of each species at a site.

The major threats from invasive weed species recorded at the majority of the selected sampling sites were habitat destruction, replacing indigenous vegetation and threatening biodiversity (Figure 25).

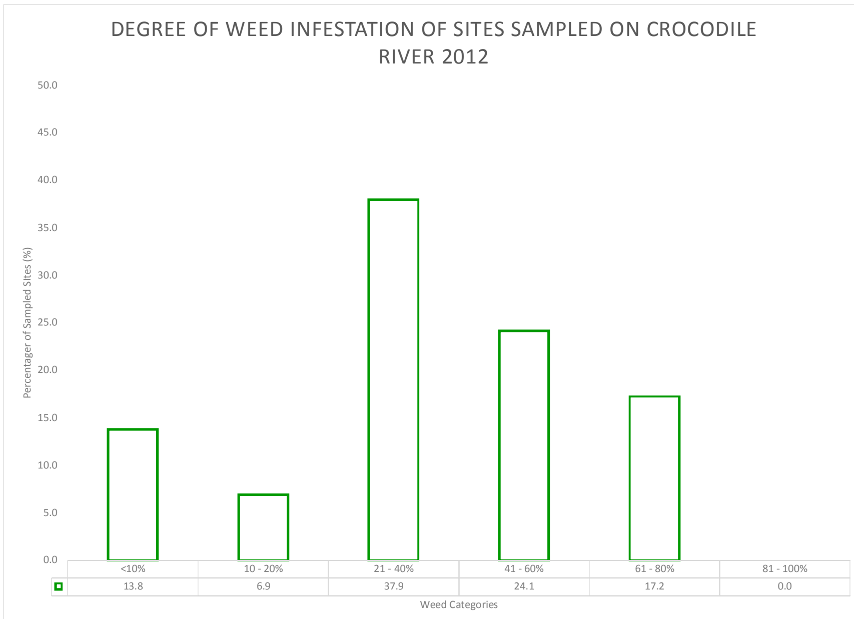



**Figure 26:** The degree of weed infestation estimated at the 29 sampling points along the Crocodile-Inkomati River from November 2012 to January 2013.

The degree of weed infestation of the riparian zone of the Crocodile-Inkomati River was estimated at between 21 - 80% at approximately 80% of the 29 sampling points visited.

## 4. DISCUSSION

This assessment of adult Odonata along the longitudinal gradient of the Crocodile-Inkomati River is the first documented assessment of the Crocodile River in South Africa. The information gathered is therefore valuable baseline data against which future monitoring can be compared.

Overall, the headwaters (Verlorenvalei to Valyspruit) appears to be in good condition, with endemic species dominant (Figure 20). This is linked to low land-use pressures and very low invasions of riparian zones by alien plant species. The relationship of adult Odonata and undisturbed indigenous riparian zones has been well documented(Clark & Samways 1996; Harrison et al. 1999; Kutcher 2011; Magoba & Samways 2010; Remsburg et al. 2008; Samways & Taylor 2004). Large portions of the terrestrial landscape in the headwater zone are natural and intact.The species composition in the headwaters is characterised by a low species diversity (Figure 14) with high numbers of endemics (Figure 22), which is a typical trend in headwater streams (Davies et al. 1993; Davies & Day 1998).

Species richness increased towards lower elevations, which is attributed to the longitudinal change towards subtropical to tropical habitat types. The decrease in ADBI despite of the increase in species richness, is attributed to the predominance of warm-adapted afrotopical fauna at the lower elevations. Most of these afrotropical fauna are more tolerant to habitat changes. Exceptions are some of the nationally threatened species, e.g. *Pseudagrion sjoestedti*, *Lestinogomphus angustus*, *Gomphidia quarrei* and *Neurogomphus zambeziensis.*

Most adult Odonata species were recorded in very specific zones along the longitudinal gradient (Figure 19). This is also illustrated in summaries of the species recorded at sites within each aquatic ecoregion (Figures 5 ï 11). This positioning of species along the longitudinal river gradient serves as excellent benchmarks for future monitoring.

Increases in land-use and the invasion of exotic plant species further reduce the ADBI. With crops in most areas along the river planted very close to the rivers edge, the natural buffering capacity of the riparian vegetation is greatly reduced. The application of agricultural chemicals (e.g. pesticides, herbicides, fertlisers, etc.) was noted at some sites where crops were located close to the rivers edge. Pesticides have been identified as a major source of water pollution, with devestating effects on stream and terrestrial fauna (Muirhead-Thomson 2009; Dabrowski et al. 2002). Contamination of water resources and aquatic and terresrtial ecosystems in poorly managed agricultural areas are inevitable.In studies on the application of pesticides, it was found that less than 0.1% of the pesticides applied reached target species (Pimental & Levitan 1986; Pimentel 1995). Due to the cost of pesticides, it is likely that application methods and equipment has improved since the 1986 and 1995 studies, but drift and run-off remains a concern. Adult Odonata are very successful aerial predators, and will be directly affected by pesticide applications, the females and young males in terrestrial areas adjacent riparian zones, and the males and ovipositing females at the waters edge and riparian zone.

Adult Odonata species are generally sensitive to riparian vegetation type. Invasive plant species in riparian zones reduce and alter structural diversity, competes for light and space, and supress indigenous vegetation to the detriment of indigenous fauna and flora (Bromilow 2010; Chamier et al. 2012; Magoba & Samways 2010; Samways & Taylor 2004; Samways & Sharratt2010). The low diversity of adult Odonata downstream from Kwena Dam to upstream of Crocodile Gorge is attributed to the high infestation of invasive plants, and structural changes in the riparian vegetation due to hydrological changes in flow.

Low Total DBIĝs were recorded at sites;

- Roodewal;
- Goedehoop;
- Die Rots;
- Sterkspruit;
- Kamagugu;
- Tenbosch Weir;
- Moamba, and;
- Sabia.

Characteristic features of these sites were:

- Agricultural crops where the application of pesticides have been recorded (all sites listed above with the exception of Roodewal);
- High weed infestation of the riparian zone within a few meters of the river's edge (Die Rots, Sterkspruit, Khamagugu and Sabia), and;
- A high number of small farm dams (400) in quaternary catchment X21A could alter the water temperature, which in turn could affect the hatching of eggs and emergence (Dallas 2008) at the Roodewal site.

As expected, high adult Odonata species diversity (>24) was recorded at sites with a variety of biotopes. These were Montrose, Botanical Gardens, Crocodile Gorge, Malelane and Komatipoort. Of these five sites, two are associated with waterfalls and four located where major tributaries enter the main channel. The Crocodile Gorge is the only site not associated with either a waterfall or confluence. Waterfalls and where tributaries merge are generally recognised as diversity hotspots. Kiffney et al. (2006) highligted fish species diversity hotspots where rivers and tributaries met during a study in the foothill streams of the Cascade Range mountains, USA. Their results suggets that "some tributary streams have fundamental effects on the larger rivers they enter". It follows that the diversity of adult Odonata would also be high where there is a rapid change in habitat complexity, e.g. structural, nutrient concentrations, flow regimes, velocity, water temperature and more.

Higher taxa diversity could be expected in the Mozambique floodplains, linked to increased habitat diversity and availability. The low diversity recorded is most likely linked to the size and vastness of the floodplain and survey limited to one hour only. More species would be encountered if all the microhabitats (e.g. oxbows, permanent and seasonal pans, seeps) are visited.

An important message from this report is the concept of species replacement (i.e. change in beta diversity). The headwater communities are completely different from those in the floodplains, with endemics at the headwaters, and threatened species in the lower reaches. Thus, all stretches of the river contribute greatly to biodiversity. This stresses the importance of assessing entire catchments from the headwater to the lowland floodplains.

## 5. RECOMMENDATIONS

The main threats to biodiversity along the Crocodile-Inkomati River recorded during the 2012-2013 adult Odonata survey include:

- Agricultural crops planted very close to the river's edge: This includes the Goedgeloof site, citrus crops in the Schoemanskloof area, citrus and tobacco areas upstream and downstream from Nelspruit, and areas along the river across from the Kruger National Park.

- Pesticide spraying of crops: This was recorded in the Goedgeloof area, and evidence of aerial spraying in the vicinity of the Tenbosch Weir site opposite the Kruger National Park according to Van Wyk, pers. comm.[6];
- Alien weed infestation of riparian zones: Most of the riparian zones were severely infested with alien invasive weed species. The majority of the weed species recorded threaten biodiversity in terms of outcompeting and replacing indigenous vegetation. The weeds also have the potential to alter the vegetation structure and composition. In a study on the management of riparian zones, Everson et al. (2007) indicated that the effective management of riparian zones and their natural vegetation significantly reduce catchment management costs and enable greater productivity of land resources;
- Impoundments: The numerous dams in the catchment are responsible for regulating river flow, altering water temperatures, and changing the composition and structure of the riparian vegetation. In addition to the large Kwena dam, there are an additional 400 small farm-trout dams in the upper catchment of the Crocodile River, which further regulate flow and increase water temperatures of the receiving river;
- Vegetation succession: Terrestrial areas previously characterised as grasslands or open woodland, are slowly succeeding to closed woodlands for various reasons (beyond the scope of this survey). Since Odonata are dependent on vegetation structure and composition any change in vegetation will influence the community.

Based on the threats recorded, the following recommendations are made:

- **Land-use Management Plans:**
  - Develop and implement management plans, in which all natural ecosystems are identified and protected;
  - Restrict development and/or the planting of crops in riparian zones. Riparian zones are hotspots in terms of biodiversity, and an important link between terrestrial and aquatic ecosystems.
  - Rehabilitate existing wetland and riparian areas to protect water resources;
  - Maintain natural vegetated corridors between crops to sustain predators (e.g., insectivorous birds and predaceous insects);
  - Implement efficient and successful weed control programmes, which are aimed at the eradication of invasive weed species through regular follow-ups.
  - Reduce agricultural chemical use (e.g. pesticides, herbicides & fertilisers), through applying good farming practices (e.g. healthy soils). Aerial spraying should be prohibited.
  - Disseminate information on the important functions of indigenous and well managed riparian vegetation, buffer zones and aquatic habitats to the land-users.
- **Pesticide Applications:**
  - The ICMA and Kruger National Park should be notified of any pesticide applications of crops bordering sensitive aquatic ecosystems, and;
  - The use of pesticides should be minimised through applying best management farming practices (e.g. healthy soils, planting crop varieties suitable to the area).
- **Farm and Trout Dams:**

[6]Mr Neels van Wyk, Section Ranger Crocodile Bridge, Kruger National Park, 30 January 2013.

  - Initiate research to determine the influence of the high number of trout dams on water temperature and the indigenous aquatic biota dependant in the headwaters of critically important aquatic ecosystems, in order to make informed decisions about reducing impacts.
- **Areas of high conservation value:**
  - Incorporate Odonata into the Mpumalanga Biodiversity Conservation Plan (MBCP) in order to improve the knowledge base of areas critical to the conservation of biodiversity.

**Use of the DBI**

The main purpose of this study was to test the DBI as an indicator of river health. The DBI is a species based indicator. Any species information is invaluable as a long-term monitoring indicator, since the distribution of species with specific environmental requirements (Figure 19) provides a future benchmark for monitoring change. Because the DBI provides species data, any appearance or disappearance of species can be quantified and related to environmental changes or shifts.

Disturbances in the riparian zone and their buffers in terms of invasive plants, anthropogenic activities, and the application of pesticides were highlighted as problems using the DBI. The link of Odonata with riparian vegetation, terrestrial and aquatic habitats provides an insight into impacts not highlighted by other indices.

Limitations with the application of the method were as follows:

- Field data collection were restricted to sunny days within the main flight period of most adult Odonata species ranging from November to March. High rainfall experienced from November through to December restricted sampling to one visit per site compared to the two site visits as suggested in the method;
- There is a need to incorporate a habitat rating, focusing on recording Odonata habitat and micro-habitat diversity. This habitat assessment will provide a platform for correlating species composition and diversity within the vegetation type or aquatic ecoregion they occupy, and;
- Application of the index in the catchment (not only main stem) would also focus more attention on the importance of tributaries. It would also provide a larger data set for interrogation. More long-term data on Odonata species are required. The larger the data set the more confidence in the interpretation.

**Approach**

For practical and time management purposes, sampling should start at the lowlands and move upward towards the headwater zone. This would mean that sampling can take place earlier in the active flight season, providing a larger time-frame for field work. It rains more regularly in the headwaters than in the lowlands.

A more comprehensive vegetation survey is required, in order to interrogate vegetation structure, composition, percentage shading of the river, and weed species distribution in the riparian zone.

## 6. REFERENCES


Allan, J. D. (2004). Landscapes and Riverscapes: The Influence of Land-use on Stream Ecosystems. *Annual Review of Ecological and Evolutionary Systems, 35*, 257-284.

Barbour, M. T., Gerritsen, J., Snyder, B. D., & Stribling, J. B. (1999). *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition*. Washington, D.C., Office of Water, U.S. Environmental Protection Agency: EPA 841-B-99-002.

Bonanno, G., & Lo Giudice, R. (2010). Heavy metal bioaccumulation by the organs of Phragmites australis (common reed) and their potential use as contamination indicators. *Ecological Indicators, 10*(3), 639-645.

Bromilow, C. (2010). *Problem Plants and Alien Weeds of South Africa* (3rd ed.). (E. du Plessis, Ed.) Pretoria, Gauteng, South Africa: BRIZA Publications.

Chamier, J., Schachtschneider, I. C., Le Maitre, D. C., Ashton, P. V., & Van Wilgen, B. W. (2012). Impacts of invasive alien plants on water quality, with particular emphasis on South Africa. *Water SA, 38*(2), 345-356.

Chovanec, A., & Waringer, J. (2001). Ecological integrity of river-floodplain systems - Assessment by Dragonfly surveys (Insecta: Odonata). *Regulated Rivers: Research and Management, 17*, 493-507.

Clark, T. E., & Samways, M. J. (1996). Dragonflies (Odonata) as Indicators of Biotope Quality in the Kruger National Park, South Africa. *Journal of Applied Ecology, 33*(5), 1001-1012.

Cummins, K. W., Merritt, R. W., & Berg, M. B. (2008). Ecology and distribution of aquatic insects. In R. W. Merrit, K. W. Cummins, & M. B. Berg (Eds.), *An Introduction to the Aquatic Insects of North America* (4th Edition ed., pp. 105-122). Dubuque, Iowa, United States: Kendall/Hunt Publishing Company.

Dabrowski, J. M., Peall, S. K., Reinecke, A. J., Leiss, M., & Schultz, R. (2002). Run-off related pesticide input into the Lourens River, South Africa: Basic data for exposure assessment and risk mitigation at the catchment scale. *Water, Air and Soil Pollution, 135*(1-4), 265-283.

Dallas, H. (2008, July). Water temperature and riverine ecosystems: An overview of knowledge and approaches for assessing biotic responses, with special reference to South Africa. *Water SA, 34*(3), 393-404.

Dallas, H. F. (2005). *River Health Programme: Site Characterisation Field-Manual and Field Data Sheets.* Resource Water Quality Services, Department of Water Affairs and Forestry. Pretoria: Department of Water Affairs & Forestry, Resource Quality Services.

Davies, B. R., O'Keeffe, J. H., & Snaddon, C. D. (1993). *A Synthesis of the Ecological Functioning, Conservation and Management of South African River Ecosystems.* WRC Report No. TT 62/93. Pretoria: Water Research Commission.

Davies, B., & Day, J. (1998). *Vanishing Waters.* Cape Town, South Africa: UCT Press.

Dudgeon, D., Arthingon, A. H., Gessner, M. O., Kawabata, Z., Knowler, D. J., Levceque, C., . . . Sullivan, C. A. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews, 18*(2), 163-182.

Everson, C., Gush, M., Moodley, M., Jarmain, C., Govender, M., & Dye, P. J. (2007). *Effective management of the riparian zone vegetation to significantly reduce the cost of catchment management and enable greater productivity of land resources.* WRC Report No. 1284/1/07. Water Research Commission.

Foote, A. L., & Hornung, C. L. (2005, June). Odonates as biological indicators of grazing effects on Canadian prairy wertlands. *Ecological Entomology, 30*(3), 273-283.

Hawking, J. H., & New, T. R. (2002). Interpreting dragonfly diversity to aid in conservation assessment: lessons from the Odonata assemblage at Middle Creek, north-eastern Victoria, Australia. *Journal of Insect Conservation, 6*, 171-178.

Hornung, J. P., & Rice, C. L. (2003). Odonata and wetland quality in southern Alberta, Canada: A prliminary study. *Odonatologia, 32*(2), 119-129.

Hughes, D. A. (2000). *River Health Programme: Aquatic Biomonitoring - Hydrology.* Resource Water Quality Services, Department of Water Affairs and Forestry. Pretoria: RHP Report Series No. 14.

Kiffney, P. M., Greene, C. M., Hall, J. E., & Davies, J. R. (2006). Tributary streams create spatial discontinuities in habitat, biological productivity, and diversity in mainstream rivers. *Candian Journal of Fisheries and Aquatic Sciences, 63*, 2518-2530.

Kleynhans, C. J. (2007). *Module D: Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2).* Water Research Commission, Department of Water Affairs and Forestry. Pretoria: WRC Report No. TT330/08.

Kleynhans, C. J., Louw, M. D., & Moolman, J. (2007). *Reference frequency of occurence of fish species in South Africa.* Water Research Commission, Department of Water Affairs and Forestry. Pretoria: WRC Report No. TT331/08.

Kleynhans, C. J., Mackenzie, J. A., & Louw, M. D. (2007). *Module F: Riparian Vegetation Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2).* Water Research Commission, Department of Water Affairs and Forestry. Pretoria: WRC Report No. TT 333/08.

Kleynhans, C. J., Thirion, C., & Moolman, J. (2005). *A Level I River Ecoregion Classification System for South Africa, Lesotho and Swaziland.* Resource Quality Services, Department of Water Affairs and Forestry. Pretoria: Report No. N/0000/00/REQ0104.

Kutcher, T. E. (2011). *Rhode Island DEM Freshwater Monitoring and Assessment, Year 5: Integrating Rapid Assessment with Biological and Landscape Indicators of Freshwater Wetland Condition.* Kingston: Rhodes Island Natural History Survey & US EPA.

Magoba, R. N., & Samways, M. J. (2010). Recovery of benthic macro-invertebrate and adult dragonfly assemblage in response to large scale removal of riparian invasive alien trees. *Journal of Insect Conservation, 14*(6), 627-636.

McPeek, M. A. (2010). Ecological factors limiting the distributions and abundances of Odonata. In A. Córdoba-Aguilar (Ed.), *Dragonflies and Damselflies: Model Organisms for Ecological and Evolutionary Research* (pp. 51-62). Oxford: Oxford University Press.

Metcalfe-Smith, J. L. (1996). Biological Water-quality Assessment of Rivers: Use of Macroinvertebate Communities. In G. Petts, & P. Calow (Eds.), *River Restoration* (pp. 17-43). Oxford, UK: Blackwell Science Ltd.

Mucina, L., & Rutherford, M. C. (Eds.). (2006). *The Vegetation of South Africa, Lesotho and Swaziland.* Pretoria, South Africa: South African National Biodiversity Institute, Strelitzia 19.

Muirhead-Thomson, R. C. (2009). *Pesticide impact on stream fauna with special reference to macroinvertebrates.* New York: Camebridge University Press.

Oertli, B. (2010). The use of dragonflies in the assessment and monitoring of aquatic habitats. In A. Córdoba-Aguilar (Ed.), *Dragonflies & Damselflies: Model Organisms for Ecological and Evolutionary Research* (pp. 79-95). Oxford: Oxford University Press.

Oppel, S. (2005). Habitat associations of an Odonata community in a lower montane rainforest in Papua New Guinea. *International Journal of Odonatology, 8*(2), 243-257.

Pimental, D., & Levitan, L. (1986). Pesticides: amounts applied and amounts reaching pests. *BioScience, 36*(2), 86-91.

Pimentel, D. (1995). Amounts of pesticides reaching target pests: Environmental impacts and ethics. *Journal of Agricultural and Environmental Ethics, 8*(1), 17-29.

Plafkin, J. L., Barbour, M. T., Porter, K. D., Gross, S. K., & Hughes, R. M. (1989). *Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish.* U.S. Environmental Protection Agency, Office of Water Regulations and Standards. Washington, D.C.: EPA 440-4-89-001.

Remsburg, A. J., Olson, A. C., & Samways, M. J. (2008). Shade Alone Reduces Adult Dragonfly (Odonata: Libellulidae) Abundance. *Journal on Insect Behaviour, 21*, 460-468.

Sahlén, G., & Ekestubbe, K. (2001). Identification of dragonflies (Odonata) as indicators of general species richness in boreal forest lakes. *Biodiversity and Conservation, 10*(5), 673-690.

Samways, M. J. (1999). Diversity and conservation status of South African dragonflies (Odonata). *Odonatologica, 28*(1), 13-62.

Samways, M. J., & Sharratt, N. J. (2010). Recovery of endemic dragonflies after removal of invasive alien trees. *Conservation Biology, 24*, 267-277.

Samways, M. J., & Steytler, N. S. (1996). Dragonfly (Odonata) distribution patterns in urban and forest landscapes, and recommendations for riparian management. *Biological Conservation, 78*(3), 279-288.

Samways, M. J., & Taylor, S. (2004). Impacts of invasive alien plants on Red-Listed South African dragonflies (Odonata). *South African Journal of Science, 100*, 78-80.

Samways, M. J., McGeoch, M. A., & New, T. R. (2010). *Insect Conservation: A Handbook of Approaches and Materials.* Oxford: Oxford University Press.

Schindler, M., Fesl, C., & Chovanec, A. (2003). Dragonfly associations (Insecta: Odonata) in relation to habitat variables: A multivariate approach. *Hydrobiologia, 497*(1-3), 169-180.

Simaika, J. P., & Samways, M. J. (2009a). An easy-to-use index of ecological integrity for prioritizing freshwater sites and for assessing habitat quality. *Biodiversity and Conservation, 18*(5), 1171-1185.

Simaika, J. P., & Samways, M. J. (2010). Valuing dragonflies as service providers. In A. Córdoba-Aguilar (Ed.), *Dragonflies & Damselflies: Model Organisms for Ecological and Evolutionary Research* (pp. 109-123). Oxford: Oxford University Press.

Simaika, J. P., & Samways, M. J. (2011). Comparative assessment of indices of freshwater habitat conditions using different invertebrate taxon sets. *Ecological Indicators, 11*(2), 370-378.

Simaika, J. P., & Samways, M. J. (2012). Advances in monitoring and prioritizing riverine habitats for conservation using biotic indices. *Organisms Diversity and Evolution*. Retrieved from http://dx.doi.org/10.1007/s13127-012-0104-4

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., & Cushing, C. E. (1980). The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Science, 37*(1), 130-137.

## **APPENDIX A:** LIST OF SPECIES RECORDED PER SAMPLING SITE

| FAM Sp. Code | VEGEGTATION TYPE | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ALL (DBI) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gm18 | | | | Gm21 | | | SVl9 | | | | | | | SVl10 | | | | FOz5 | SVl3 | | | | | SVl5 | | ATO725 | | ATO119 | |
| | Sites Numbers (Headwaters to Ocean) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | |
| Calopterygidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Phaon iridipennis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | **(2)** |
| Chlorocyphidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Platycypha caligata* | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(2)** |
| *P. fitzsimonsi* | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(4)** |
| Synlestidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Chlorolestes fasciatus* | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(4)** |
| Lestidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Lestes plagiatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(2)** |
| Platycnemididae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Mesocnemis singularis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| Protoneuridae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Elattoneura glauca* | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | **(1)** |
| Coenagrionidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Ceriagrion glabrum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | **(0)** |
| *Pseudagrion acaciae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | **(3)** |
| *P. caffrum* | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(5)** |
| *P. citricola* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *P. coeleste coeleste* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | **(4)** |
| *P. commoniae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | **(2)** |
| *P. gamblesi* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(4)** |
| *P. glaucescens* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **(1)** |
| *P. hageni tropicanum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(2)** |
| *P. hamoni* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | **(2)** |
| *P. kersteni* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(1)** |
| *P. massaicum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | **(1)** |
| *P. salisburyense* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(1)** |
| *P. sjoestedti* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(7)** |
| *P. spernatum* | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *P. sublacteum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | **(2)** |
| *P. sudanicum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | **(4)** |
| *Ischnura senegalensis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | **(0)** |
| *Africallagma glaucum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(1)** |
| *A. sapphirinum* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(4)** |

| **FAM Sp. Code** | **VEGEGTATION TYPE** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | **ALL (DBI)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Gm18** | | | | **Gm21** | | | **SVl9** | | | | | | | **SVl10** | | | | **FOz5** | **SVl3** | | | | | **SVl5** | | **ATO725** | | **ATO119** | |
| | **Sites Numbers (Headwaters to Ocean)** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | |
| *Azuragrion nigridorsum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *Agriocnemis gratiosa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **(5)** |
| Aeshnidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Zosteraeschna minuscula* | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(5)** |
| *Pinheyschna subpupillata* | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(4)** |
| *Anax imperator* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | **(1)** |
| *A. speratus* | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | **(2)** |
| Gomphidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Ictinogompus ferox* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | **(2)** |
| *Gomphidia quarrei* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(6)** |
| *Lestinogomphus angustus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(4)** |
| *Notogomphus praetorius* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(5)** |
| *Neurogomphus zambeziensis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(6)** |
| *Crenigomphus hartmanni* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *Ceratogomphus pictus* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(2)** |
| *Paragomphus cognatus* | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(1)** |
| *P. genei* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *P. sabicus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(4)** |
| Corduliidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Phyllomacromia contumax* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(2)** |
| *P. picta* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(2)** |
| Libellulidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Tetrathemis polleni* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *Notiothemis jonesi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *Orthetrum caffrum* | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *O. chrysostigma* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | **(2)** |
| *O. hintzi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *O. julia falsum* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(1)** |
| *O. machadoi* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *O. trinacria* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(1)** |
| *Nesciothemis farinosa* | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | **(1)** |
| *Palpopleura jucunda* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(2)** |
| *P. lucia* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(2)** |
| *P. portia* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | **(2)** |
| *Acisoma variegatum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **(2)** |
| *Diplacodes lefebvrii* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |
| *Crocothemis erythraea* | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | **(0)** |
| *C. sanguinolenta* | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(3)** |

| FAM Sp. Code | VEGEGTATION TYPE | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ALL (DBI) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gm18 | | | | Gm21 | | | SVl9 | | | | | | | SVl10 | | | | FOz5 | SVl3 | | | | | SVl5 | | ATO725 | | ATO119 | |
| | Sites Numbers (Headwaters to Ocean) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | |
| *Bradinopyga cornuta* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | **(5)** |
| *Brachythemis lacustris* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | **(3)** |
| *B. leucosticta* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | **(2)** |
| *Sympetrum fonscolombii* | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(0)** |
| *Trithemis annulata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | **(1)** |
| *T. arteriosa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | **(0)** |
| *T. donaldsoni* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(4)** |
| *T. dorsalis* | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(0)** |
| *T. furva* | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(0)** |
| *T. kirbyi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | **(0)** |
| *Zygonyx natalensis* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | **(2)** |
| *Z. torridus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | **(2)** |
| *Zygonoides fuelleborni* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | **(4)** |
| *Olpogastra lugubris* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | **(4)** |
| *Rhyothemis semihyalina* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(1)** |
| *Pantala flavescens* | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | **(0)** |
| *Tramea basilaris* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **(0)** |
| *T. limbata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | **(0)** |
| *Urothemis edwardsii* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **(2)** |

**APPENDIX B:** Reference to voucher specimens and DNA samples.

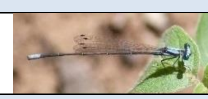
**Table B-1:** Records of specimens collected are listed with voucher numbers allocated to each specimen, with the site code and a code where DNA samples were collected. The number in brackets in the site code refers to numbers used for sites in Table A-1.

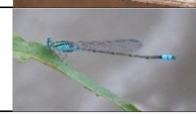
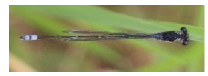
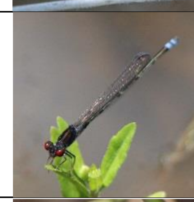
| DATE | SITE | SPECIES | VOUCHER NO. | DNA SAMPLE CODE |
|---|---|---|---|---|
| 18/11/2012 | X2CROC-EHOEK (2) | *Pseudagrion caffrum* | GDCROC12-019 | |
| | | *Pseudagrion spernatum* | GDCROC12-039 | |
| | | *Trithemis dorsalis* | GDCROC12-007 | |
| | | *Trithemis dorsalis* | GDCROC12-034 | DF12-016 |
| | | *Trithemis furva* | GDCROC12-024 | DF12-024 |
| 18/11/2012 | X2CROC-VERLO (1) | *Chlorolestes fasciatus* | GDCROC12-036 | DF12-009 |
| | | *Chlorolestes fasciatus* | GDCROC12-022 | PM11-A161 |
| | | *Pinheyschna subpupillata* | GDCROC12-013 | DF12-018 |
| | | *Pseudagrion caffrum* | GDCROC12-016 | PM11-A195 |
| | | *Pseudagrion caffrum* | GDCROC12-038 | PM11-A207 |
| | | *Pseudagrion caffrum* | GDCROC12-015 | PM11-A178 |
| | | *Pseudagrion spernatum* | GDCROC12-037 | PM11-A189 |
| | | *Pseudagrion spernatum* | GDCROC12-021 | PM11-A183 |
| | | *Trithemis dorsalis* | GDCROC12-023 | PM11-A177 |
| | | *Zosteraeschna minuscula* | GDCROC12-012 | DF12-035 |
| 19/11/2012 | X2CROC-DONKE (5) | *Chlorolestes fasciatus* | GDCROC12-004 | DF12-004 |
| | | *Crocothemis erythraea* | GDCROC12-041 | DF12-001 |
| | | *Nesciothemis farinosa* | GDCROC12-009 | DF12-047 |
| | | *Orthetrum julia falsum* | GDCROC12-003 | DF12-034 |
| | | *Orthetrum machadoi* | GDCROC12-008 | DF12-036 |
| | | *Orthetrum machadoi* | GDCROC12-020 | DF12-011 |
| | | *Paragomphus cognatus* | GDCROC12-001 | DF12-039 |
| | | *Platycypha caligata* | GDCROC12-002 | DF12-033 |
| | | *Pseudagrion spernatum* | GDCROC12-005 | DF12-021 |
| | | *Pseudagrion spernatum* | GDCROC12-040 | DF12-050 |
| 19/11/2012 | X2CROC-ROODE (4) | *Chlorolestes fasciatus* | GDCROC12-028 | DF12-026 |
| | | *Platycypha fitzsimonsi* | GDCROC12-027 | DF12-003 |
| | | *Trithemis furva* | GDCROC12-043 | DF12-015 |
| | | *Trithemis furva* | GDCROC12-029 | DF12-049 |
| 19/11/2012 | X2CROC-VALYS (3) | *Africallagma sapphirinum* | GDCROC12-030 | |
| | | *Africallagma sapphirinum* | GDCROC12-031 | DF12-008 |
| | | *Elattoneura glauca* | GDCROC12-033 | DF12-032 |
| | | *Paragomphus cognatus* | GDCROC12-026 | DF12-042 |
| | | *Platycypha fitzsimonsi* | GDCROC12-032 | DF12-040 |
| | | *Pseudagrion citricola* | GDCROC12-024 | DF12-007 |
| 20/11/2012 | X2CROC-DOORN (7) | *Paragomphus cognatus* | GDCROC12-010 | DF12-038 |
| | | *Paragomphus cognatus* | GDCROC12-042 | DF12-006 |
| | | *Phyllomacromia picta* | GDCROC12-014 | DF12-010 |
| | | *Pseudagrion gamblesi* | GDCROC12-006 | DF12-037 |
| 20/11/2012 | X2CROC-GOEDE (6) | *Pseudagrion salisburyense* | GDCROC12-025 | DF12-043 |
| 23/11/2012 | X2CROC-BOTAN (15) | *Pseudagrion hageni tropicanum* | GDCROC12-074 | DF12-017 |
| | | *Tetrathemis polleni* | GDCROC12-073 | DF12-030 |
| 24/11/2012 | X2CROC-KAAPM (20) | *Brachythemis lacustris* | GDCROC12-077 | DF12-045 |
| | | *Elattoneura glauca* | GDCROC12-084 | DF12-019 |
| | | *Lestinogomphus angustus* | GDCROC12-075 | DF12-079 |
| | | *Orthetrum chrysostigma* | GDCROC12-080 | DF12-027 |
| | | *Pseudagrion acaciae* | GDCROC12-076 | DF12-057 |
| | | *Pseudagrion sublacteum* | GDCROC12-083 | |
| | | *Pseudagrion sublacteum* | GDCROC12-087 | DF12-005 |
| | | *Zygonoides fuelleborni* | GDCROC12-078 | DF12-013 |
| 24/11/2012 | X2CROC-WELT1 (19) | *Ceriagrion glabrum* | GDCROC12-089 | DF12-023 |
| | | *Crenigomphus hartmanni* | GDCROC12-091 | DF12-025 |
| | | *Pseudagrion sjoestedti* | GDCROC12-088 | DF12-100 |
| | | *Pseudagrion sjoestedti* | GDCROC12-047 | |
| | | *Nesciothemis farinosa* | GDCROC12-095 | DF12-067 |
| | | *Pseudagrion acaciae* | GDCROC12-094 | |
| | | *Pseudagrion sublacteum* | GDCROC12-093 | DF12-028 |
| 03/01/2013 | X2CROC-MONTR (11) | *Lestes plagiatus* | GDCROC13-007 | |

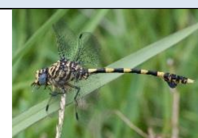
| DATE | SITE | SPECIES | VOUCHER NO. | DNA SAMPLE CODE |
|---|---|---|---|---|
| | | *Notiothemis jonesi* | GDCROC13-003 | DF12-074 |
| | | *Orthetrum julia falsum* | GDCROC13-005 | DF12-059 |
| | | *Pseudagrion kersteni* | GDCROC13-004 | |
| | | *Pseudagrion salisburyense* | GDCROC13-006 | |
| | | *Trithemis furva* | GDCROC13-022 | |
| | | *Trithemis furva* | GDCROC13-021 | |
| | | *Trithemis furva* | GDCROC13-002 | |
| 03/01/2013 | X2CROC-RIETV (9) | *Trithemis furva* | GDCROC13-001 | |
| 29/01/2013 | X2CROC-DNELS (18) | *Mesocnemis singularis* | GDCROC13-012 | |
| 29/01/2013 | X2CROC-KINGS (17) | *Pseudagrion acaciae* | GDCROC13-011 | DF12-080 |
| 30/01/2013 | X2CROC-CBRDG (23) | *Pseudagrion hamoni* | GDCROC13-020 | |
| | | *Pseudagrion massaicum* | GDCROC13-019 | |
| 30/01/2013 | X2CROC-MAROE (22) | *Nesciothemis farinosa* | GDCROC13-018 | |
| | | *Pseudagrion massaicum* | GDCROC13-016 | DF12-055 |
| | | *Pseudagrion sudanicum* | GDCROC13-017 | DF12-060 |
| 30/01/2013 | X2CROC-RIVER (21) | *Crocothemis erythraea* | GDCROC13-012 | |
| | | *Neurogomphus zambeziensis* | GDCROC13-013 | DF12-084 |
| | | *Paragomphus sabicus* | GDCROC13-014 | DF12-082 |
| | | *Urothemis edwardsii* | GDCROC13-015 | DF12-075 |
| 19/02/2013 | X4INCO-MOAMB (27) | *Ceriagrion glabrum* | GDINCO13-002 | |
| | | *Pseudagrion hamoni* | GDINCO13-001 | |
| 20/02/2013 | X4INCO-LCHUA (29) | *Agriocnemis gratiosa* | GDINCO13-008 | DF12-090 |
| | | *Agriocnemis gratiosa* | GDINCO13-006 | DF12-092 |
| | | *Agriocnemis* sp. | GDINCO13-007 | DF12-053 |
| | | *Agriocnemis* sp. | GDINCO13-003 | DF12-069 |
| | | *Agriocnemis* sp. | GDINCO13-010 | DF12-054 |
| | | *Agriocnemis* sp. | GDINCO13-011 | DF12-093 |
| | | *Agriocnemis* sp. | GDINCO13-009 | DF12-072 |
| | | *Ceriagrion glabrum* | GDINCO13-004 | |
| | | *Olpogastra lugubris* | GDINCO13-013 | DF12-089 |
| | | *Pseudagrion glaucescens* | GDINCO13-005 | DF12-08 |
| | | *Urothemis edwardsii* | GDINCO13-012 | DF12-071 |

# APPENDIX C

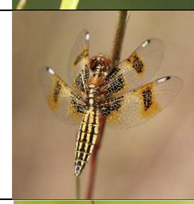
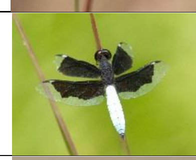
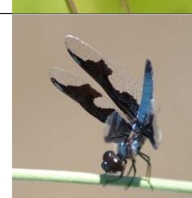
Table C-1: Photos of some of the species recorded during the field survey November 2012 to March 2013. Most of the photos were taken in the Crocodile-Inkomati Catchment. Unless stated otherwise, photos were taken by Gerhard Diedericks.

| FAMILY - SPECIES | COMMON NAME | PHOTO |
|---|---|---|
| CALOPTERYGIDAE | | |
| *Phaon iridipennis* | Glistening Demoiselle |  |
| CHLOROCYPHIDAE | | |
| *Platycypha caligata* | Dancing Jewel |  |
| *Platycypha fitzsimonsi* | Boulder Jewel |  |
| SYNLESTIDAE | | |
| *Chlorolestes fasciatus* | Mountain Malachite |  |
| LESTIDAE | | |
| *Lestes plagiatus* | Highland Spreadwing |  |
| PLATYCNEMIDIDAE | | |
| *Mesocnemis singularis* | Riverjack |  |
| PROTONEURIDAE | | |
| *Elattoneura glauca* | Common Thorntail |  |
| COENAGRIONIDAE | | |
| *Ceriagrion glabrum* | Common Citril |  |
| *Pseudagrion acaciae* | Green-naped Sprite |  |

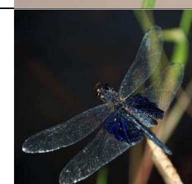
| | | |
|---|---|---|
| *Pseudagrion caffrum* | Springwater Sprite |  |
| *Pseudagrion citricola* | Yellow-faced Sprite |  |
| *Pseudagrion coeleste* | Catshead Sprite |  |
| *Pseudagrion commoniae* | Black Sprite |  |
| *Pseudagrion gamblesi* | Great Sprite |  |
| *Pseudagrion hageni* | Painted Sprite |  |
| *Pseudagrion hamoni* | Drab Sprite |  |
| *Pseudagrion kersteni* | Kerstenǿs Sprite |  |
| *Pseudagrion massaicum* | Masai Sprite |  |
| *Pseudagrion salisburyense* | Slate Sprite |  |
| *Pseudagrion sjoestedti* | Rufous Sprite | |
| *Pseudagrion spernatum* | Powder Sprite |  |
| *Pseudagrion sublacteum* | Cherry-eye Sprite |  |
| *Pseudagrion sudanicum* | Sudan Sprite |  |
| *Ischnura senegalensis* | Marsh Bluetail |  |

| | | |
|---|---|---|
| *Africallagma glaucum* | Swamp Bluetail |  |
| *Africallagma sapphirinum* | Sapphire Bluet | |
| *Azuragrion nigridorsum* | Sailing Bluet |  |
| *Agriocnemis gratiosa* | Gracious Wisp | |
| AESHNIDAE | | |
| *Zosteraeschna minuscula* | Friendly Hawker |  |
| *Pinheyschna subpupillata* | Stream Hawker |  |
| *Anax imperator* | Blue Emperor |  |
| *Anax speratus* | Orange Emperor |  |
| GOMPHIDAE | | |
| *Ictinogomphus ferox* | Common Tigertail |  |
| *Gomphidia quarrei* | Quarreôs Fingertail |  |
| *Lestinogomphus angustus* | Spined Fairytail | |
| *Neurogomphus praetorius* | Yellowjack |  |
| *Neurogomphus zambeziensis* | Zambezi Siphontail | |
| *Crenigomphus hartmanni* | Clubbed Talontail |  |
| *Ceratogomphus pictus* | Common Thorntail |  |

| | | |
|---|---|---|
| *Paragomphus cognatus* | Boulder Hooktail |  |
| *Paragomhus genei* | Green Hooktail |  |
| *Paragomphus sabicus* | Clubbed Hooktail |  |
| CORDULIIDAE | | |
| *Phyllomacromia contumax* | Two-banded Cruiser |  |
| *Phyllomacromia picta* | Darting Cruiser |  |
| LIBELLULIDAE | | |
| *Tetrathemis polleni* | Black-splashed Elf |  |
| *Notiothemis jonesi* | JonesôForestwatcher |  |
| *Orthetrum caffrum* | Two-striped Skimmer |  |
| *Orthetrum chrysostigma* | Epaulet Skimmer |  |

| | | |
|---|---|---|
| *Orthetrum hintzi* | Hintzôs Skimmer |  |
| *Orthetrum julia* | Julia Skimmer |  |
| *Orthetrum machadoi* | Machadoôs Skimmer | |
| *Orthetrum trinacria* | Long Skimmer |  |
| *Nesciothemis farinosa* | Black-tailed Skimmer |  |
| *Palpopleura jucunda* | Yellow-veined Widow |  |
| *Palpopleura lucia* | Lucia Widow |  |
| *Palpopleura portia* | Portia Widow |  |
| *Acisoma variegatum* | Grizzled Pintail |  |
| *Diplacodes lefebvrii* | Black Percher |  |
| *Crocothemis erythraea* | Broad Scarlet |  |

| | | |
|---|---|---|
| *Crocothemis sanguinolenta* | Little Scarlet |  |
| *Bradinopyga cornuta* | Horned Rockdweller |  |
| *Brachythemis lacustris* | Red Groundling |  |
| *Brachythemis leucosticta* | Banded Groundling |  |
| *Sympetrum fonscolombii* | Nomad |  |
| *Trithemis annulata* | Violet Dropwing |  |
| *Trithemis arteriosa* | Red-veined Dropwing |  |
| *Trithemis donalsoni* | Denim Dropwing |  |
| *Trithemis dorsalis* | Round-hook Dropwing |  |
| *Trithemis furva* | Navy Dropwing |  |
| *Trithemis kirbyi* | Kirby's Dropwing |  |
| *Zygonyx natalensis* | Scuffed Cascader |  |

| | | |
|---|---|---|
| *Zygonyx torridus* | Ringed Cascader |  |
| *Zygonoides fuelleborni* | Robust Riverking |  |
| *Olpogastra lugubris* | Slender Botteltail |  |
| *Rhyothemis semihyalina* | Phantom Flutterer |  |
| *Pantala flavescens* | Pantala |  |
| *Tramea basilaris* | Keyhole Glider |  |
| *Tramea limbata* | Voyaging Glider |  |
| *Urothemis edwardsii* | Blue Basker |  |