A preliminary survey and analysis of the spatial distribution of aquatic invertebrates in the Okavango Delta, Botswana

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The spatial distribution of aquatic macroinvertebrates in the Okavango River Delta, Botswana, was investigated during the low-water period in February 2003. This complements an earlier study undertaken during high-water in June 2000. Seventy-five samples were taken in a range of aquatic habitats at 29 georeference points in four focal areas: Upper Panhandle (UPH), Lower Panhandle and Guma Lagoon (LPH), Moremi Game Reserve/Xakanaka (MGR), and Chief's Island (CI). Over 180 morphospecies (approximately 63 families) were recorded during the survey. Multivariate analyses of macroinvertebrate assemblages indicated that assemblages in each of the four focal areas were at least 54% similar at morphospecies level, and 71% similar at family level, although some taxa were more or less common in different areas. Differences in macroinvertebrate assemblages were observed amongst different habitat types, with differences most pronounced between the deltaic habitats and isolated seasonally-flooded pools and temporary rain-filled pools in MGR and CI. The highest number of taxa was recorded in the MGR (125), followed by the UPH (96), CI (93) and the LPH (89) areas. The most families were recorded in the Hemiptera (11), followed by Mollusca (10), Diptera (nine), Coleoptera (nine), Crustacea (six), Ephemeroptera (six) and Odonata (four). Three families of Hirudinea and Trichoptera, and one family of Lepidoptera, were also recorded. Hydracarina were common but not identified beyond order, while Oligochaeta were less frequently recorded. With respect to the different aquatic habitats sampled, the highest number of taxa was recorded in marginal vegetation in the channels and lagoons, although inundated floodplains, floating vegetation and marginal vegetation in backwaters also supported many taxa. The fewest taxa were recorded in sediment. This survey, whilst representing a 'snapshot' of the system under low-water conditions, highlights the importance of maintaining a mosaic of aquatic habitats in the Delta. Further studies would enhance our knowledge of the aquatic macroinvertebrate biodiversity of the Okavango Delta, thereby contributing to its conservation.

Keywords: biodiversity, conservation, freshwater habitats, habitat heterogeneity, species assemblages

Introduction

The Okavango Delta, one of the largest inland deltas in the world, is a highly variable and complex aquatic ecosystem. Other inland deltas in Africa include the Niger Inland Delta in Mali and the Sudd, which straddles the Nile in southern Somalia. The Okavango Delta has been recognised as a unique and valuable ecosystem and has been frequently cited as being extremely vulnerable to external influences (Ellery and McCarthy 1994, McCarthy *et al.* 2000, Ashton and Neal 2002, Ashton *et al.* 2003b). Its structure is determined largely by the climatic regime, physical and chemical environment, and the biological interactions that occur within it (Gronberg *et al*. 1995, Gronberg 1996). The Delta is divided into three major biomes: permanent swamp, seasonal swamp and drainage rivers, which create a mosaic of aquatic habitats for the biota occurring there. Rain falling in the catchment in Angola drains via the Cuito and Cubango-Okavango Rivers, entering Botswana at Mohembo in the Upper Panhandle of the Delta. Ninety-five percent of the runoff entering the Delta originates in Angola (Ashton 2000). The annual flooding of the Delta, which peaks between February and May in the Upper Panhandle and reaches the distal end of the Delta by July, is vital for the survival of the Okavango Delta ecosystem. One of the great ecological values of the Okavango Delta is that the flood here is at its peak when the surrounding Kalahari Desert is at its driest, thereby providing a crucial source of water to its inhabitants.

Whilst a significant amount of scientific research has been undertaken on the hydrology, physico-chemistry, geology, geomorphology and vegetation of the Delta (e.g. Sawula and Martins 1991, Ellery *et al*. 1993, Hart 1997, McCarthy and Ellery 1998, McCarthy *et al*. 1998, McCarthy *et al*. 2000, Ashton *et al*. 2003a), few studies — with the exception of those on fish (e.g. Merron 1993) and fisheries (Tweddle *et al.* 2003) — have examined its aquatic biology. Whilst no studies have been conducted in the Angola sector of the Delta, Taylor's (1999) study in the perennial rivers of

the Caprivi and Kavango regions investigated the prevailing water quality and tested and modified a biomonitoring method originally developed in South Africa (Chutter 1998). In particular, studies on the Delta's aquatic macroinvertebrates are very limited (Masundire *et al*. 1998) and have focused largely on molluscs (Appleton 1979, Curtis and Appleton 1987, Brown *et al*. 1992, Curtis 1997) and coleopterans (Bilardo and Rocchi 1987), with one general assessment undertaken during high-water levels in 2000 (Appleton *et al*. 2003).

Macroinvertebrates form a major component of the biota of aquatic ecosystems and are associated with various aquatic habitats (e.g. Palmer *et al*. 1991, Collier 1995, Dallas 1997, Dallas 2002, 2007, Bonado *et al*. 2006) such as the following: stony beds; marginal, floating and instream vegetation; and sand. They are mostly primary (feeding on plant material), and secondary (feeding on planktonic or benthic organisms), consumers near the base of the food chain and are therefore essential elements in the functioning of aquatic ecosystems. Macroinvertebrates are largely dependent on the aquatic environment in which they live and are sensitive to factors such as water quality, water quantity (environmental flows), and habitat and food availability. They are therefore frequently used as indicators of the general ecological condition, also referred to as ecosystem health.

The aims of this study were to assess the spatial distribution of aquatic macroinvertebrates amongst and within four focal areas of the Okavango River Delta during the low-water period in February 2003, and to examine the association between macroinvertebrate assemblages and aquatic habitats.

Materials and methods

Study area

Aquatic macroinvertebrates were sampled at 29 georeference points ('sites') in four focal areas of the Delta, namely: (1) Upper Panhandle (UPH); (2) Lower Panhandle and Guma Lagoon (LPH); (3) Moremi Game Reserve/Xakanaka (MGR); and (4) Chief's Island (CI) (Figure 1). The number of sites and habitats sampled in each focal area are given in Table 1. Whilst the sites represent a relatively limited spatial distribution within the Okavango River Delta, they are representative of areas in the permanent swamp, the seasonal swamp and the drainage rivers, and thus represent different types of broad habitat within the Delta.

Aquatic invertebrate sampling

The key criterion for sampling was to ensure that a variety of available aquatic habitats within each of the four focal areas were sampled. Ten habitats were identified: marginal vegetation in channels; marginal vegetation in lagoons; marginal vegetation in backwater areas joined to the main channel; inundated floodplain areas adjacent to, but isolated from, the main channel; floating vegetation, either in channels or lagoons; instream vegetation submerged in the water; sediment in either channels or backwater areas; isolated seasonally-flooded pools; isolated temporary rain-filled pools; and backwater detritus areas. Semi-quantitative sampling of macroinvertebrate assemblages from each habitat was undertaken using two nets, a D-net (500µm mesh) and a kick net (30cm x 30cm square frame, 950µm mesh). Two people sampled each habitat intensively for 2min by sweeping nets through the vegetation, sediment and/or water. Given the variation in habitat type and accessibility to different habitats, sampling was standardised as sampling effort (i.e. time sampled). Based on preliminary sampling over a longer time period, two minutes was considered sufficient to collect the variety of aquatic taxa associated with a particular habitat. Material collected in each of the two nets was combined and the sample was sorted on site, using large sorting trays, and the abundance of each taxon was estimated using the following scale: 1 individual, 2–10 individuals, 11–100 individuals, 101–1 000 individuals and >1 000 individuals. No replicate sampling was undertaken, due to time constraints. Taxa were initially identified in the field, mostly to family level, and specimens were collected and preserved in 7% formalin and later transferred to 70% ethanol. Further separation of taxa was undertaken by identifying taxa to 'morphospecies', which were verified in the laboratory and identified to genus where possible. Certain groups were not identified beyond class (Oligochaeta), order (Acarina) or family (Baetidae, Caenidae, Lepidoptera and some Diptera), due either to the unavailability of taxonomic specialists or to inadequate identification keys or to poorly-known taxonomy. Thus, whilst sampling aimed to collect all aquatic macroinvertebrate taxa, specialist identification beyond family level was limited to crustaceans, ephemeropterans, hemipterans, trichopterans, coleopterans and molluscs.

Data analysis

Statistica (Version 6.1) was used for univariate analyses and Primer (Version 5) for multivariate analyses. Cluster analysis and non-metric multidimensional scaling (MDS) were used to examine similarities amongst focal areas, sites and aquatic habitats, based on macroinvertebrate assemblage composition (Clarke and Warwick 1994). Semi-quantitative data were either presence/absence-transformed or not transformed, in which case rank abundances were used. In both instances, the Bray-Curtis coefficient was applied to the data. Hierarchical agglomerative clustering, using group-average linking, was applied to the data matrix, to produce a dendrogram. Ordination of samples by MDS was undertaken and stress values used to assess the reliability of the MDS ordination.

Results

Aquatic vegetation in the Upper and Lower Panhandle and Guma Lagoon areas was dominated by *Cyperus papyrus*, *Vossia cuspidata* and *Phragmites* sp./spp. Species assemblages changed in the Moremi Game Reserve and Chief's Island areas to a mosaic of aquatic, semi-aquatic and terrestrial habitats and species (Murray-Hudson and Heinl in press). Marginal vegetation and inundated floodplains in these areas largely comprised different proportions of *Phragmites australis*, *C. papyrus*, grasses (including *V. cuspidata*, *Pycreus mundii*, *Echinochloa pyramidalis*, *Panicum repens* and *Miscanthus junceus*), or aquatic species such as *Ceratophyllum demersum*. Floating vegetation was

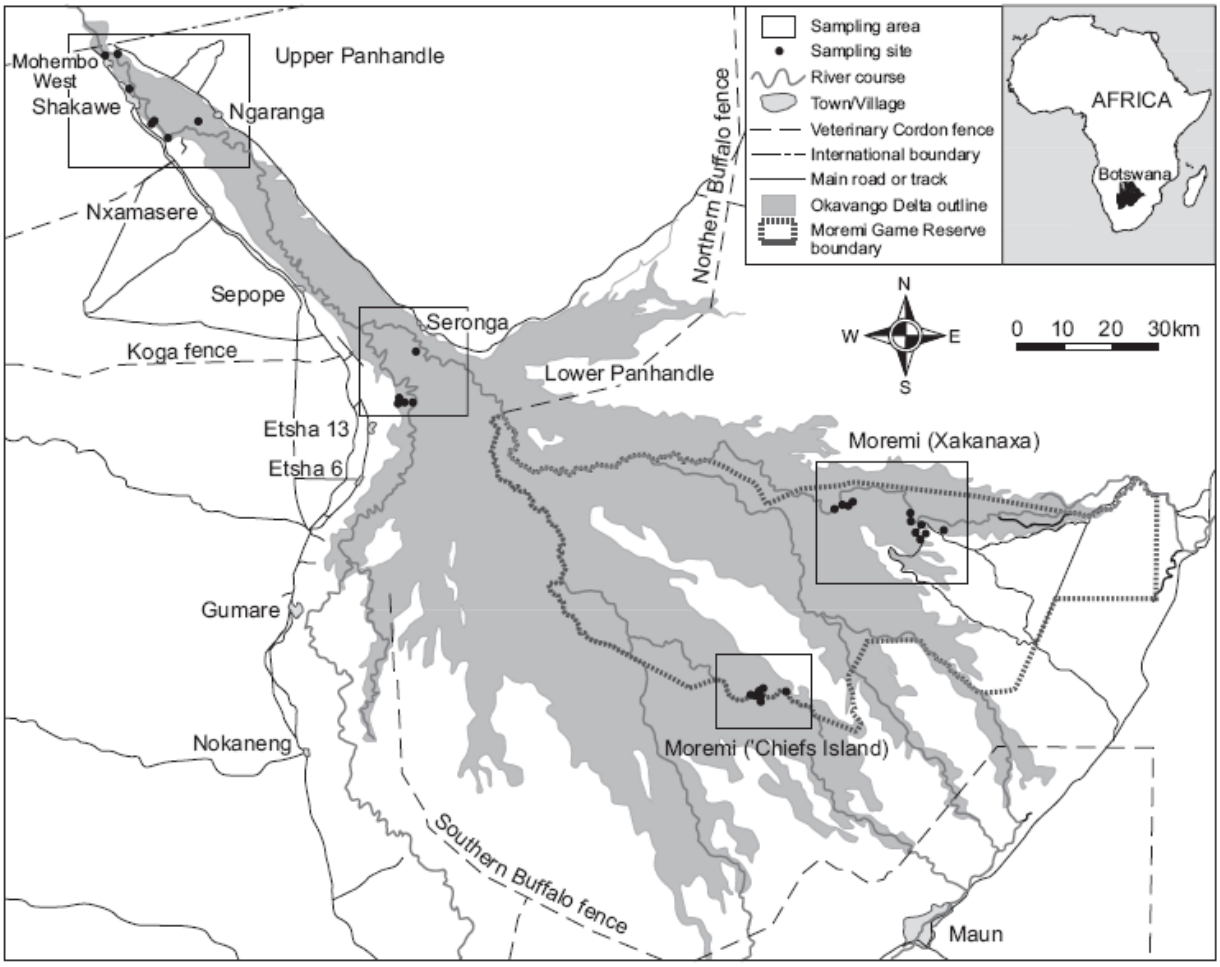

Figure 1: The Okavango Delta, Botswana, showing georeference points in each of the four focal areas

Table 1: The number of sites and habitats sampled in four focal areas of the Okavango Delta: Upper Panhandle (UPH), Lower Panhandle (LPH), Moremi Game Reserve (MGR) and Chief's Island (CI)

Focal area		UPH	LPH	MGR	CI
Number of sites		7	6	9	8
Number of habitats sampled		20	21	19	15
Habitat types sampled	Marginal vegetation in channels	8	4	2	3
	Marginal vegetation in lagoons	1	8	5	2
	Floating vegetation	2	3	1	5
	Inundated floodplains	3	1	1	0
	Marginal vegetation in backwaters	3	1	1	1
	Temporary rain-filled pools	0	0	2	2
	Seasonally-flooded pools	0	0	3	1
	Instream vegetation	0	0	2	0
	Sediment	2	4	2	1
	Backwater detritus	1	0	0	0

largely *Nymphaea nouchalii* and *Trapa natans*, while instream vegetation included *Potamageton* spp. or *Rotala myriophylloides*. Further details are available in Murray-Hudson and Heinl (in press).

Macroinvertebrate assemblages per focal area

Upper Panhandle

Although this survey was conducted in the low-flow period, floodwaters had arrived early during the year of study and

had reached the Upper Panhandle approximately three weeks prior to the survey. Marginal vegetation was dominated by *V. cuspidatus*, *C. papyrus* and *P. australis*. Floating vegetation was dominated by *Nymphaea* spp. (water lilies) and *T. natans*. A total of 96 morphospecies was recorded. Oligochaetes were present and crustaceans, particularly conchostracans and Atyidae, as well as Hydracarina, were common. Five families of Ephemeroptera (Baetidae, Caenidae, Heptageniidae, Polymitarcyidae and Tricorythidae) were recorded, mostly in marginal vegetation in channels. Three families of odonates (Aeschnidae, Gomphidae and Libellulidae) were recorded, of which the Libellulidae were commonest. Several families of Hemiptera (nine), Coleoptera (seven), Diptera (six) and Mollusca (six) were recorded. Three families of Trichoptera were recorded, including one hydroptilid and three leptocerid caddisflies. Molluscs, both prosobranchs and pulmonates, were frequently recorded in inundated floodplains and marginal vegetation-backwater habitats. *Cleopatra elata* (Thiaridae) was common and three species of *Bulinus* (Planorbidae) were recorded. No mutelid, unionid or sphaerid bivalves were recorded.

Of note here was the decrease in taxon richness downstream of the Samochima agricultural pump station. A sample taken in the same marginal vegetation (*V. cuspidatus)* habitat 50m upstream of the pump had 16 taxa, including four ephemeropteran families and two trichopteran families, whereas one from 50m downstream of it had six taxa, with only two ephemeropteran taxa and no trichopterans. Downstream of the pump, oligochaetes and '*Chironomus*' midges were recorded and the grasses were coated with algae.

Lower Panhandle and Guma Lagoon

Most samples were taken in Guma Lagoon, with one in the Thaoge Channel and associated lagoon. One additional site was selected on the main channel upstream of the confluence of the Okavango River and the Thaoge Channel. The early floodwaters had also recently reached this point on the main channel and the water was very turbid. A total of 89 morphospecies was recorded. Hydracarina, conchostracans and Atyidae were common in marginal vegetation habitats. Baetid, caenid and polymitarcyid mayflies were recorded in marginal vegetation in lagoons. A number of families of Odonata (three), Hemiptera (nine), Coleoptera (seven), Diptera (four) and Mollusca (nine) were recorded across the range of habitats. Two families of Trichoptera were recorded, including one ecnomid and two leptocerid caddisflies. Lepidopteran larvae were recorded in floating and marginal vegetation in channels. Molluscs recorded included prosobranchs, pulmonates and bivalves, with mutelid and unionid bivalves restricted to sandy sediments. *Biomphalaria pfeifferi*, the intermediate host for *Schistosoma mansoni* (the parasite causing human intestinal schistosomiasis) was recorded at all sites in this focal area.

Moremi Game Reserve/Xakanaka Lagoon

The Gadikwe and Xakanaka lagoons and the Maunachira Channel joining them, and isolated seasonally-flooded pools and temporary rain-filled pools, were sampled. The range of aquatic habitats was diverse (n = 9) and a total of 125 morphospecies was recorded. A number of families of Odonata (three), Hemiptera (nine), Coleoptera (six), Diptera (seven) and Mollusca (eight) were recorded in the lagoon and channel habitats. Hydracarina were common, as were conchostracans and Atyidae in marginal vegetation habitats. Baetid, caenid and polymitarcyid mayflies were regularly recorded in marginal vegetation in channels and lagoons. The only Leptophlebid mayfly collected in the Delta during this survey, *Euthraulus* sp., was recorded here. One ecnomid and four leptocerid cased-caddisflies were recorded in instream vegetation and marginal vegetation in channels and lagoons. One of these, *Setodes* sp., was an unusual record and is likely to be a new species (FC de Moor, Albany Museum, South Africa, pers. comm.). Lepidopteran larvae were recorded in instream and floating vegetation. Eight families of molluscs were recorded, including prosobranchs, pulmonates (mostly Planorbidae) and bivalves, with mutelid and unionid bivalves restricted to sandy sediments. The thiarid snail *Melanoides victoriae* was recorded only in the MGR, where it was found buried in the marginal sediment and vegetation of the lagoons. *Bulinus pfeifferi* was present in the Gadikwe and Xakanaka Lagoons and the Maunachira Channel. Tipulid diptera were recorded only in the inundated floodplain habitat in the MGR.

Seasonally-flooded and temporary rain-filled pools were similar to one another, yet were different from the other aquatic habitats with respect to their macroinvertebrate assemblages. Hemiptera and Coleoptera dominated their fauna; several crustaceans, including Anostraca and Cladocera, were common, while molluscs were absent. Of the hemipterans, two species of Notonectidae — *Anisops sardea* and *A.* sp. — were largely restricted to the seasonally-flooded and temporary rain-filled pools. The water scorpions (Nepidae) *Laccotrephes fabricii* and *L. vicinus*, and a tabanid dipteran, were also recorded only in the temporary rain-filled pools.

Chief's Island

At the time of the survey, the Boro River had shrunk to become a narrow slow-flowing channel in the centre of the usually-inundated main channel. The range of aquatic habitats was reasonably diverse (n = 7) and a total of 93 morphospecies was recorded. Various families of Odonata (two), Hemiptera (10), Coleoptera (five), Diptera (three) and Mollusca (four) were recorded across the range of channel and lagoon habitats. Oligochaetes and Hirudinea were recorded. Hydracarina were common, as were conchostracans, but no Atyidae were recorded. Amongst the mayflies, only baetids and caenids were recorded. No Trichoptera or Lepidoptera were recorded. Several molluscs were recorded, including prosobranchs (notably *Lanistes ovum*), pulmonates (mostly Planorbidae) and bivalves (only Sphaeridae). No thiarid snails, mutelid bivalves or unionid bivalves were recorded. Seasonally-flooded and temporary rain-filled pools were similar to one another, yet different from the other aquatic habitats, with respect to their macroinvertebrate assemblages. Hemiptera, in particular Corixidae, and Coleoptera dominated their fauna; several crustaceans, including Anostraca and Ostracoda, were common, but odonates and molluscs were absent. The notonectid *Aniops sardea* was abundant in these pools.

Variation in macroinvertebrate assemblages amongst focal areas

Approximately 184 morphospecies ('taxa') of aquatic invertebrates, constituting approximately 63 families, were recorded in the entire survey of 75 macroinvertebrate samples. A full list of taxa recorded in this survey is available in Dallas and Mosepele (in press). It should be noted however that this is likely to be an underestimate of the total number of taxa, since certain groups were not identified beyond class (Oligochaeta), order (Acarina) or family (Baetidae, Caenidae, Lepidoptera and some Diptera).

The highest number of taxa was recorded in the MGR region (125 taxa), followed by the UPH (96 taxa), CI (93 taxa) and the LPH (89 taxa). Mean number of taxa per site was highest in the LPH region (32) and lowest at CI (26) (Table 2). Although taxon richness was relatively high, the number of individuals within each taxonomic group was low. In some instances, single individuals were recorded in a sample. The exceptions to this were Mollusca, Hemiptera, Coleoptera and culicid dipterans. Examination of the overall number of families within each taxonomic group (Table 3) showed that hemipterans had the most families (11), followed by molluscs (10), dipterans (nine), coleopterans (eight), crustaceans (six), ephemeropterans (six) and odonates (four).

Multivariate analysis of the macroinvertebrate fauna recorded in each focal area (i.e. taxa from all samples combined per focal area) revealed that focal areas were at least 54% similar at morphospecies level and 71% similar at family level (Table 4). Multivariate analysis of the macroinvertebrate fauna recorded at each site (i.e. taxa from all habitats combined for each site) revealed a relatively uniform distribution of invertebrates amongst the four focal areas, if similar habitats were sampled (Figure 2). Seasonally-flooded and temporary rain-filled pools in the MGR and at CI were least similar to the other sites and formed distinct faunal groups, both in morphospecies and family level analysis.

Table 2: Mean, minimum and maximum number of morphospecies collected in each focal area, calculated using number of morphospecies per georeference point. Focal areas: Upper Panhandle (UPH), Lower Panhandle (LPH), Moremi Game Reserve (MGR) and Chief's Island (CI)

Focal area	UPH	LPH	MGR	CI
Mean	27	32	29	26
Minimum	19	24	12	9
Maximum	43	38	55	51

Variation in macroinvertebrate assemblages amongst aquatic habitats

Multivariate analysis of the macroinvertebrate fauna recorded in each habitat showed that there were differences in assemblages amongst aquatic habitats. Notable was the grouping together of four of the five inundated floodplain habitats sampled, the grouping of five of the eight seasonally-flooded and temporary rain-filled pools, and the general dissimilarity of sediment habitat from other habitats (Figure 3). The highest number of taxa was recorded in marginal vegetation, both in the channels and in the lagoons (Table 5), although inundated floodplains, floating vegetation, and marginal vegetation in backwaters also supported large numbers of taxa. Fewest taxa were recorded in backwater-detritus habitat and in sediment, although for backwater-detritus habitat this is likely to be a reflection of the sampling having been limited to one event. Further sampling of this habitat is needed to validate this finding. It should however be noted that marginal vegetation, both in channels and in lagoons, was the most common habitat and thus was sampled more frequently than some of the other habitats, such as instream vegetation, seasonal or temporary pools.

The number of families in each order of macroinvertebrates varied amongst habitat types (Figure 4). Most taxa occurred across the range of habitat types, although their relative proportions differed from one habitat type to another. Molluscs were notably absent from both seasonal and temporary pools. This may be a reflection of their relatively short period of inundation, although further sampling would be needed to validate this. The mean, minimum and maximum number of taxa recorded in each habitat type is given in

Table 3: Number of families in each taxonomic group recorded in this survey (note that groups indicated with an * were not identified beyond class and order, respectively)

Taxonomic group	Number of families
Hemiptera	11
Mollusca	10
Diptera	9
Coleoptera	8
Crustacea	6
Ephemeroptera	6
Odonata	4
Hirudinea	3
Trichoptera	3
Oligochaeta*	1
Acarina*	1
Lepidoptera	1

Table 4: Percentage similarity of macroinvertebrate assemblages in the four focal areas, based on morphospecies and family-level taxonomy (presence/absence transformation; Primer Version 5). Focal areas: Upper Panhandle (UPH), Lower Panhandle (LPH), Moremi Game Reserve (MGR) and Chief's Island (CI)

Focal area	Taxonomic level					
	Morphospecies level			Family level		
	UPH	LPH	MGR	UPH	LPH	MGR
LPH	61			78		
MGR	55	60		81	80	
CI	54	62	60	72	71	75

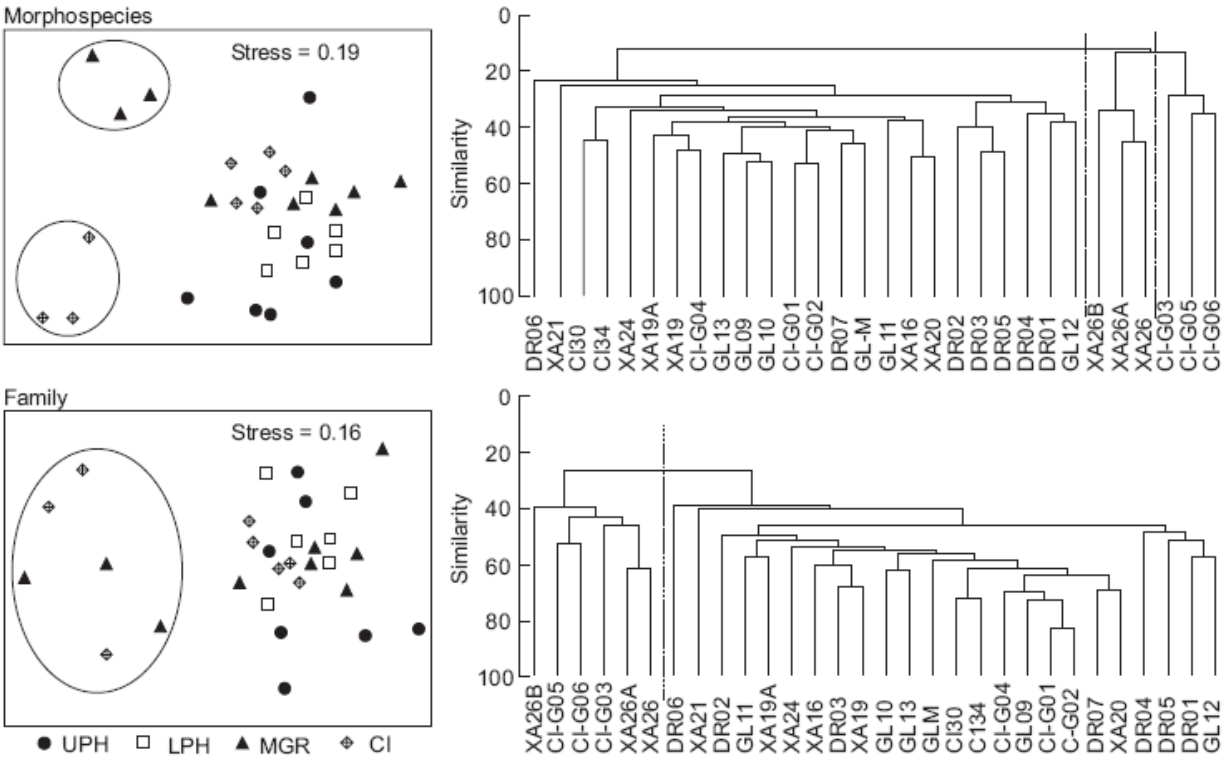

Figure 2: Multi-dimensional scaling (MDS) ordination and dendrogram showing the grouping of georeference points within each of the four focal areas, based on the similarity of their macroinvertebrate faunas: Upper Panhandle (UPH: DR), Lower Panhandle (LPH: GL), Moremi Game Reserve (MGR: XA) and Chief's Island (CI). Analyses were performed at morphospecies and family level using rank abundance (Primer version 5)

Figure 5. Inundated floodplains had the highest mean number of taxa, whilst the fewest taxa were recorded in sediment. Marginal vegetation, both in channels and in lagoons, exhibited the greatest variability in the number of taxa from one sample to another. The mean, minimum and maximum number of morphospecies recorded in each habitat type is also given separately for each focal area (Figure 6). This demonstrates the variation in the availability and relative importance of different habitat types amongst the four focal areas (see Table 1 for habitats sampled per focal area). Of note was the increase in the mean number of taxa associated with marginal vegetation in the channels as one moved from the upper and lower panhandle towards the MGR and CI. Five such sites held more than 40 taxa.

Discussion

The results of this survey suggest that the distribution of macroinvertebrates amongst the different focal areas is relatively uniform, with the exception of the isolated seasonally-flooded and temporary rain-filled pools of the MGR and CI, and the inundated floodplain habitats of the UPH, the LPH and the MGR. In relation to particular groups, the hemipteran fauna of the Delta is predominantly of Pan African and Afrotropical/subtropical origin. A small number of Congolian taxa were recorded, notably *Hydrocyrius longifemorata* and *Ranatra* sp., but as yet no species endemic to the Delta have yet been recorded (P Reavell, University of Zululand, South Africa, pers. comm.). *Appasus ?ampliatus*, a species of Belastomatid new to science (Alonsa and Nordin 2003), was recorded at 13 sites in all focal areas in the current survey.

The coleopterans recorded comprised about 35% primarily detritivorous genera, with the remainder being predaceous. Nearly all genera encountered were characteristic of slow-flowing waters and lentic systems, with a small proportion (e.g. *Eretes*) associated with seasonal and temporary pools. The presence of larger Dytiscidae (i.e. *Cybister* and *Hydaticus*) indicated that at least a few sites had a reasonable incidence of amphibians and fish and, along with the presence of the hydrophiloid genera *Hydrochara*, *Amphiops*, *Hydrophilus* and *Sternolophus*, indicated at least a few sites with rich organic matter deposits undergoing vegetation reclamation (C Turner, Plymouth United Kingdom, pers. comm.). Data for aquatic Coleoptera were analysed only to generic level and would greatly benefit from a full species-level examination. Generic analysis is acceptable for generalist quantitative ecological analyses but the time-consuming and difficult species-level analyses are certainly required for a true conservation evaluation of the habitat (C Turner, pers. comm.). The same applies if macroinvertebrates are to be

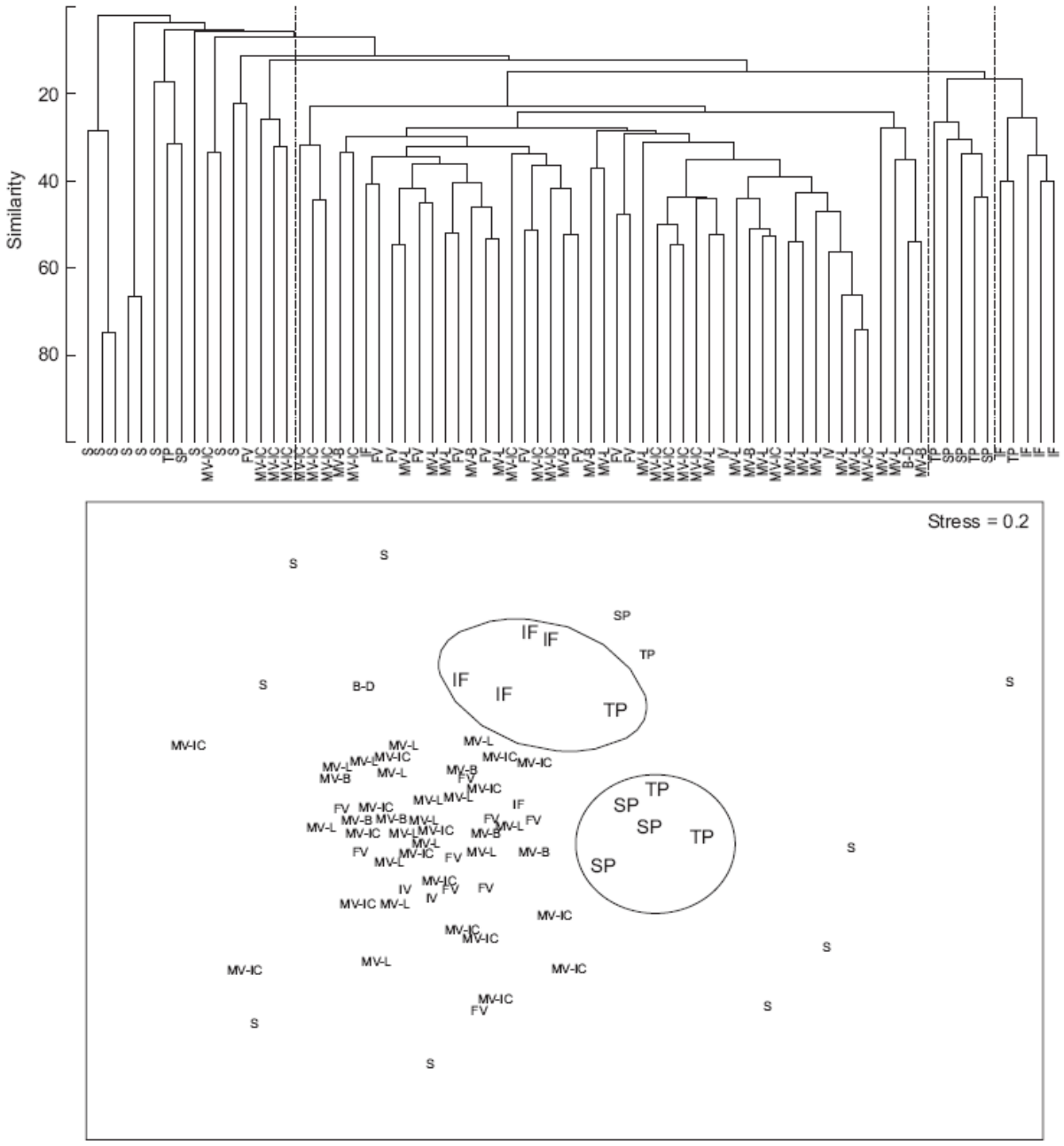

Figure 3: Multi-dimensional scaling (MDS) ordination and dendrogram showing the grouping of aquatic habitats based on the similarity of their macroinvertebrate fauna. Analyses were performed at morphospecies level using presence/absence transformation (Primer version 5). Habitat codes: marginal vegetation in channel (MV-IC), marginal vegetation in lagoon (MV-L), marginal vegetation in backwaters (MV-B), inundated floodplain (IF), floating vegetation (FV), instream/submerged vegetation (IV), sediment (S), isolated, seasonally-flooded pools (SP), isolated temporary, rain-filled pools (TP) and backwater-detritus (B-D)

used in the development of Community Conservation Indices (CCI), which summarise macroinvertebrate data into expressions of conservation value (Chadd and Extence 2004). For effective conservation evaluation of the local water beetle fauna, a standard quantitative methodology will need to be supplemented with more specialist methodologies to locate the truly cryptic and often endemic species.

A detailed account of the Delta's molluscan fauna was published by Appleton *et al.* (2003), but the present survey added two planorbid species, *Bulinus tropicus* and *Gyraulus*

Table 5: Number of morphospecies recorded in each of the 10 aquatic habitats sampled

Habitat	Number of morphospecies per habitat	Number of samples per habitat
Marginal vegetation in channels	99	17
Marginal vegetation in lagoons	94	16
Floating vegetation	66	11
Inundated floodplains	56	5
Marginal vegetation in backwaters	57	6
Temporary rain-filled pools	41	4
Seasonally-flooded pools	44	4
Instream vegetation	22	2
Sediment	18	9
Backwater detritus	11	1

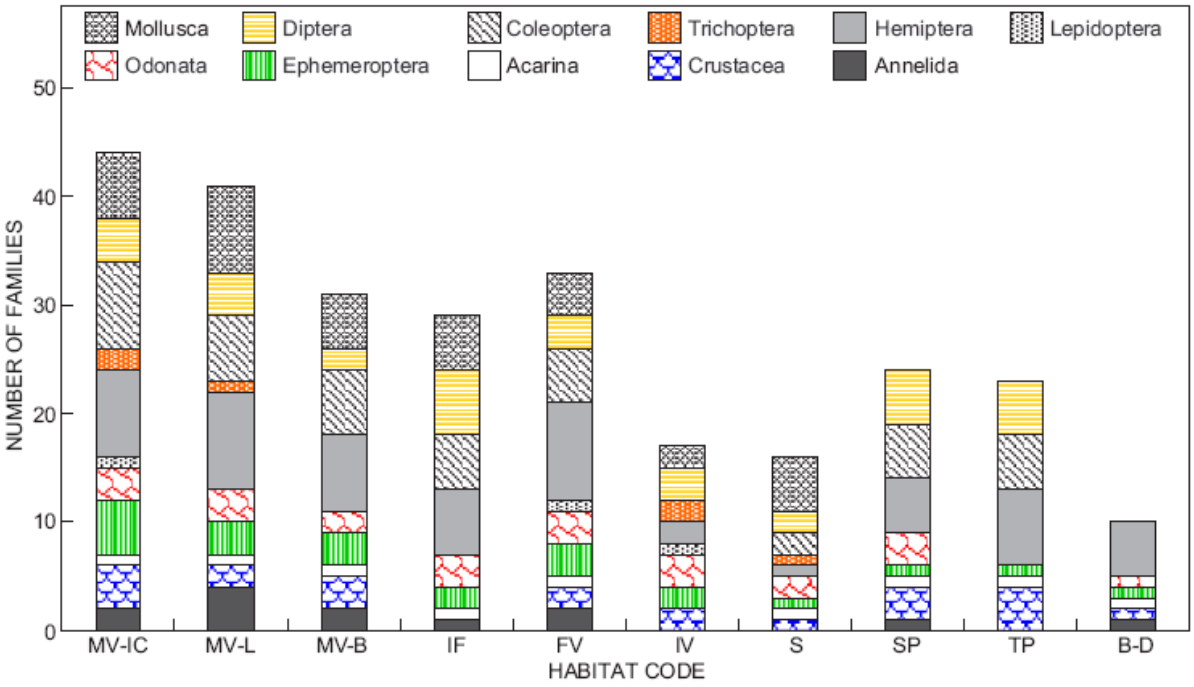

Figure 4: Numbers of families in each macroinvertebrate group (mostly order) calculated per habitat type. Habitat codes: marginal vegetation in channel (MV-IC), marginal vegetation in lagoon (MV-L), marginal vegetation in backwaters (MV-B), inundated floodplain (IF), floating vegetation (FV), instream/submerged vegetation (IV), sediment (S), isolated, seasonally-flooded pools (SP), isolated temporary, rain-filled pools (TP) and backwater-detritus (B-D)

costulatus, to the list. *Bulinus tropicus* is widely distributed over the southern African subcontinent, while *G. costulatus* has been recorded in the north and eastern highveld, KwaZulu-Natal, eastern Zimbabwe and the Okavango River System (Appleton 2002). Two planorbid snails, *Biomphalaria pfeifferi* and *Bulinus globosus*, the intermediate hosts for *Schistosoma mansoni* (the parasite causing human intestinal schistosomiasis) and *S. haematobium* and *S. mattheei* (the parasite causing human urinary and cattle schistosomiasis, respectively), were recorded at several sites in the Delta. *Bulinus pfeifferi* was recorded at 14 of the 29 sites, mostly in the marginal, instream and floating vegetation of the Guma Lagoon and Thaoge Channel (Lower Panhandle), Gadikwe and Xakanaka lagoons (Moremi Game Reserve), and Boro River Channel (Chief's Island). No *B. pfeifferi* snails were recorded in the UPH during this survey, although they were recorded here by Appleton *et al.* (2003). *Bulinus globosus* was recorded at seven of the 29 sites in similar habitats as *B. pfeifferi*, and in all focal areas.

This study, together with a previous high-water survey (Alonso and Nordin 2003), has enhanced our understanding of the aquatic macroinvertebrate biodiversity of the Okavango Delta. However, given the nature of these surveys, i.e. rapid assessments, there are likely to be some species that have not yet been recorded or described. None of the species recorded during this survey appear to be

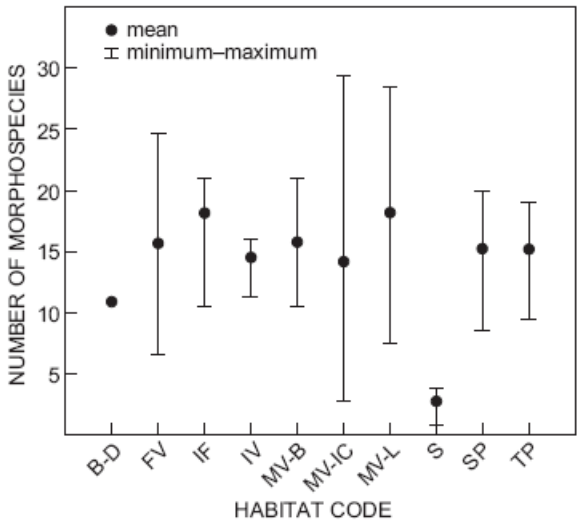

Figure 5: Mean, minimum and maximum number of morphospecies recorded in each habitat type. Habitat codes: marginal vegetation in channel (MV-IC), marginal vegetation in lagoon (MV-L), marginal vegetation in backwaters (MV-B), inundated floodplain (IF), floating vegetation (FV), instream/submerged vegetation (IV), sediment (S), isolated, seasonally-flooded pools (SP), isolated temporary, rain-filled pools (TP) and backwater-detritus (B-D)

restricted to the Okavango River Delta, although certain groups such as the Trichoptera and Ephemeroptera may yield different information once the morphospecies are described by specialists. From a conservation perspective, this survey highlights the importance of maintaining a range of aquatic habitats in the Delta, i.e. a mosaic of habitats. Differences in aquatic macroinvertebrate assemblages were most apparent amongst certain habitat types, with seasonally-flooded and temporary rain-filled pools having a distinct fauna. Similarly, the aquatic fauna of the inundated floodplain habitats was different from that of channel and lagoon habitats. Inundated floodplains were present in the UPH area, but became increasingly scarce lower down in the Delta, and were absent from Chief's Island because, at the time of the survey, the floods had not yet reached this area. Water levels in these inundated floodplains were often 10–20cm deep. Ashton (2000) reported on the potential environmental impacts associated with the proposed abstraction of water from the Okavango River in Namibia. He concluded that there would be a slight reduction in the surface area and depths of the backwater channels that are flooded, with an estimated reduction in inundated area of 7.0km² in the Delta. Given the shallow nature of the inundated floodplains, it is possible that this habitat would be reduced in extent and the associated macroinvertebrates would be affected. The seasonal flooding of the Delta is, therefore, crucial for the maintenance of this habitat and also for the maintenance of aquatic macroinvertebrate diversity.

The Okavango River Basin is shared by three nations: Angola, Botswana and Namibia. In 1994, the Permanent Okavango River Basin Commission (OKACOM, see http://www.irbm.co.bw) was officially formed (Taylor and Bethune 1999), its aim being to promote coordinated and sustainable regional water resources development approaches for the Okavango River Basin, while addressing the legitimate social and economic needs of these three riparian states (see http://www.irbm.co.bw). At present, the Okavango River Basin is one of the least human-impacted basins on the African continent, but increasing socio-economic pressures on the Basin in the riparian countries threaten to change its present character. The Okavango Delta is not only an area of ecological importance, but is one of extreme socioeconomic importance. Local communities are highly dependent on the natural resources of the Delta, while ecotourism in the region ranks high on the global scale. Threats include water abstraction (Ashton 2000), modification of the flow regime, structures that impede sediment supply (Ashton *et al.* 2003a, 2003b), increased tourism activities, and reduction in water quality (via insensitive waste disposal practices, hydrocarbon and agrochemical pollutants, insecticide spraying, and elevated organic and nutrient loads — mainly from upstream sources, especially resettlement in the Angolan part of the Okavango Basin). The number of people in and around the Delta is also increasing, placing additional pressure on its natural resources. The need to conserve and manage the Delta in a sustainable manner, based on reliable scientific knowledge, is thus very important.

To date, few studies have examined the aquatic macroinvertebrate fauna of the Okavango River Delta. While the present survey represents only a 'snapshot' of the system under low-water conditions, it provides insight into the distribution and diversity of aquatic macroinvertebrates of the Delta. The Delta is, however, a dynamic system, both in terms of seasonal differences related to local rainfall and in relation to inundation from flooding, the timing and extent of which varies from area to area and from year to year. Further studies are thus needed in order to understand the temporal and spatial variations in the distribution of aquatic macroinvertebrates. Moreover, a more detailed examination of the association between macroinvertebrate assemblages and aquatic habitat types and the temporal variation in habitat availability in response to different levels of inundation is needed. This would provide valuable information that could then be used in the determination of the potential impacts of future modifications to water quantity and quality in the Delta.

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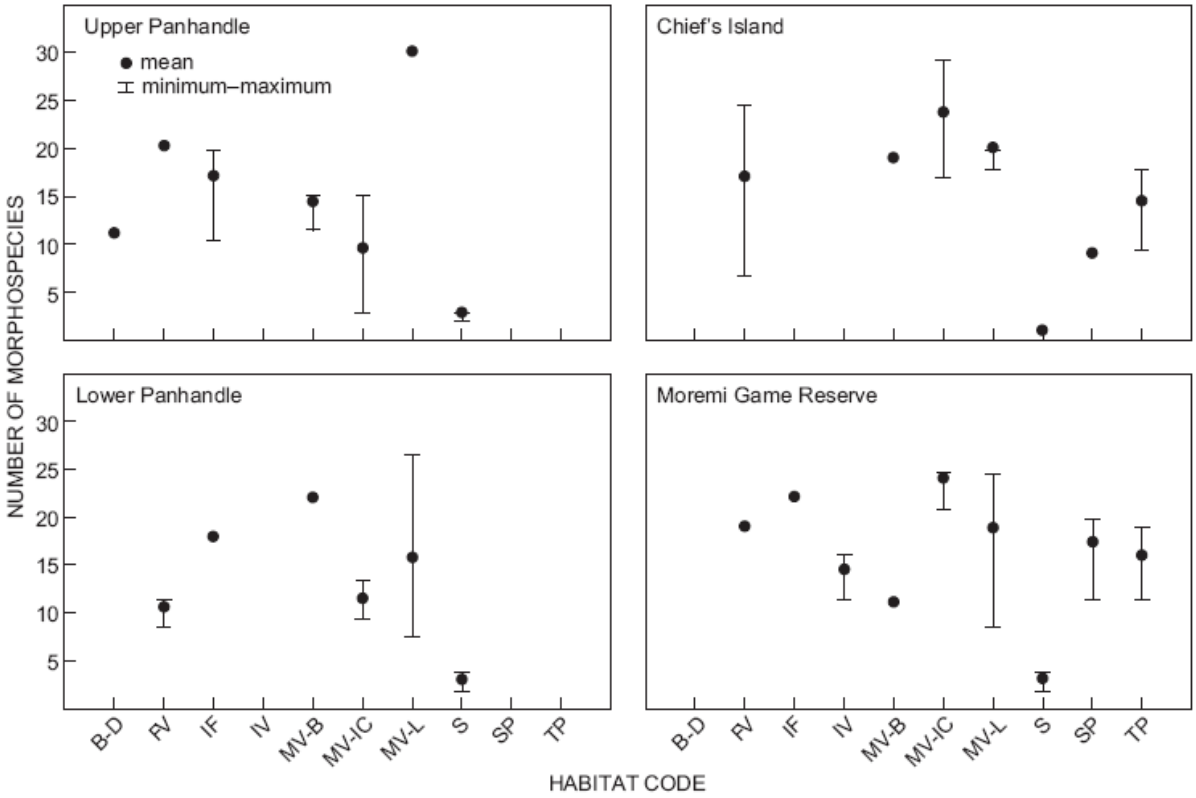

Figure 6: Mean, minimum and maximum number of taxa per habitat type given separately for each focal area. Habitat codes: marginal vegetation in channel (MV-IC), marginal vegetation in lagoon (MV-L), marginal vegetation in backwaters (MV-B), inundated floodplain (IF), floating vegetation (FV), instream/submerged vegetation (IV), sediment (S), isolated, seasonally-flooded pools (SP), isolated temporary, rain-filled pools (TP) and backwater-detritus (B-D)

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