Baseline Surveys of Koodaideri Spring in 2010 and 2011

Final Report

Prepared for Rio Tinto
by Bennelongia Pty Ltd

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Report 2010/120

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Cover picture: *Nannoplebia injibandi*

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EXECUTIVE SUMMARY

Koodaideri Spring lies in the northern part of the Hamersley Range about 50 km north of Weeli Wolli Spring. No previous sampling of aquatic fauna has occurred at Koodaideri Spring, although biological surveys have been undertaken in the surrounding area and some information on riparian vegetation at the spring is available. Results of surveys in October 2010 and April 2011 to document the biological values of Koodaideri Spring in the late dry season and late wet season are reported here.

The spring is a freshwater system with relatively low salinity, nutrient and metal levels, probably partly owing to it being located in the headwaters of its catchment.

A total of 175 species of aquatic invertebrates were collected, with the list dominated by dipterans which accounted for almost one-third of species collected. No fish were collected and there was no evidence of the occurrence of fish in the Koodaideri system. A total of 69 species of plant were recorded in the spring and creek system and on the associated floodplain. Most of these species are associated with the waterbody, although some terrestrial species that have encroached on the floodplain.

The main conservation values of the Koodaideri Spring system are related to three factors: lack of disturbance, aesthetics and the occurrence of a large number of aquatic invertebrates including a suite of groundwater and spring species. The lack of disturbance is demonstrated by only 6% of plant species being introduced. The aesthetic appeal is based on the presence of flowing water in the dry climate of the Pilbara, the extensive growth of riparian tree species associated with the water of the spring, and the occurrence of *Ficus* trees and vines in the riparian zone.

In terms of aquatic invertebrates, Koodaideri had more species than most of the well known Pilbara springs with which comparisons were made. The water mite *Stygolimnochares* nr *australica* represents either the first Western Australian record of the Queensland species *Stygolimnochares australica* or is a new species that is known to date only from Koodaideri Spring. It is also possible that the amphipod *Chydaekata* sp. represents an undescribed species collected to date only from Koodaideri Spring.

Other than the occurrence of a single Priority 4 species, *Rhynchosia bungarensis*, the vascular flora did not have high conservation value at the species level. A species of *Chara* that could not be identified beyond genus level may also have some conservation significance, although this was considered to be unlikely.

In conclusion, based on results of the two surveys undertaken, the main conservation values of the Koodaideri Spring system are its lack of disturbance, the aesthetics of the site, and the presence of a large number of aquatic invertebrates. One way of assessing the conservation significance of Koodaideri Spring is to compare it with other Pilbara springs that are already of recognized value. Koodaideri has aquatic conservation values that are similar to those of Weeli Wolli Spring, although Koodaideri contains about 10% more species. It supports about 60% more species than were recorded in the Millstream delta during the Pilbara Biodiversity Survey.

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1. INTRODUCTION

The Pilbara region of Western Australia contains a surprising number of wetlands for an arid zone region (Pinder *et al*. 2010). While the eastern end of the Fortescue Valley, and some other areas, contain ephemeral claypans, most Pilbara wetlands are riverine.

The three most common types of Pilbara wetlands are:

- large river pools scoured out by streamflow (most frequent in the Ashburton and De Grey river systems),
- smaller rockpools created by scouring flow around large rocks or cliffs intruding into the stream (often found in small creek lines), and
- springs where groundwater discharges strongly.

The best known examples of such springs include Millstream in the Chichester Range and Weeli Wolli Spring in the Hamersley Range. Circular Pool in Karijini National Park within the Hamersley Range is an example of a spring discharging into a rockpool, with permanent flow in the downstream creek.

Koodaideri Spring lies in the northern part of the Hamersley Range about 50 km north of Weeli Wolli Spring (Figure 1.1). It consists of a small spring discharging into a narrow valley, with a series of small channels and pools downstream of the spring (Figures 1.2, 1.3). There was no sampling of aquatic fauna at Koodaideri Spring prior to 2010, although biological surveys have been undertaken in the surrounding area and some information on riparian vegetation at the spring is available (Biota 2007). There is a substantial amount of information on the aquatic fauna and vegetation of Pilbara wetlands that provide context for the results of surveys at Koodaideri Spring (Morgan and Gill 2004; Halse *et al*. 2007; Pinder *et al*. 2010; Lyons *et al*. unpublished data).

The overall objective of the survey reported here was to document the biological values of Koodaideri Spring through sampling in both the dry (October 2010) and wet (April 2011) seasons. Specific objectives were:

- to document the species of aquatic invertebrate present,
- to determine whether the spring supported fish and, if so, which species,
- to document the aquatic vegetation of the spring with a list of aquatic, emergent and riparian plant species, and
- to assess the conservation status of species recorded.

2. METHODS

2.1. Study site

Koodaideri Spring (22° 32' 28"S, 119° 03' 24"E) lies about halfway along a small stream, located on the northern side of the Hamersley Range, that discharges onto the Fortescue Marsh floodplain. The spring arises from under a rock wall running across the narrow gorge (Figures 1.2, 1.3A). The stream flowing from the spring travels about 40 m north before intersecting a larger gorge running east-west. Most of the stream flow enters the eastern part of this gorge and flows north-east; there were only a few small pools to the west at the time of sampling.

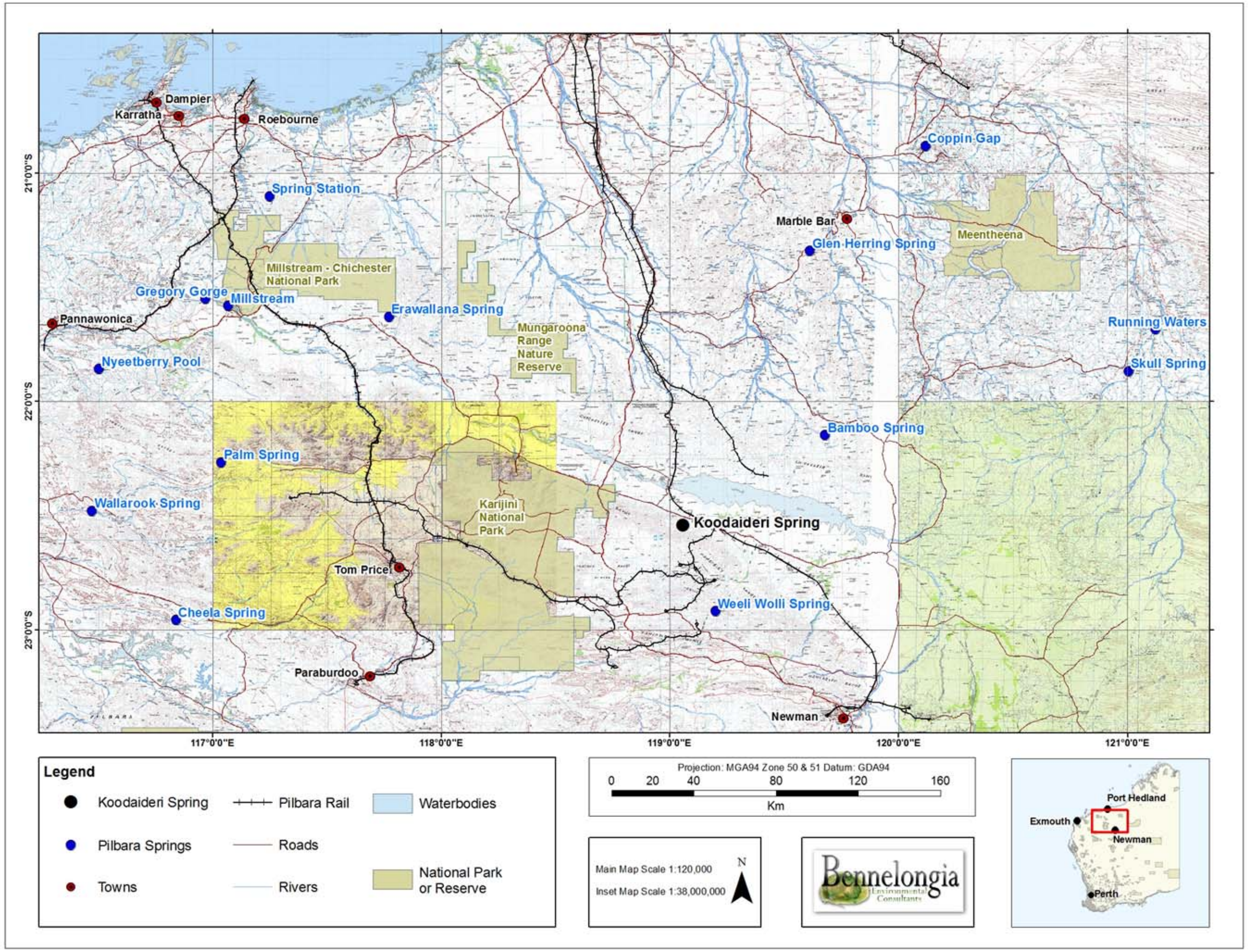


Figure 1.1. Location of Koodaideri Spring in the central Pilbara**.**

Other springs from which invertebrate results are used are also shown.

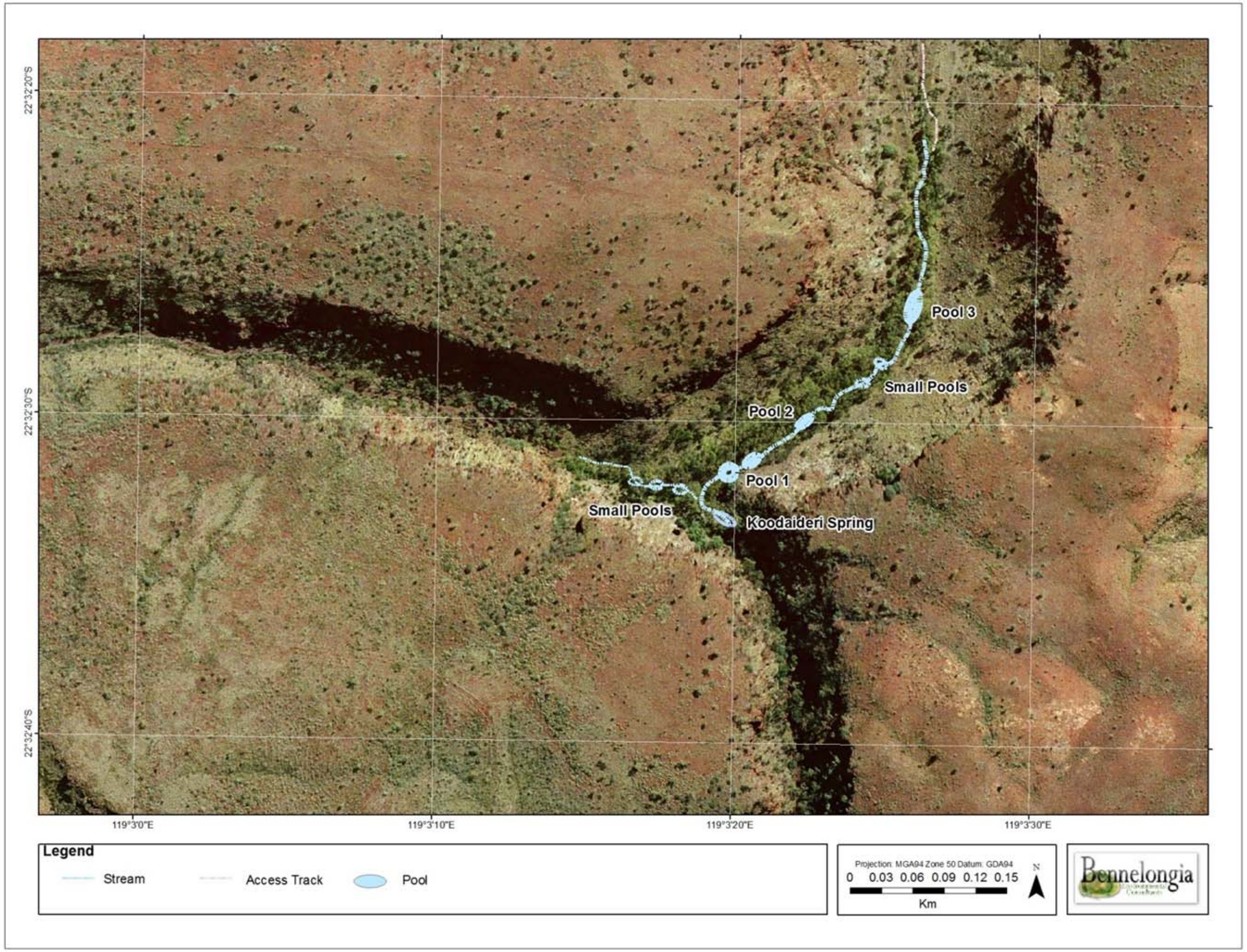


Figure 1.2. Position of spring, pools and streams at Koodaideri Spring.

In the wider north-eastern gorge, the stream lies within a small grassy floodplain and consists of a series of narrow channels connecting wider, deeper pools (Figures 1.2, 1.3C,E). Surface water was present in the stream for about 475 m from the junction during April 2011.

2.2. Field sampling

Field sampling occurred from 4 - 6 October 2010 and 6 – 8 April 2011. Water chemistry measurements were made in October 2010 and three elements of the biota (aquatic invertebrates, fish and plants) were sampled during both sampling periods. A general description of the spring was compiled.

2.2.1. Water chemistry

In October 2010, a water sample was collected from 10 cm below the surface of Pool 3 (Figures 1.2, 1.3D) for laboratory analysis by the ChemCentre, which is NATA accredited. Electrical conductivity, pH and temperature were also measured at Pool 3 with a WP 81 field meter in both October 2010 and April 2011. Full analysis of water was undertaken only in 2010 because the first sample showed no evidence of pollution and relative concentrations of ions and metals are unlikely to vary seasonally in fresh, unpolluted water.

2.2.2. Aquatic invertebrates

Three aquatic invertebrate samples were collected in both October 2010 and April 2011, following the sampling protocols employed by Pinder *et al*. (2010) for the Pilbara Biodiversity Survey. The benthic sample was collected by 50 m of discontinuous, vigorous kick sampling and sweep sampling with a D-framed pond net with 250 µm mesh. All habitats along the length of the stream were sampled, including streambed, vegetation and water column. The net was regularly emptied into a bucket to prevent build up of sample in the net and then the sample in the bucket was elutriated to remove rocks and sediment. As much vegetation and organic matter as possible was also removed from the sample, with the material being washed vigorously as it was removed.

The plankton sample was collected by sweep sampling from the same areas and habitats as the benthic sample, except that the stream bed was not sampled and areas of vegetation were sampled carefully to avoid collecting too much filamentous algae. A D-framed pond-net with 50 µm mesh was used.

The hyporheic sample was collected by digging a 0.5 by 0.5 m hole in the stream-bank about 10 m downstream of the source of the spring. Water and sediment were bailed from the hole, elutriated and passed through a 53 µm sieve.

All samples were preserved in the field using 100% ethanol. Water was drained off samples prior to fixation.

2.2.3. Fish

Fish were sampled intensively in October 2010 and April 2011 using four methods. Five fish traps, baited with chook pellets, were set for the duration of fieldwork in various pools. The largest pool (Pool 3, Figure 1.2) was dragged with 5 mm and 10 mm diagonal seine nets. Gill nets (5 and 15 mm) were set overnight in Pool 3 and Pool 1, closer to the junction of the gorges. A fishing line baited with odonate nymphs was left set in different pools for the duration of fieldwork. In addition to deliberate sampling for fish, pools were searched for visual evidence of fish, including one hour of spotlighting after dusk.

2.2.4. Vegetation

During both October 2010 and April 2011 surveys, plant species were collected by walking through the different habitats and collecting each species when first encountered. The percentage cover of each species in different habitats was estimated visually while collecting. In addition, during April 2011 riparian and floodplain habitats were sampled using eight 40 m x 5 m quadrats (four in each habitat, coordinates provided in Appendix 1). All plants collected were pressed for later identification.

Figure 1.3. Koodaideri Spring.

A, Headwaters near the spring; B, Downstream of spring before junction with east-west gorge; C, Pool 2 in north-eastern gorge; D, Pool 3; E, Downstream of Pool 3 in grassy floodplain; F, typical vegetation within the riparian zone.

Three indices of plant abundance were measured for each species in each quadrat. These were:

- number of individual plants,
- estimated percentage cover, and
- canopy cover.

Canopy cover was estimated using an adaptation of the methods outlined in MacFarlane (2007). Within each quadrat, eight vertical (skywards) photographs were taken and percentage crown cover (leaves, branches, trunks) of each species was calculated. This measurement is a way of quantifying above-head canopy cover that is fast, accurate, and can be used to assess change over time without influence from different sampling teams.

2.3. Species identification

2.3.1. Aquatic invertebrates

All aquatic invertebrate samples were washed and sieved in the laboratory through a set of sieves (2000, 500, 250, 90, 53 µm) to facilitate sorting under a dissecting microscope. Animals were identified to species or morpho-species using published and unpublished keys and recognized taxonomic characters according to the taxonomic framework developed by the Pilbara Biodiversity Survey (Pinder *et al*. 2010).

A compound microscope with differential interference contrast lighting was used for identification as necessary.

2.3.2. Plants

Plant species were identified using existing keys, with uncertain identifications being verified by Mattiske Consulting. Four plant taxa could not be identified to species level because they lacked flowers or fruits.

2.4. Multivariate analysis

Species composition of the dry season and wet season aquatic invertebrate communities at Koodaideri were compared with communities at other well known Pilbara Springs (Figure 1.1) using multivariate analysis in the PATN package (Version 3, www.patn.com.au). Data for the springs were obtained from Pinder *et al*. (2010). Prior to analysis, some taxa were combined with related taxa or were removed from the dataset to reduce differences between sites as a result of uneven identifications. In addition, species that occurred only once in all sampling (i.e. at only one site in one season) were excluded from analysis.

The communities were compared by both cluster analysis and ordination, using the Bray-Curtis association measure, UPGMA clustering and three-dimensional SSH ordination with default settings. The ordination stress (0.26) was high, indicating that relationships amongst communities were not well represented.

2.5. Personnel

Fieldwork was undertaken by Grant Pearson and Michael Curran. Aquatic invertebrate samples were sorted by Jane McRae and identified by Jane McRae, Stuart Halse (ostracods) and Mike Scanlon (oligochaetes). Plants were identified by Michael Curran and Mattiske Consulting.

3. RESULTS

3.1.1. Habitat and water chemistry

An aerial overview of the Koodaideri Spring system is shown in Figure 1.2. Four broad habitat zones were identified in the spring system. These were:

- aquatic zone, which covered approximately 0.09 ha in October 2010, comprising the open water sections of the spring itself, sections of narrow stream and pools,
- emergent zone, which covered 0.12 ha, comprising parts of the watercourse and pool supporting dense emergent plants,
- riparian zone, which covered 1.34 ha, comprising the sloping banks of the channels containing the stream and pools and other associated low-lying areas. This encompasses the area of regular flooding, and
- floodplain zone, which covered 1.43 ha, comprising the bench of the floodplain around the channels. This zone represents the geological floodplain rather than the area that is regularly inundated.

The substrate in the larger pools of the spring system consisted of about 80% bedrock, 10% cobble and 10% finer sediment. The streambed was covered by filamentous algae in October 2010. Filamentous algae was mostly absent from the substrate in April 2011, although still present on macrophytes and emergent plants. Smaller pools (especially those to the west) contained a higher proportion of sediment (up to 40%) than larger pools. The stream channel was mostly bedrock.

Water in Pool 3 was fresh and neutral, with salinity and pH values of 220 $\mu S\ cm^{-1}$ and 7.04 in October 2010 and 418 $\mu S\ cm^{-1}$ and 7.85 in April 2011. In October 2010, measured depth of water was 0.3 m at the source of the spring, 0.1 m as the stream reached the east-west gorge, 1.2 m in Pool 3 and an estimated 1.5 m in Pool 2. In April 2011, depths were 0.4 m at the spring source, 0.3 m as the stream reached the gorge, 1.4 m in Pool 3 and 1.6 m in Pool 2. Streamflow at the spring was approximately 0.10 $m\ sec^{-1}$ in October 2010 and 0.15 $m\ sec^{-1}$ in April 2011. Surface water extended only 3 m further downstream in April 2011 than October 2010.

Analysis of water samples from October 2010 indicated that water at Koodaideri Spring was strongly bicarbonate-dominated (Appendix 2). Nutrient values were at trigger levels for slightly disturbed tropical ecosystems (ANZECC & ARMCANZ 2000), which reflects good water quality in a small stream during the late dry season. Turbidity was high (12 NTU) for a spring site, owing to high levels of phytoplankton and breakdown products of filamentous algae; this phenomenon is sometimes seen in other isolated pools in the Pilbara during the late dry season. To provide some context, Cheela Spring and the Spring Station (refer Figure 1.1) had NTU values during the dry season about one-third those at Koodaideri during the Pilbara Biodiversity Survey (Pinder *et al*. 2010). The concentrations of all metals were low at Koodaideri and in no case exceeded the guidelines for protection of 95% of aquatic species, although chromium and cobalt concentrations were approximately at trigger levels (ANZECC & ARMCANZ 2000). It is common to find one or more metals close to trigger levels in undisturbed sites.

3.1.2. Aquatic invertebrates

A total list (adjusted for some higher level identifications that may represent double counting of the same species) of at least 175 species of aquatic invertebrates were collected at Koodaideri Spring (Appendix 3). Overall, about three-quarters of the total species were collected each sampling trip, with 126 species in October 2010 and 139 in April 2011. The dominant invertebrate group was dipterans,

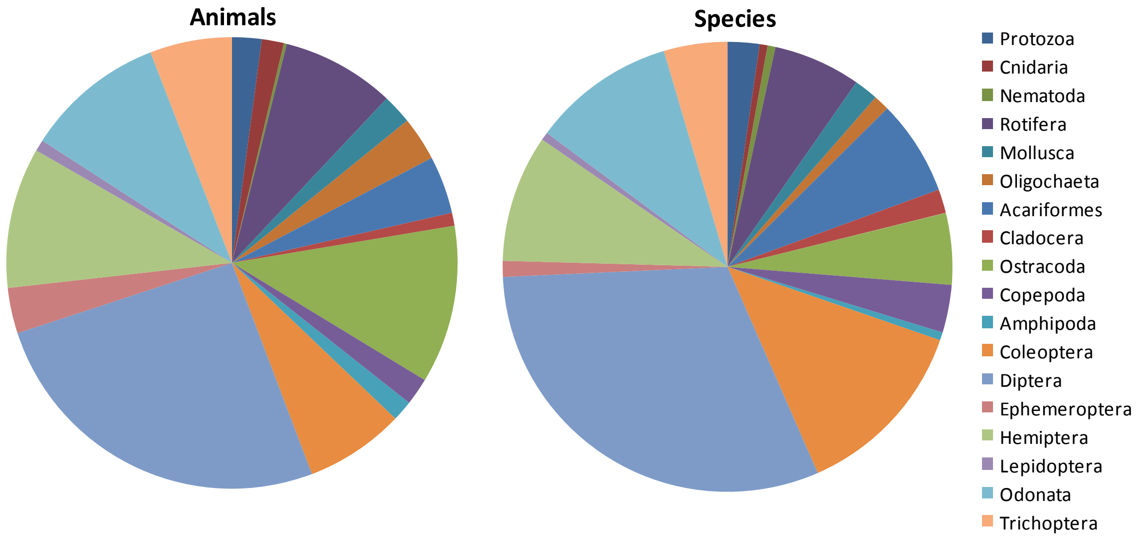


Figure 3.1. Taxonomic composition of the aquatic invertebrate fauna.
In the left hand pie chart sectors are proportional to the number of animals belonging to the group; in the right hand chart they are proportional to number of species.

which accounted for 31% of all species (Figure 3.1). It was also the dominant group in terms of animals collected, although the sorting process contains biases that make comparisons between groups somewhat unreliable. Chironomids constituted 56% of all dipteran species.

Other groups represented by 10 or more species were rotifers, water mites (Acariformes), coleopterans, hemipterans and odonates. With the exception of rotifers, all the more speciose groups were insects. Crustaceans were relatively species-poor at Koodaideri, although the actual abundance of ostracods appeared to be second only to dipterans (Figure 3.1).

Nearly all species collected at Koodaideri are known more widely in the Pilbara and, in most cases, other parts of Australia. Many of the species collected are typical of situations where significant groundwater discharge occurs. The species of greatest scientific and conservation interest were the species with strong groundwater affinity that are known rarely from surface water. Such species tend to have small ranges and, at Koodaideri, included the crustaceans *Chydaekata* sp. and *Vestenula matildae* and the water mites *Stygolimnochares* nr *australica* and *Aspidiobates pilbara*. Other groundwater-associated species included the water mites *Gretacarus bifalcisetus* and *Austraturus longipalpis*, the ostracods *Vestalenula marmonieri* and *Penthesilenula brasiliensis*, the copepod *Australoeucyclops kuraytugi*, the hemipterans *Limnogonous luctuosus*, *Laccotrephes tristis* and *Enithares woodwardi* and the odonate *Nannophlebia injibandi*.

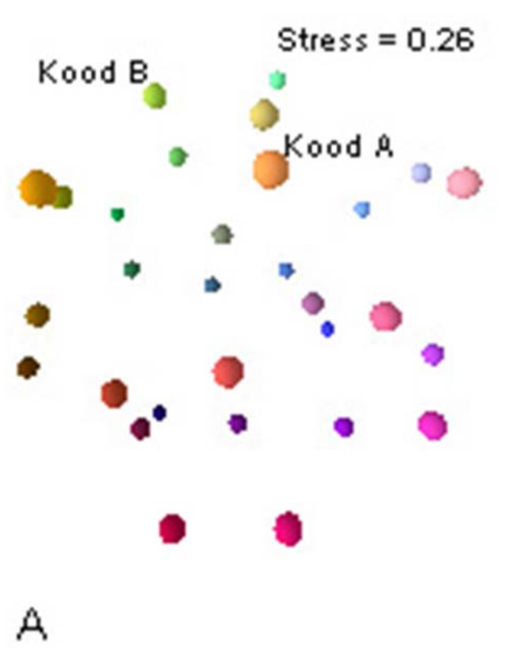
The following may be said about the species with greatest scientific and conservation interest:

- the amphipod genus *Chydaekata* occurs in groundwater throughout the central and upper part of the Fortescue River basin and was previously recorded from surface water only at Weeli Wolli Spring. It is unclear whether the species of *Chydaekata* at Koodaideri Spring is the same as recorded at Weeli Wolli Spring,

- the ostracod *Vestalenula matildae* occurs in groundwater throughout the Pilbara but was previously recorded in surface water only at Chalyarn Pool on the Robe River (west of Pannawonica) and at Coppin Gap in the De Grey River system (refer Figure 1.1),
- *Stygolimnochares* is a genus of mites that inhabits the hyporheic zone, with *Stygolimnochares australica* being known from streams in Queensland (see Smit 2007). *Stygolimnochares* nr *australica* is probably a new species and its collection at Koodaideri Spring was either the first record of the new species or the first Western Australian record of *Stygolimnochares australica,* and
- *Aspidiobates pilbara* is an endemic Pilbara species that was previously recorded only from Weeli Wolli Spring, Millstream and three other springs in the Pilbara (Harvey 1988, Pinder *et al*. 2010).

3.1.3. Aquatic invertebrate community

Cluster analysis showed less inter-seasonal difference in the aquatic invertebrate community of Koodaideri Spring than other Pilbara springs (Figure 3.2). The reasons for the greater consistency of fauna between seasons at Koodaideri are not clear but may be related to the minimal change in flow conditions and the extent of surface water between the two surveys.



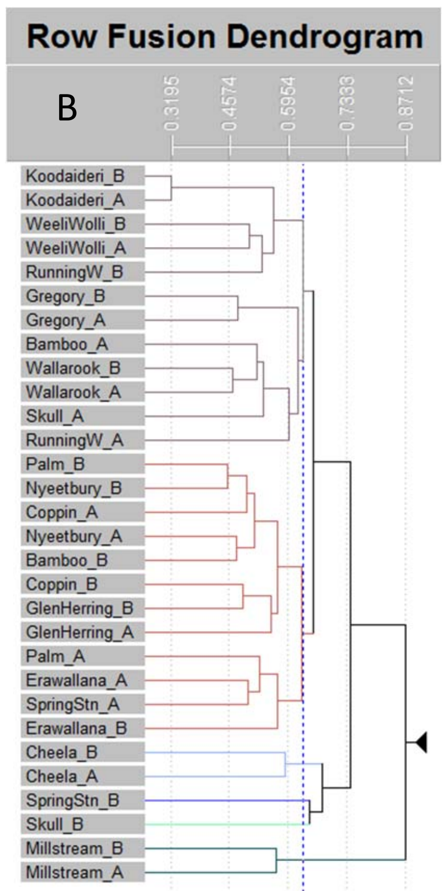


Figure 3.2. Invertebrate communities of Pilbara springs in the wet and dry seasons. A, Ordination of samples. B, Classification of samples. Seasons: A, dry season; B, wet season. See Figure 1.1 for full names and site locations

The invertebrate community at Koodaideri was most closely related to that at Weeli Wolli Spring (Figure 3.2B), located about 50 km south of Koodaideri and the closest site sampled. Given that both systems flow northwards out of the Hamersley Range into the Fortescue Valley, the similarity of fauna is to be expected. More surprisingly, the community at Running Waters (200 km north-east) showed similarity to that at Koodaideri in the wet season. However, differences between the communities of all springs (except Koodaideri) were little greater than the inter-seasonal community differences at individual springs and the Koodaideri communities fitted into the ordination 'cloud' of other springs (Figure 3.2A).

3.1.4. Fish

No fish were collected in either October 2010 or April 2011 and there was no evidence of the occurrence of fish in the Koodaideri system. This may reflect intermittent surface flow of the spring because most permanent water systems in the Pilbara contain fish. The isolated nature of the Koodaideri Spring system, with no downstream connection to other waterbodies, means that the re-establishment of fish populations after periods of prolonged drought and drying of surface water is likely to be very slow.

3.1.5. Vegetation

The Koodaideri Spring system is relatively rich floristically with 69 species of plant recorded, representing 28 families (Appendix 4). The richest families were Fabaceae (18 species), Poaceae (9), Amaranthaceae (4) and Malvaceae (4). In addition, significant quantities of algae were recorded in the waterbody, especially in October 2010. Filamentous algae is common in some Pilbara streams and its significance as an indicator of stream health is unclear (Halse *et al*. 2007).

Based on all collecting, species richness was high in both the riparian zone (44 species) and on the floodplain (55 species). However, quadrat sampling yielded twice the number of species in the floodplain zone as in the riparian zone (40 vs 20). Only two species were collected from the emergent zone (*Cyperus vaginatus* and *Typha domingensis*). Two species of plants were collected in the aquatic zone, the macrophyte *Chara* sp. and an unknown species of Cyperaceae.

Vegetation structure was more complex in the riparian and floodplain zones than in the aquatic and emergent zones (Figure 3.3). Vegetation in the emergent zone consisted only of sedges and rushes. Trees dominated the riparian zone, although the cover of grass was also high. Shrubs, together with the introduced buffel grass *Cenchrus ciliaris*, dominated the floodplain. Vine species were mostly restricted to the riparian zone (where they accounted for little plant cover, although visually prominent), whereas herbs were more common on the floodplain. The dominance of trees in the riparian zone is common in the Pilbara, where watercourses are frequently conspicuously marked by concentrations of eucalypts.

Quadrat sampling showed that there was more than twice as much canopy cover in the riparian zone as floodplain, although in both zones cover tended to diminish with increasing distance from the spring source (Figure 3.4). In contrast to the canopy results, mean cover of all vegetation was only 21% higher in the riparian zone than floodplain, illustrating the dominance of trees as a life-form in the riparian zone (Table 3.1).

Walk-around and quadrat sampling found *Eucalyptus camaldulensis* var. *obtusa* (up to 30 m in height) was the common tree through most of the riparian zone (71% in quadrats, Table 3.1) but *Ficus brachypoda* (30 m high at the junction of the gorges) was more abundant around the spring itself. *Cyperus vaginatus* and *Cenchrus ciliaris* were the most common understory species. *Cyperus vaginatus* (24% in quadrats) dominated the understorey of the riparian zone, whereas *Cenchrus ciliaris* (5% in quadrats) was more abundant in the floodplain, where it has displaced other grasses and sedges (Table 3.1). Mixed species thickets of *Acacia* (mainly *Acacia tumida* 14%) occur widely on the floodplain and, to a lesser extent, in the riparian zone.

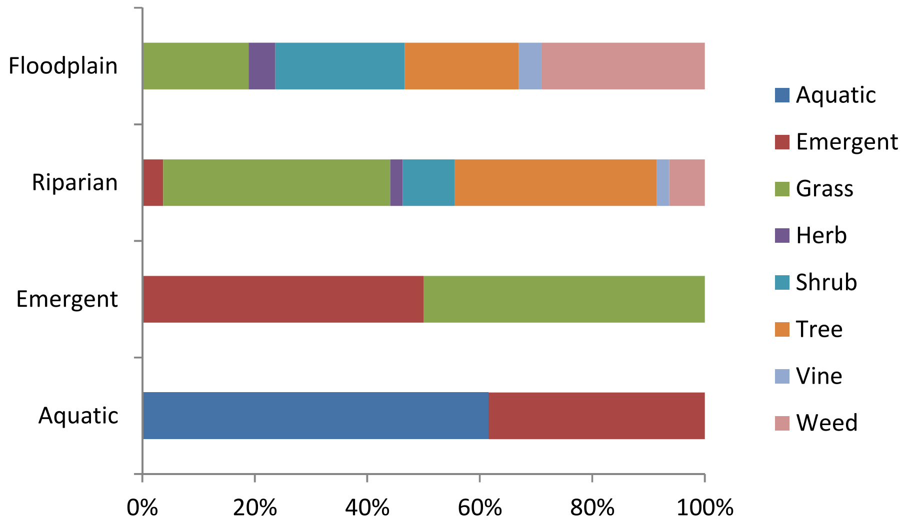


Figure 3.3. Proportion of cover by different plant life forms at Koodaideri Spring in October 2010 and April 2011 based on walk-around survey.
Grass = grass or sedge

Table 3.1. Average cover (%) of five most abundant plants in quadrats by zone and overall.

	Lifeform	Riparian	Floodplain	Overall
Eucalyptus camaldulensis subsp. *obtusa*	Tree	71	12	42
Cenchrus ciliaris	Weed	5	70	38
Cyperus vaginatus	Grass	46	0.25	23
Ficus brachypoda	Tree	24	0.25	12
Acacia tumida var. *pilbarensis*	Shrub	0.25	14	7

It should be pointed out in relation to the estimates of plant cover that the walk-around and quadrat based surveys presented quite different estimates of cover. While quadrat sampling provides more accurate data for the areas sampled, it often fails to capture the full species richness of a wetland. Quadrat sampling may also result in biased estimates of cover if the wetland system is heterogeneous, unless large numbers of quadrats are used. Cover estimates were improved by use of large quadrats (200 m^2) and the addition of walk-around sampling.

Three points can be made in regard to the conservation significance of the vegetation community at Koodaideri Spring. First, a significant number of species found on the floodplain at Koodaideri (and at other Pilbara wetlands) mainly occur in more elevated habitats and cannot be regarded as wetland-dependent, although they are reported here as part of the Koodaideri Spring flora. Second, it is significant that only four introduced plant species were recorded (6% of species), with buffel grass representing the most extensive introduced plant species (Appendix 4). Third, the wetland-dependent plant species of greatest conservation interest at Koodaideri Spring is the shrub *Rhynchosia bungarensis*. The record at Koodaideri is at the eastern limit of the known range of this Priority 4 species.

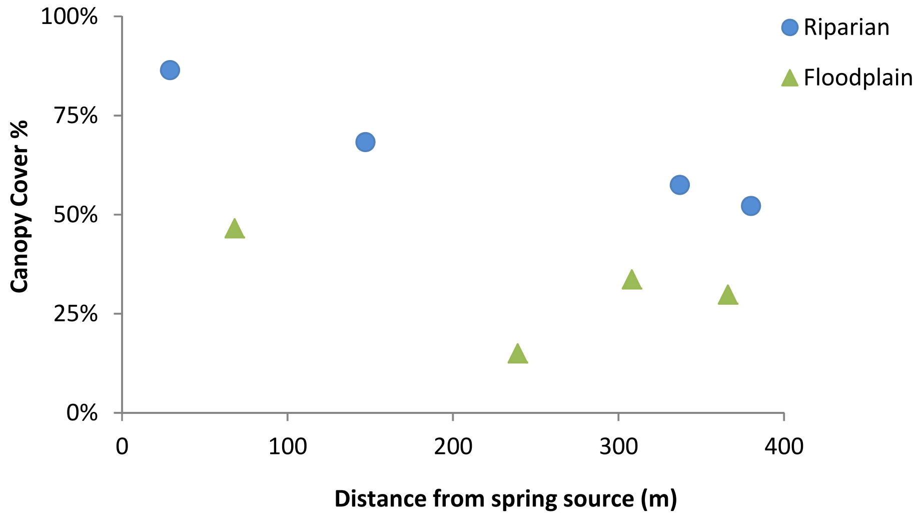


Figure 3.4. Relative canopy cover in quadrats in riparian and floodplain zones.
Cover declined significantly (r=-0.976, P<0.05) with distance from spring.

4. DISCUSSION

The main conservation values of the Koodaideri Spring system are related to three factors: lack of disturbance, aesthetics and a large number of aquatic invertebrates including a suite of groundwater and spring species. The low level of disturbance is demonstrated by only 6% of plant species being introduced; in comparison about 12% of wetland species are introduced in most parts of Western Australia studied (e.g. Gibson *et al*. 2000; Lyons *et al*. 2004).

The aesthetic appeal is based on the presence of flowing water in the dry climate of the Pilbara, the extensive growth of riparian tree species associated with the supply of water at the spring and in the associated creek channel, and the occurrence of *Ficus* trees and vines in the riparian zone. Any potential heritage value of Koodaideri Spring was outside the scope of this study.

Water quality

The water in Koodaideri Spring is fresh and nutrient levels are low. The system is fresher than most springs in the Pilbara, reflecting a tendency throughout the Pilbara for headwater springs to be fresher than those on main tributaries. Dry season salinity of the well-known springs mapped in Figure 1.1 varies from about 850 to 3500 µS cm^{-1} (Pinder *et al*. 2010) compared with 220 µS cm^{-1} at Koodaideri. Metal levels are probably what would be expected in undisturbed Pilbara streams and were within ANZECC & ARMCANZ (2000) guidelines for protection of 95% of freshwater species. Almost no data are publically available on metal levels of other Pilbara headwater streams to provide the basis for quantitative comparison with other sites.

Aquatic invertebrates

In terms of aquatic invertebrates, with 175 species Koodaideri has greater species richness than most of the 15 well-known springs shown in Figure 1.1. These other Pilbara springs had means of 125±8 (SE) and 114 ±8 species, respectively, during the dry and wet seasons (Pinder *et al*. 2010) compared with 126 and 139 species at Koodaideri (Figure 4.1).

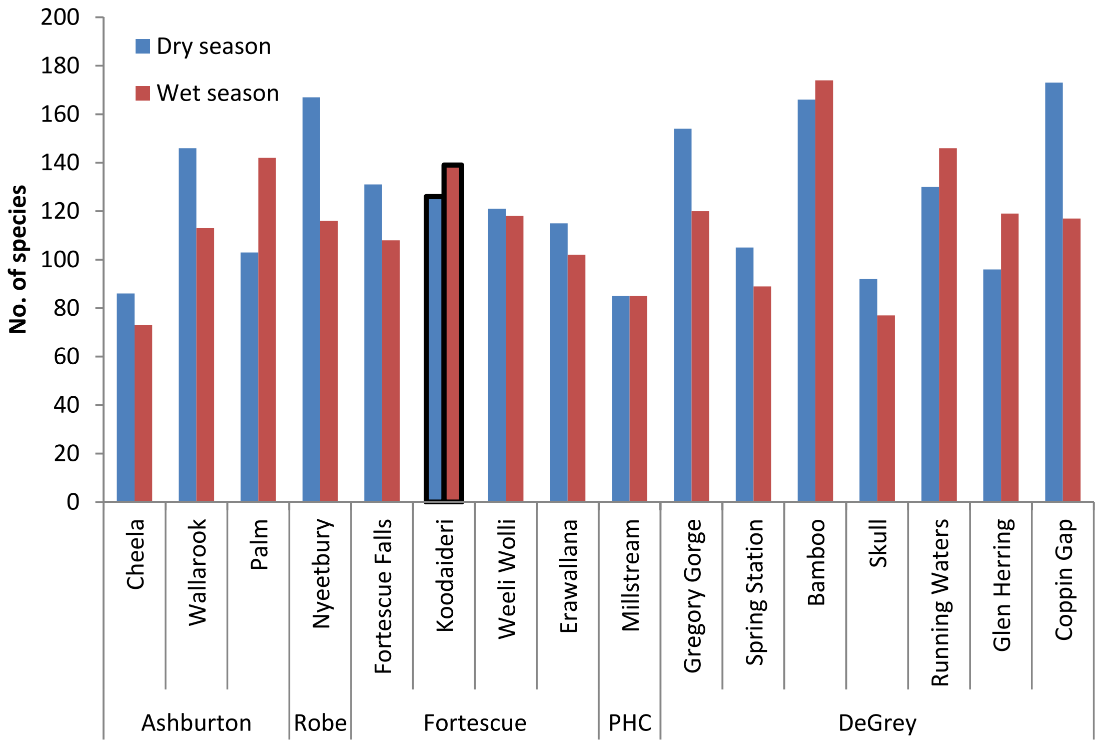


Figure 4.1. Numbers of aquatic invertebrate species collected from Pilbara springs.
All data from spring sampling by Pinder *et al*. (2010), except for Koodaideri.

Species composition was similar to other springs of the Pilbara except for the occurrence of more dipterans at Koodaideri and substantially fewer rotifer species (see Pinder *et al*. 2010). The lack of restricted species at Koodaideri is typical of Pilbara waterbodies, where individual sites are rich in invertebrates but turnover between sites is low and most species are shared by many sites. However, the water mite *Stygolimnochares* nr *australica* may be a new species. Its collection at Koodaideri Spring represents either the first Western Australian record of the Queensland species *Stygolimnochares australica*is or a new species that is known to date only from Koodaideri Spring. It is also possible that *Chydaekata* sp. represents a new species; the upper Fortescue catchment appears to support several species of *Chydaekata* in groundwater that are best separated genetically (Finston *et al*. 2007). In both cases taxonomic work would be required to resolve the status of the species but it is unlikely they have ranges restricted to a site as small as Koodaideri Spring (Eberhard *et al*. 2009; Pinder *et al*. 2010).

The occurrence of some species at Koodaideri Spring that are usually found only in deeper groundwater (*Chydaekata* sp., *Vestenula matildae* and perhaps *Stygolimnochares* nr *australica*) suggests that Koodaideri Spring is better connected with the underlying aquifer than most Pilbara springs. The spring appears to support a relatively rich suite of 'spring-associated' species.

Vegetation

Data on the vegetation associated with watercourses in the Pilbara are scattered, with varied collecting effort and taxonomic resolution in the different studies (e.g. Masini 1988; Masini and Walker 1989;

Loomes 2010 and many unpublished reports of Pilbara flora). The basis for assessing the significance of the vegetation at Koodaideri is not well developed and, therefore, no attempt has been made to relate plant species richness at Koodaideri to other sites. Data from the Pilbara Biodiversity Survey (Lyons *et al*. unpublished data) is likely to become available in 2012 to provide an ideal framework for assessment.

Other than the occurrence of a single Priority 4 species, *Rhynchosia bungarensis*, the riparian and floodplain flora did not have high conservation value at the species level. The presence of large, old *Ficus* trees adds to the aesthetic and conservation values of the spring and the vegetation at Koodaideri is relatively intact, with no evidence of current disturbance by livestock and few weeds. However, overall, the plant community at Koodaideri Spring does not have particular conservation significance. This situation is typical of Pilbara wetlands (M.N. Lyons personal communication).

Macrophytes are the component of the wetland flora with the highest conservation value in the Pilbara (Casanova 2004). For this reason, the single species of *Chara*, which could not be further identified, may have some conservation significance. However, most wetlands with high conservation value macrophytes contain several macrophyte species. This is not the case at Koodaideri where a single species was recorded. On this basis, it is considered unlikely that *Chara* sp. will be of conservation importance. No comment can be made about the unidentified Cyperaceae in the aquatic zone other than it is unlikely to be a conservation significant species.

Fish

The framework for assessing the value of Pilbara watercourses for fish is well developed (Morgan and Gill 2004). Most waterbodies in the Pilbara contain fish and their absence from the Koodaideri Spring system in both sampling seasons is surprising. While it remains possible that fish were present, but not collected by the range of survey methods employed here, this scenario is considered to be unlikely. WRM (2009) recorded no fish from some headwater sites upstream of waterfalls, although they also used an electro-fisher, and concluded that lack of connectivity and occasional drying were the most likely explanations for the absence of fish. At Koodaideri, the isolation of the stream from other surface water and possible occasional drying are also the likely reasons fish were absent.

Survey limitations

The results of this provide the basis for characterising the biological community at Koodaideri Spring. While the identity of the two plant species in the aquatic zone could not be determined, it is considered that species level determinations would be unlikely to affect the assessment of the conservation significance of the site.

No survey of aquatic algae was undertaken, although Pilbara wetlands may contain significant diversity of benthic and planktonic algae, especially diatoms and desmids.

5. CONCLUSIONS

The wet season and dry season surveys of Koodaideri Spring showed:

- the spring has a relatively rich aquatic invertebrate fauna with more species than most well-known spring sites,
- two invertebrate species may be known only from the spring. These invertebrate species are the mite *Stygolimnochares* nr *australica* and amphipod *Chydaekata* sp. In both cases taxonomic

work is required to resolve the status of the species and it is expected that this work would show the species have wider distributions than Koodaideri Spring,

- the riparian and floodplain flora did not have high conservation value at the species level, although the vegetation community was relatively undisturbed and aesthetically attractive. This is typical of Pilbara wetlands,
- a single conservation-significant plant species, *Rhynchosia bungarensis*, was found, and
- there was no evidence of fish at Koodaideri. This was attributed to occasional drying of surface water and the difficulty of re-colonising a remote headwater site.

In conclusion, based on results of the two surveys undertaken, the main conservation values of the Koodaideri Spring system are its lack of disturbance, the aesthetics of the site, and the presence of a large number of aquatic invertebrates, including a suite of species characteristic of groundwater or spring habitats.

One way of assessing the conservation significance of Koodaideri Spring is to compare it with other Pilbara springs that are already of recognized value. Koodaideri has aquatic conservation values that are similar to those of Weeli Wolli Spring, although Koodaideri contains about 10% more species. It supports about 60% more species than were recorded in the Millstream delta during the Pilbara Biodiversity Survey.

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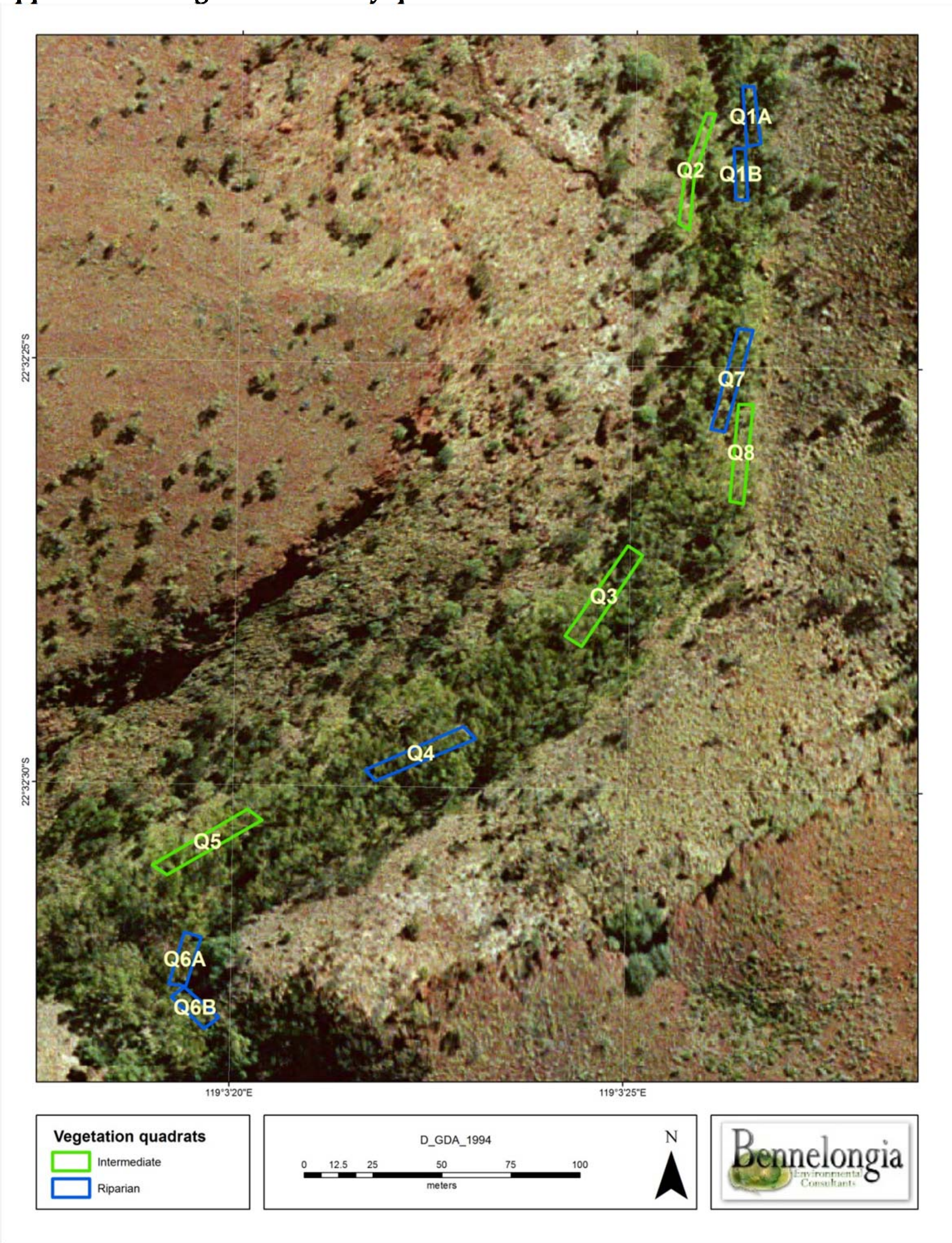
7. APPENDICES

Appendix 1a. Coordinates of vegetation survey quadrats.

Habitat	Quadrat	Location	Waypoint	Coordinates
Riparian	1	North of Pool 3	Q1A NE	-22º32’21.70” S, 119º3’26.35” E
		Two 20x5m quadrats (A & B) on	Q1A NW	-22º32’32.37” S, 119º3’26.21” E
		east & west sides of channel	Q1A SE	-22º32’32.36” S, 119º3’26.42” E
			Q1A SW	-22º32’32.36” S, 119º3’26.24” E
			Q1B NE	-22º32’32.38” S, 119º3’26.24” E
			Q1B NW	-22º32’32.38” S, 119º3’26.10” E
			Q1B SE	-22º32’32.37” S, 119º3’26.28” E
			Q1B SW	-22º32’32.37” S, 119º3’26.14” E
Floodplain	2	North-west of Pool 3, begins	Q2 NE	-22º32’32.38” S, 119º3’25.85” E
		10m south of Q1	Q2 NW	-22º32’32.38” S, 119º3’25.74” E
		One 40x5m quadrat	Q2 Mid E	-22º32’32.39” S, 119º3’25.60” E
			Q2 Mid W	-22º32’32.39” S, 119º3’25.49” E
			Q2 SE	-22º32’32.37” S, 119º3’25.52” E
			Q2 SW	-22º32’32.37” S, 119º3’25.42” E
Floodplain	3	South of Pool 3	Q3 NE	-22º32’32.47” S, 119º3’25.02” E
		One 40x5m quadrat, north-	Q3 NW	-22º32’32.47” S, 119º3’24.80” E
		west of channel	Q3 SE	-22º32’32.45” S, 119º3’24.26” E
			Q3 SW	-22º32’32.45” S, 119º3’24.05” E
Riparian 4	4	Alongside south-east bank	Q4 NE	-22º32’32.50” S, 119º3’22.93” E
		of Pool 2	Q4 NW	-22º32’32.50” S, 119º3’22.75” E
		One 40x5m quadrat	Q4 SE	-22º32’32.49” S, 119º3’21.67” E
			Q4 SW	-22º32’32.49” S, 119º3’21.53” E
Floodplain	5	North-west of Pool 1	Q5 NE	-22º32’32.52” S, 119º3’20.23” E
		One 40x5m quadrat	Q5 NW	-22º32’32.52” S, 119º3’20.05” E
			Q5 SE	-22º32’32.51” S, 119º3’19.01” E
			Q5 SW	-22º32’32.51” S, 119º3’18.83” E
Riparian	6	North of spring source	Q6A NE	-22º32’32.54” S, 119º3’19.48” E
		Two 20x5m quadrats on east	Q6A NW	-22º32’32.54” S, 119º3’19.26” E
		and west banks of channel	Q6A SE	-22º32’32.53” S, 119º3’19.30” E
			Q6A SW	-22º32’32.53” S, 119º3’19.08” E
			Q6B NE	-22º32’32.55” S, 119º3’19.26” E
			Q6B NW	-22º32’32.55” S, 119º3’19.12” E
			Q6B SE	-22º32’32.54” S, 119º3’19.69” E
			Q6B SW	-22º32’32.54” S, 119º3’19.51” E
Riparian	7	Immediately south of Pool 3	Q7 NE	-22º32’32.43” S, 119º3’26.35” E
		on west bank of channel	Q7 NW	-22º32’32.43” S, 119º3’26.17” E
		One 40x5m quadrat	Q7 SE	-22º32’32.41” S, 119º3’26.03” E
			Q7 SW	-22º32’32.41” S, 119º3’25.85” E
Floodplain	8	20m south of Q7 on east	Q8 NE	-22º32’32.44” S, 119º3’26.39” E
		of channel	Q8 NW	-22º32’32.44” S, 119º3’26.21” E
		One 40x5m quadrat	Q8 SE	-22º32’32.42” S, 119º3’26.28” E
			Q8 SW	-22º32’32.42” S, 119º3’26.10” E

Appendix 1b. Vegetation survey quadrats.



Appendix 2. Water chemistry at Koodaideri spring in October 2010.

Analysis by ChemCentre, all results in mg L^{-1} except conductivity (µS cm^{-1}), turbidity (NTU) and colour (TCU), trigger values for protection of 95% of freshwater aquatic species (ANZECC & ARMCANZ 2000). nd = no data, * indicates marine trigger value.

Analyte	Concentration	Trigger value
Total Dissolved Solids	220	-
Electrical conductivity	403	-
pH	7.04	-
Turbidity	12	-
Colour	4	-
Anions		-
Na	17.6	-
K	4.7	-
Ca	19.7	-
Mg	21.6	-
Mn	0.019	-
Cations		-
Cl	31	-
HCO_3	153	-
CO_3	<1	-
SO_4	24.7	-
Nutrients		-
Total P	0.01	-
Total N	0.18	-
N_NO3	0.09	-
N_NO2	<0.01	-
N_NH_3	0.02	-
Metals		-
Al	<0.005	0.055
As	<0.001	0.024
B	0.18	0.370
Ba	0.004	nd
Cd	<0.0001	0.020
Co	<0.005	nd, 0.001*
Cr	<0.001	0.001
Cu	<0.002	0.001
Fe	0.048	nd
Mo	<0.001	nd
Ni	<0.001	0.011
Pb	<0.0001	0.003
V	<0.005	nd, 0.100*
Zn	<0.005	0.008

Appendix 3. Aquatic invertebrate species.

Aquatic invertebrates collected from Koodaideri Spring in October 2010 and April 2011.
Number of animals identified each sampling date is shown.

Group	Species	2010	2011
Protozoa	*Arcella* sp.		5
	Centropyxis sp.		10
	Lecquereusia sp.	10	10
	Euglypha sp.	2	2
Cnidaria	*Hydra* sp.	20	9
Nematoda	Nematoda sp.	2	2
Rotifera	*Pleuretra* sp. B1 (nr *brycei*)		2
	Bdelloidea sp. 2:2	20	10
	Lepadella patella	1	1
	Euchlanis dilatata	2	5
	Lecane bulla	30	20
	Lecane hornemanni		1
	Lecane luna		2
	Lecane papuana	10	20
	Lecane ungulata	20	
	Mytilina ventralis	2	1
	Trichocerca similis		2
Mollusca	*Austropeplea vinosa*	10	10
	Ferrissia sp.	3	
	Gyraulus sp.	12	
	Gyraulus sp. (KIM-MS)		4
Annelida	Glossiphoniidae sp.	8	
	Allonais pectinata	30	20
Acariformes	*Hydrachna* sp.		1
	Limnochares sp.	2	
	Stygolimnochares nr *australica*		1
	Rutacarus sp.	1	
	Limnesia sp. 4 (PSW)	8	27
	Aspidiobates pilbara	2	2
	Austraturus longipalpis	1	
	Gretacarus bifalcisetus		1
	Arrenurus sp. P2 (nr *roobecki*)(PSW)		17
	Halacaridae sp.	2	
	Oribatida sp.	5	3
	Oribatida sp. 4 (PSW)	1	
	Mesostigmata sp		3
Cladocera	*Alona rectangula*	3	
	Alonella cf. *clathratula*	3	1
	Dunhevedia crassa		10
Ostracoda	*Limnocythere dorsosicula*	5	10
	Penthesilenula brasiliensis		2
	Vestalenula marmonieri	50	5
	Vestalenula matildae	5	1
	Candonocypris fitzroyi	80	15
	Cypretta sp. PSW074 (PSW)	10	16

Group	Species	2010	2011
	Ilyodromus sp BOS025		3
	Stenocypris major	5	6
	Cypridopsis sp.	200	5
Copepoda	*Microcyclops varicans*	1	2
	Ectocyclops phaleratus	5	
	Australoeucyclops karaytugi	10	
	Mesocyclops darwini	10	5
	Paracyclops chiltoni		2
	Parastenocaris sp.	1	
Amphipoda	*Chydaekata* sp.	22	5
Coleoptera	Carabidae sp.		1
	Laccophilus sharpi		5
	Hydrovatus sp.	1	
	Rhantus suturalis		1
	Hydaticus daemeli		8
	Onychohydrus atratus	10	
	Austrodytes insularis		4
	Cybister tripunctatus	3	2
	Cybister sp.		4
	Macrogyrus gibbosus	10	9
	Macrogyrus sp.		2
	Dineutus australis		2
	Regimbartia attenuata		1
	Paranacaena horni	3	4
	Enochrus elongatus		2
	Enochrus deserticola		2
	Limnoxenus zelandicus		1
	Paracymus spenceri		1
	Sternolophus marginicollis	1	2
	Sternolophus australis	5	5
	Unknown hydrophillid P1 (PSW)	2	
	Hydraena sp.	1	5
	Scirtidae sp.	16	17
	Staphylinidae sp.		1
	Pselaphinae sp.		4
Diptera	Tipulidae type P2 (nr SAP type H) (PSW)	4	
	Tipulidae type P4 (nr SAP type I) (PSW)		2
	Anopheles annulipes s.l.	2	2
	Culex (Culex) annulirostris		2
	Culex starkae	11	
	Alluaudomyia sp.	2	
	Bezzia sp. P1 (PSW)	3	
	Bezzia sp. P2 (PSW)	2	
	Culicoides sp.	1	
	Monohelea sp. P1 (PSW)	3	2
	Monohelea sp. B1		1
	Monohelea sp. B2		1
	Nilobezzia sp. P2 (PSW)	1	4
	Stilobezzia sp.	5	

Group	Species	2010	2011
	Brachypogon sp.	1	
	Dasyheleinae sp. P1 (PSW)	8	
	Dasyheleinae sp. P2 (PSW)	6	1
	Simulium sp.	2	
	Simulium nr *nicholsoni*		9
	Tabanidae sp.	2	9
	Stratiomyidae sp.	5	7
	Dolichopodidae sp. P1 (PSW)	3	1
	Syrphidae sp.		1
	Sciomyzidae sp.	2	1
	Muscidae sp.	2	
	Procladius paludicola	5	25
	Ablabesmyia hilli	1	2
	Ablabesmyia notabilis	10	3
	Paramerina sp.A (?*parva*) (SAP)		10
	Pentaneurini sp. P1 (PSW)	3	2
	Rheocricotopus cf. P1 (KMS)	10	10
	Parakiefferiella sp P1 (PSW)	30	2
	Corynoneura sp. P2 (PSW)	7	1
	Larsia albiceps	10	2
	Thienemanniella sp. P1 (PSW)	3	1
	Orthocladiinae sp. G (SAP)	2	
	Tanytarsus sp. D (SAP)	5	
	Tanytarsus sp. H (SAP)	20	15
	Tanytarsus sp. P1 (PSW)	20	10
	Tanytarsus sp. P9 (PSW)	5	
	Tanytarsus sp. P10 (PSW)		2
	Rheotanytarsus trivittatus	3	
	Stenochironomus watsoni	3	
	Stenochironomus sp.		5
	Chironomus aff. *alternans* (V24) (CB)	20	5
	Dicrotendipes jobetus		2
	Dicrotendipes 'CA1' Pilbara type 3 (= 'K4', P3)) (PSW)	20	
	Dicrotendipes sp P4 (PSW)	10	3
	Kiefferulus tumidus	2	3
	Polypedilum nubifer		1
	Polypedilum nr *vespertinus* (M2) (SAP)	4	4
	Polypedilum sp. S1 (PSW)	10	10
	Polypedilum sp. K1 (PSW)	10	
	Paratendipes sp. 'K1' (PSW)		10
	Skusella subvittata	3	10
	Cryptochironomus griseidorsum	1	10
Ephemeroptera	*Cloeon* sp.	2	10
	Tasmanocoenis arcuata	18	30
Hemiptera	*Mesovelia vittigera*	1	1
	Hebrus sp.	1	
	Merragata hackeri	3	
	Microvelia (Austromicrovelia) peramoena	9	40
	Limnogonus luctuosus	3	15

Group	Species	2010	2011
	Laccotrephes tristis	4	
	Ranatra diminuta		8
	Diplonychus eques	2	11
	Micronecta lansburyi		12
	Micronecta n. sp. P3 (PSW)	17	
	Enithares woodwardi	15	20
	Anisops hackeri		2
	Anisops elstoni	2	3
	Anisops nabillus		1
	Anisops sp. A	6	10
	Paraplea sp.		1
Lepidoptera	Pyralidae sp. 3 of JHH (PSW)	10	3
	Lepidoptera sp.		2
Odonata	*Argiocnemis rubescens*	4	26
	Ischnura aurora aurora	2	2
	Ischnura heterosticta heterosticta	1	1
	Pseudagrion aureofrons	1	
	Xanthagrion erythroneurum	3	
	Adveraeshna brevistyla		7
	Hemianax papuensis	4	2
	Austroepigomphus (Xerogomphus) gordoni		3
	Diplacodes bipunctata	3	
	Diplacodes haematodes	7	2
	Nannophlebia injibandi	2	10
	Orthetrum caledonicum		2
	Orthetrum pruinosum migratum	12	28
	Rhodothemis lieftincki	10	1
	Traema stenoloba	6	40
	Zyxomma elgneri		1
	Ictinogomphus dobsoni		1
	Hemicordulia tau		3
Trichoptera	*Hellyethira* sp.	4	
	Chimarra sp AV17 (PSW)	9	3
	Cheumatopsyche wellsae	8	10
	Ecnomus pilbarensis	11	5
	Oecetis sp. Pilbara 4 (PSW)	2	
	Triaenodes sp.		2
	Triplectides australis	2	2
	Triplectides ciuskus seductus	20	30

Appendix 4. Percentage cover of different plant species according to stream zone.

Results of walk-around survey are included under headings 1, aquatic; 2, emergent; 3, riparian; 4, floodplain. *, introduced. Quadrat survey results are included in the Q1-Q8 headings. To highlight, covers for the walk-around are for the entire areas of each zone compared to that of the cover of plants in the 40x5m quadrats.

		Walk-around				Riparian				Floodplain			
Family	Species Name	1	2	3	4	Q1	Q4	Q6	Q7	Q2	Q3	Q5	Q8
Amaranthaceae	*Achyranthes aspera*			1	1						0.5		
	**Aerva javanica*				1					0.5			
	Chenopodiaceae sp.			1	1								
	Gomphrena cunninghamii				1					0.5			
Apocynaceae	*Cynanchum floribundum*			1	1		1	1	0.5	0.5			
Asteraceae	**Lactuca serriola*			1	1	5				0.5			
	**Sonchus oleraceus*			1	1	0.5							
Boraginaceae	*Trichodesma zeylanicum* var. *zeylanicum*			1	1								
Capparaceae	*Capparis lasiantha*			1	1								
	Capparis spinosa var. *nummularia*			1	1			0.5		0.5	0.5		
	Capparis umbonata				1							1	
Characeae	*Chara* sp.	5											
Cladophoraceae	Algae sp.	50											
Cleomaceae	*Cleome viscose*			1	1					0.5			
Convolvulaceae	*Duperreya commixta*			1	1	1.5	0.5			0.5	1	1	0.5
Cucurbitaceae	*Cucumis maderaspatanus*			1									
Cyperaceae	Cyperaceae sp.	1											
	Cyperus vaginatus		60	40		25	90	20	50			1	
Euphorbiaceae	*Euphorbia schultzii*			1	1								
	Euphorbia australis			1	1								
	Zelaya galericulata subsp. *galericulata*			1	1								
Fabaceae	*Acacia arida*				1						0.5		
	Acacia bivenosa			1	1						2	0.5	
	Acacia coriacea subsp. *pendens*				1						0.5		0.5
	Acacia inaequilatera				1					0.5		1	
Fabaceae	*Acacia pruinocarpa*				1					0.5	0.5	0.5	0.5
	Acacia pyrifolia DC. var. *pyrifolia*				1					1	1	1	1
	Acacia tumida var. *pilbarensis*			1	5	1				25	20	2	10
	Crotalaria novae-hollandiae			1							0.5		

		Walk-around				Riparian				Floodplain			
Family	Species Name	1	2	3	4	Q1	Q4	Q6	Q7	Q2	Q3	Q5	Q8
	Cullen lachnostachys				1								
	Flueggea virosa			1				0.5					
	Glycine canescens			1	1						1		
	Petalostylis cassioides			1	1						0.5		0.5
	Phyllanthus reticulates			5		4	0.5	2					
	Rhynchosia bungarensis			1	1						4	5	2
	Rhynchosia minima				1					0.5	0.5		0.5
	Senna notabilis				1								
	Senna venusta			1									
	Tephrosia rosea			1	1								0.5
Loranthaceae	*Lysiana casuarinae*				1								
Malvaceae	*Abutilon dioicum* ms			1	5						0.5	0.5	0.5
	Corchorus lasiocarpus subsp. *lasiocarpus*			5							0.5		0.5
	Gossypium australe			1	5						1	0.5	0.5
	Gossypium robinsonii			1	1	1			0.5	5	5	0.5	2
Menispermaceae	*Tinospora smilacina*			1				1					
Moraceae	*Ficus brachypoda*			15	5	1	35	60		0.5	0.5		
	Ficus virens				5								
Myrtaceae	*Corymbia hamersleyana*				1						5	2	15
	Eucalyptus camaldulensis subsp. *obtusa*			80	10	75	90	50	70	5	10	30	5
Oleaceae	*Jasminum didymum* subsp. *lineare*			1									
Poaceae	*Aristida inaequiglumis*				1								
	**Cenchrus ciliaris*			15	40	20		0.5	1	90	80	75	35
	Cymbopogon ambiguus			1	10				0.5		0.5		0.5
	Enneapogon lindleyanus			1	1								
	Enteropogon ramosus			1	5							15	
	Eriachne helmsii				1								
Poaceae	*Eulalia aurea*			60	5	15			10				
	Iseilema membranaceum			1	1								
	Themeda sp. Mt. Barricade (M.E. Trudgen 2471)			5	5	0.5					2		15
Proteaceae	*Grevillea wickhamii* subsp. *hispidula*				1								
Rutaceae	*Clerodendrum tomentosum*			1			0.5						
	Clerodendrum tomentosum var. *lanceolatum*				5								0.5
Santalaceae	*Santalum lanceolatum*			1	1						0.5	1	1

		Walk-around				Riparian				Floodplain			
Family	Species Name	1	2	3	4	Q1	Q4	Q6	Q7	Q2	Q3	Q5	Q8
Sapindaceae	*Atalaya hemiglauca*			1	1			0.5			2	1	0.5
	Dodonaea sp.				1								
Scrophulariaceae	*Eremophila longifolia*				1							0.5	
Solanaceae	*Solanum ?lasiophyllum*			1	1					0.5	0.5	1	
Surianaceae	*Stylobasium spathulatum*				1						0.5	4	
Typhaceae	*Typha domingensis*	35	60	10		5	0.5	0.5	6				