Darwin Initiative – Final Report

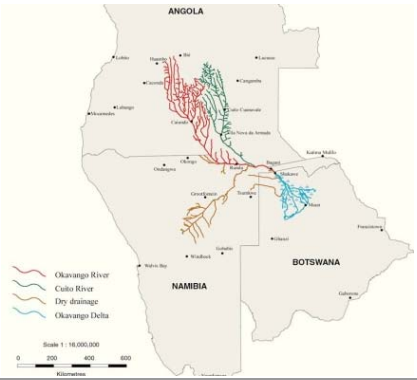
*(To be completed with reference to the Reporting Guidance Notes for Project Leaders (http://darwin.defra.gov.uk/resources/reporting/) - it is expected that this report will be a **maximum** of 20 pages in length, excluding annexes)*

Darwin project information

Project Reference	162/14/029
Project Title	Monitoring and simulating threats to aquatic biodiversity in the Okavango Delta
Host country(ies)	Botswana
UK Contract Holder Institution	UCL
UK Partner Institution(s)	
Host Country Partner Institution(s)	Harry Oppenheimer Okavango Research Centre (HOORC), University of Botswana
Darwin Grant Value	£188,441
Start/End dates of Project	01-Jan-06 to 30-Apr-09
Project Leader Name	M. Todd & AW Mackay
Project Website	*www.geog.ucl.ac.uk/~mtodd/accord*
Report Author(s) and date	Mackay, A.W., Todd, M., Wolski, P. Jul 2009

1 Project Background

The Okavango Delta (OD) is maintained by annual flooding of the Okavango River creating habitats with high beta diversity. Threats include development initiatives and climate change. The project purpose was to assist in the implementation of the CBD through a training and research programme. Achievements include extensive training and production of databases on climate, hydrology and biodiversity. Important findings: flood regime variability is associated with ocean and atmosphere drivers; projections of future flood show greater changes but high uncertainty; constrained models suggest substantial drying; human impact is minor; the quantification of changing water-level regime on aquatic diversity.



2 Project support to the Convention on Biological Diversity (CBD)

As highlighted in the CBD, inland water ecosystems are amongst the most threatened. The OD is no exception, supporting a population of 125,000 in a semi-arid region where water resources are seasonally scarce for humans and other organisms alike. Future threats to the OD, both natural (e.g. climate) and anthropogenic (e.g. pollution; abstraction; habitat degradation) are real. Our project has contributed to the CBD objectives by addressing several, relevant crosscutting issues, including climate change and biodiversity; ecosystem approach; Identification, Monitoring, Indicators and Assessments; 2010 biodiversity target. These are especially relevant to the CBD thematic programme: inland waters biodiversity.

Climate change and biodiversity: Whilst future warming is highly likely there is little agreement between climate models of future rainfall changes in southern Africa. This is a real problem for trying to estimate impacts on water resources and associated biodiversity. To address this, we have simulated the impact of climate change on flood frequency and duration of flood in the OD using ensemble simulations drawing on the 21 GCM models from IPCC AR4, involving prescribed warming scenarios and various downscaling methods. The results show a wide envelope of future flood conditions (both wetter and drier), with a tendency towards drier conditions by the end of the 21st Century. To constrain this uncertainty a GCM 'weighting' technique (Reliability Ensemble Averaging (REA)), was applied. Results indicate strong changes in hydrology in the Delta, in which substantial drying suggests severe consequences to the distribution and area of major wetland ecosystem units. Most notable consequences include a decline in aquatic communities and an increase in savannah ecotope. An analysis of natural variability in the flood regime was undertaken, indicating that the substantial year-to-year and decade-to-decade variability in flood extent is associated with variability in specific patterns of the global ocean and atmosphere. This information will be used to develop a more sophisticated REA method. **Identification, Monitoring, Indicators and Assessments**: through training, monitoring and research we have provided new, important baseline information on the identification of aquatic insects and algae (diatoms). By taking an **ecosystem approach** to the work, we are able to identify indicator species, which are important for future monitoring. Our data have been uploaded into HOORC environmental databases and made available to the *Biokavango* programme. [This is a GEF funded project that aims to build local capacity for the conservation and sustainable use of biodiversity in the OD]. In relation to the aquatic organisms studied, it became clear that the Okavango Delta is still in a pristine state with respect to human impact. However, our project still has direct relevance to **2010 biodiversity target** in terms of (i) provision of new data on biodiversity and (ii) identifying environmental variables which have significant impact on aquatic diversity in the Delta. By linking our work on climate and hydrology to biodiversity, we are able to predict which aquatic species are statistically most likely to be impacted by future change in the Delta.

In order to support the host country's institutions to build capacity to meet CBD commitments, our project had a strong training component that was developed to run through the three years. A number of HOORC staff at various levels gained in-depth knowledge of aspects of biodiversity conservation. HOORC maintains institutional links with government, NGOs and research community and is heavily involved in research, community work, planning and management processes focusing on biodiversity issues in the Okavango Delta. This ensures that capacity developed during the project is and will be utilized, directly and indirectly, towards biodiversity conservation. Importantly, the current project significantly enhanced partnership between UCL and HOORC, a scientific partnership that had been developed earlier (see Section 3 below). The working relationships and mutual trust developed between the involved individuals ensure that further joint research/training activities are likely to happen. For example, collaborative work has recently started on a new project investigating floodplain diversity in the Delta.

The contribution made by different components of the project to the main measures for biodiversity conservation defined in the CBD Articles to which the project is relevant is outlined in Annex 3. Our project interacted with host country CBD focal points, via HOORC and the ODMP. We have not supported the biodiversity conventions CMS and CITES.

3 Project Partnerships

UCL and HOORC share joint responsibility for all aspects of the programme. However, UCL have overseen the financial management and reporting of the project, while HOORC have overseen local logistics, such as fieldwork and workshop planning.

Our partnership developed from a previous project (EU FPV WERRD) which sought to model the basin hydrology of the Okavango Delta and socio-economic and livelihood activities in the region. While impacts on ecotope type were modelled, impacts on aquatic biodiversity were not considered. Given the importance of aquatic diversity to ecosystem services in the Delta, a Scoping Project was funded by the DI, which involved key WERRD personnel (Todd, Wolski). The Scoping Project funded a trip to Botswana for Todd and Mackay, during which time the full Darwin proposal was conceived and largely written. HOORC and UCL have remained strong and equal partners over the life of the project, and both have been involved in project planning and decision-making. The science base of the project falls into three main components: modelling future climate change; hydrology and chemistry; compilation of baseline biodiversity. HOORC and UCL have worked and shared information on each of these components, We did establish an MoU, and this has been updated every financial year, linked to sub-contract funds passing between UCL and HOORC. A particular strength of the partnership has been its interdisciplinary approach, linking each of the three components (climate (Todd & Wolski), hydrology (Wolski) and biodiversity (Mackay, Mazebedi, Davidson)) together. For example, the biologists have used the hydrological data produced for the project to model species responses using statistical regression techniques. A challenge to the project has been the lack of recruiting suitable biological expertise in Botswana, and this was met by some of the biological work being undertaken at UCL.

More recently, a project partnership has developed between our programme and a new initiative at HOORC on floodplain biodiversity in the Delta, with Ramberg co-supervising two PhDs (one based at HOORC and a second based at UCL).

During the second year of the project, the World Conservation union (IUCN Cambridge) started work on "*Okavango freshwater biodiversity information case study*" a component of an EU FP6 funded IUCN Species Survival Commission project which aims to enable water resource managers and environmental planners throughout Africa to integrate information on freshwater biodiversity within the development process. For a period of about one year, a freshwater biodiversity co-ordinator (Jessica Jones) was employed at HOORC to coordinate the three main projects working on freshwater biodiversity in the Delta: Darwin, IUCN and *Biokavango*. Weekly meetings were held at HOORC, and minutes distributed to main partners. However, due to contractual difficulties, funding for the IUCN freshwater project on the Okavango Delta was subsequently withdrawn after two years. We were able to maintain links with IUCN and are contributing to a book focussed on the freshwater biodiversity profile of the Okavango Delta - "*The Living Okavango*" by John Mendelsohn (Research and Information Services of Namibia). An update to this book is available for review by the Report referee, although this is still a confidential document.

4 Project Achievements

4.1 Impact: achievement of positive impact on biodiversity, sustainable use or equitable sharing of biodiversity benefits

In terms of impact, our project has been focussed on improving awareness and institutional capacity in support of biodiversity conservation in the Okavango Delta. In this context, the Okavango Delta Management Plan has recently been completed (2007), although implementation of the Plan is on going. The overall goal of the ODMP is to "*…integrate resource management for the OD that will ensure its long-term conservation and that will provide benefits for the present and future well-being of people through sustainable use of its natural resources*", in direct relation to the CBD and Ramsar Protocol. The ODMP has several strategic objectives, including the maintenance and conservation of biotic and abiotic status of the Delta, and the maintenance of its ecosystem processes. Our Darwin project contributes to HOORC's role of developing and managing the Okavango Delta Information System database

(ODIS) to be used by all the planning and implementing agencies involved in ODMP. For example, our data are of direct relevance to future development plans and the monitoring of global climate change effects on the Delta.

Furthermore, the *Biokavango* project aims to support the elaboration and implementation of the ODMP. *Biokavango* highlights that mechanisms for biodiversity data collection, analysis and interpretation are limited. Our project has gone some way to address these concerns through training and the provision of new data on aquatic organism biodiversity. For example, Darwin jointly funded a training video for water quality monitoring on the Delta (available for download from our website). This video still needs some final edits, but draft versions have been circulated amongst the safari camps for comment.

In our project we have not been directly working with local communities. However, an important aspect to note is that while undertaking our extensive fieldwork, project staff interacted with safari camps staff, Department of Water Affairs staff, fishermen and villagers. Information shared (e.g. about the Darwin Initiative and our project) created awareness and interest. Responses and interactions were always positive.

4.2 Outcomes: achievement of the project purpose and outcomes

The project purpose was to assist in the ability of the Botswana to implement the CBD in the OD region, through programme of capacity building, training and scientific research. We think that we have been successful in our purpose, as is evidence by the information given below, and in the relevant Annexes.

4.3 Outputs (and activities)

The project has largely achieve its outputs as laid out in the logical framework - see Annex 1.

The main criterion for site selection was to sample sites along hydrological and chemical gradients, because when hydrology in the Delta does change, we needed to be certain that we captured as full a range of species responses as possible. A second criterion was to select sites close to e.g. tourist camps for potential human impact. It should be noted here that the *Biokavango* project has more comprehensively targeted very local regions e.g. sections of water where boats are used intensively next to some tourist camps. Finally, some sites were chosen to build on previous projects carried out in the Delta over the last decade, to provide continuity between Darwin and past projects.

On conducting analyses of the biological and chemical data, it became clear from our data that levels of human impact on the Delta ecosystems are very low. Moreover, at the final project meeting, *Biokavango* representatives also found limited human impact in their project. Where impacts were observed, they were very localised and recovery was quick. **Given our data therefore we feel that at this stage it is not appropriate to create IBIs (indicators of biological integrity) as these are reliant on comparing species between impacted and non-impacted sites.** However, this has the advantage that models derived in this project are based on water-level regime and associated hydrochemistry, rather than pollution, and so we can confidently relate species responses to changes in water-level regime linked to associated threats such as climate change. Moreover, the biological data that we have collected will act as baseline data for non-impacted ecosystems, from which to monitor future change. (see Final Workshop presentations on our website for details).

One of the major challenges in developing climate change adaptation policy is the uncertainty in projections of future climate. This is particularly pertinent to the Okavango Delta, which is a flood pulse wetland system driven by rainfall over the Angolan Highlands. The ensemble of 21 GCMs included in the IPCC AR4 show a wide range of changes in rainfall over this region for the 21st century with no consensus on the sign or magnitude of changes. We attempted to address this problem by (i) application of dynamical downscaling methods to the GCM output using a suite of regional climate models. The results suggest an expanded envelope of uncertainty; (ii) calculating a weighting ensemble mean of GCM projections using the Reliability Ensemble Average (REA) approach; (iii) evaluation of interannual to multi-decadal climate variability in the study region for incorporation into the REA method.

We have presented our results at national and international meetings (see Annex 1 for details) plus several guest lectures at academic departments both in Botswana and the UK. Several publications are currently in press or in preparation (see Annex for details). We have also made a significant contribution to the forthcoming book "*The Living Okavango*", which is being compiled by IUCN in partnership with our project, HOORC, Biokavango and the South African Institute for Aquatic Biodiversity. This book forms a comprehensive overview of the Delta's freshwater biodiversity, and is audience target includes policy and decision makes, politicians, OKACOM, upriver environmental agencies, researchers, stake holders, including private sector agencies such as the tourism operators, interested residents and tourists in general.

4.4 Project standard measures and publications

See Annex 4 and 5 for details.

4.5 Technical and Scientific achievements and co-operation

Scientific co-operation and achievements

The science case for our project was focussed around (i) improving climate prediction scenarios for the hydrological catchment of the Okavango Delta; (ii) creation of spatial maps of water-level regime at high resolution throughout the delta; (iii) compilation of hydrochemical variables for up to 100 sites, spanning a hydrological gradient; (iv) compilation of aquatic biodiversity data from the same sites (macroinvertebrates, macrophytes, diatoms); modelling species responses to hydrochemical variables; (v) simulate impact of future climate change on aquatic biodiversity in the Okavango Delta. All this scientific work was conducted collaboratively between HOORC and UCL researchers (see publications).

(i) Improving climate prediction scenarios for the hydrological catchment of the Okavango Delta. Todd and Wolski have led this part of the project. First, we constructed a large ensemble of future flood scenarios (for the 21st century) using hydrological models driven by an ensemble of future climate derived from GCMs. This ensemble included the 21 IPCC AR4 GCMs under various greenhouse gas emission scenarios and uniquely under a series of 'prescribed warming' scenarios. In addition, we evaluated the various downscaling techniques, both statistical and dynamical. The results indicated a wide envelope of uncertainty in future flood extent, in which substantial expansion or decline of the OD is possible. These average changes are greater in magnitude than the large natural variability experienced in the 20th century, such that it is possible the OD will experience a regime change unknown in recorded history. However, uncertainty in the direction of change is clearly problematic for policy decision-making. To address this (i.e. how can we reduce this uncertainty by, for example, intelligently choosing one GCM scenario over another) we undertook three different approaches, highlighted in Section 4.3 above. This level of analysis was not planned on in the original proposal. For example, we employed the novel approach of reliability ensemble averages, where models are weighted according to their bias and convergence. Bayesian averaging was then used to predict the most likely climate output that had least uncertainty. Our results indicate that there will be strong changes in the hydrology of the Delta, with severe consequences to the distribution and area of major wetland ecosystem units (or ecotopes). Ongoing work will develop a more sophisticated GCM 'weighting' method which incorporates not just GCM bias but GCM representation of variability.

(ii) Creation of spatial maps of water-level regime at high resolution throughout the delta.

Inundation frequency maps for the whole of the OD have been created by Wolski using satellite images between 1989-2007). These maps have been used to create two new water-level regime variables, hydroperiod and flood frequency. Every site visiting during our project (see below) was subsequently assigned a hydroperiod and flood frequency class, which were used as explanatory variables in the species regression modelling outlined below.

(iii) Compilation of hydrochemical variables for up to 100 sites, spanning hydrological gradients. During the project, 5 fieldtrips were undertaken in 6 regions of the OD. We visited c. 120 sites, and collected samples from 219 locations. For example, at some sites, 2 or 3 samples were collected from different locations because of significant habitat (macrophyte)

variability. Also, we made multiple visits to c. 20 'core' locations during at least 3 trips, to try and account for season variability. Habitats for each location were characterised according to whether they were associated with e.g. marginal vegetation in channels, or were seasonal floodplains etc. Explanatory variables including limnology (e.g. water depth, velocity, temperature, pH, conductivity, dissolved oxygen) were measured at all 219 locations. Water samples were collected for chemical analysis back at the HOORC laboratories (e.g. alkalinity, nitrate, phosphate, cations, anions, silica etc) from c. 90 of the sites. Hydrological variables (hydroperiod and flood frequency) were estimated for each of the 219 locations. Compilation of the explanatory data utilised most of the UCL and HOORC staff participating in the project and was truly collaborative. Regression analysis of just the explanatory data by themselves (e.g. using principal components analysis PCA) highlighted significant variability between the 6 regions, on top of which season also had a major influence, especially during high-flood period.

(iv) Compilation of aquatic biodiversity data (macroinvertebrates, macrophytes, diatoms)

Diatoms have been investigated by Mackay at UCL. Unfortunately we were not able to match this expertise in HOORC, nor were we able to recruit an MPhil student to be trained in Botswana (although Dr Mapila did attend a training course at UCL on diatoms). We focussed on collecting only epiphytic species, as these have been used in other wetlands for biomonitoring. Over 180 species were identified in the Delta from 47 genera. Over 150 of these species have been identified in the Delta for the first time. Floristic analyses shows that in general the diatoms are indicative of low-alkalinity waters. Many species are global, some are African, and a few are very rare, and more work needs to be done to determine if any are endemic. Some common species found are very tolerant to elevated levels of nutrient enrichment. However, in the OD their presence is not indicative of eutrophication, but is linked to energy flows and nutrient release from inundated floodplains. These taxa can act as biomonitors, should pollution levels increase in the future from e.g. the tourism industry. Using multiple regression techniques such as redundancy analysis (RDA) six explanatory variables were shown to significantly influence diatom distribution in the OD. These mainly included cation composition of the waters, hydroperiod and flood. We were able determine which species grow best in locations with e.g. high and low hydroperiod. Using this information we can predict what will happen to certain species should hydroperiod in the Delta decline due to climate change or abstraction. For example, if hydroperiod does decline then species indicative of elevated nutrients in the Delta will increase (e.g. *Nitzschia bacata*). As well as providing new and important biodiversity data on primary producers in the OD, we can use our data to provide information on diatom species optima and tolerances, relevant to ecosystem functioning of other freshwater environments in Africa.

Aquatic macrophytes were investigated by Davidson and Mackay at HOORC/UCL, with special emphasis on submerged species because little work has been done on this group of plants. Collection of data occurred in 4 regions of the Delta at 21 sites. 85 spp were identified with little compositional variation between the regions. However, using regression analysis we have been able to demonstrate that there are significant regional differences between submerged and emergent species. Part of this regional variation is controlled by habitat type. But using RDA, the most significant driver of this variation is hydroperiod, which in turn influences conductivity and water depth. We are able to conclude therefore that any reduction to the water-level regime in the Delta will pose significant threats to macrophyte diversity, e.g. the economically important *Cyperus papyrus*.

Macroinvertebrates were investigated by Mazebedi at HOORC and Mackay at UCL. 64 macroinvertebrate families were identified from 219 locations,. There was a significant amount of variation between habitats and regions, with highest diversity in the seasonally inundated floodplains. Multiple regressions highlighted that hydrological (hydroperiod and flood) and habitat variables controlled most of the variation in macroinvertebrates throughout the Delta. Contrary to expectations, we were also able to demonstrate that seasonal variation is an important driver of diversity variation.

To summarise, water-level regime variables (especially hydroperiod) have an over-riding influence on assemblage structure on primary producers and their consumers in the OD. We are able to model such hydrological variables using future predictions of climate change. We are thus able to make qualitative predictions (based on quantitative empirical data) on how future climate change will impact aquatic biodiversity in the Delta. Our data suggest that levels

of biodiversity themselves will not change between regions of low and high hydroperiod, but species compositional changes will occur. These findings are currently being written up for publication in scientific journals (see Annex 5).

4.6 Capacity building

Through the provision of several high quality datasets, we have strengthened the institutional environment of HOORC by building capacity in its Okavango Delta Information System database, crucial to the implementation of the ODMP. Furthermore, one of the biggest contributions to capacity building has been made through an extensive training programme in biodiversity and numerical methods. Evidence of success includes the subsequent employment of key personnel within the University of Botswana, and newly commenced projects beyond the life of this project.

Specifically, we have provided extensive training of colleagues both employed on the project and those employed by government of Botswana and OD stakeholders, covering topics such as field methods in measuring and monitoring aquatic biodiversity, chemical analysis of freshwaters, analysis of ecological data using multivariate techniques, and the science of climate change and climate modelling. Several staff have benefited from this training. For example, Laone Pitso was trained in water chemistry for the duration of our project and has recently taken up a permanent technician job at the main campus of University of Botswana. Uanee Kauheva through training on the project has also been offered a technical post in the main campus at UB. Richard Mazebedi has recently been offered a research assistant post with the Biokavango project, to participate in field collection and analysis of biological (macroinvertebrates and the invasive *Salvinia*) and water chemistry samples.

The ECRC-UCL has certainly added to its expertise on biodiversity in freshwater ecosystems ecosystems and hydrological processes in the wetland system.

4.7 Sustainability and Legacy

The project achievements most likely to endure are the provision of datasets which will be use for on-going and future projects on the Delta, and implementation of ODMP goals in relation to CBD. Now that our project has ended, resources bought including scientific meters, nets, software have all been left at HOORC. Indeed, HOORC's new project on floodplain biodiversity is already making use of these resources. Three out of four technical staff have gone on to find full-time employment with the University of Botswana. The MPhil student (Mazebedi) has just been employed by the *Biokavango* on biological and water quality monitoring of the Delta.

Project partners are keen to further collaboration. In the first instance, contact will be on-going through writing of publications (see Annex 5). However, Mackay and Wolski will also present Darwin findings at a major international conference to be held at HOORC in February 2010 (http://www.orc.ub.bw/floodpulse/index.html). We will also continue our efforts to try and find future funding to extend the work on floodplains in the Delta (we were unsuccessful with post-project funding) and hydro-climate processes. Collaboration will also continue through joint supervision of PhD student on a floodplain biodiversity project currently being undertaken at HOORC (with Ramberg). We fully expect the partnership to continue through funded and non-funded collaboration.

5 Lessons learned, dissemination and communication

For us, staffing was the biggest issue encountered in the project. We had originally planned for a PDRA with biodiversity skills to drive forward our project within Botswana (Mosopele). However, Biokavango subsequently employed her shortly after the start of the project, which left us with a significant gap in terms of personnel with taxonomic expertise. There was also a lack of local expertise matching that of the UK participants. For example we were not able to secure a second MPhil student to undertake training and research on diatoms in the Delta. Convincing bodies such as OKACOM that predicting future climate change has uncertainties is challenging. Despite a robust dialogue at the final project workshop in April, they have since

requested a single future flood scenario, which is clearly problematic and indicates that we have not been able yet to impress upon them the complexity of uncertainty adequately. This is work ongoing.

Although we have maintained excellent links with IUCN and *Biokavango* our project was realised separately from those two at the proposal stage. Better integration would have been achieved by being more realistic in terms of planning of contribution from the host country and having better integrated projects rather than parallel activities.

We have targeted various audience groups: (i) academics and other researchers through conference participation, papers and book chapters; (ii) stakeholders and policy makers through meetings, workshops and the book "*The Living Okavango*"

Dissemination will be continue through presentation of data at national and international meetings, and through publication in the scientific literature. The target audience will mainly be other researchers and policy makers.

5.1 Darwin identity

We have used the Darwin logo on our project web page, on all our oral presentations, posters, training manuals, advertising of training courses to Botswana government employees and the University of Botswana. Darwin has also specifically been credited with helping to fund the macroinvertebrate training video. We also promoted the Darwin Initiative when we interacted with people in the field, including local inhabitants, tour operators and tourists (who often took an interest in our work). All publications will acknowledge funding from Darwin.

The Darwin Initiative was recognised as a distinct project with a clear identity. Although our aims were similar to IUCN working in the region, the methodologies employed were different.

Understanding of the Darwin Initiative was restricted to the people working at HOORC and on related projects / organisations in particular (*Biokavango*, ODMP, DWA).

6 Monitoring and evaluation

No major changes to the logframe were requested, except Darwin were informed in the Y2 annual report that only one MPhil student could be secured rather than the two in our original application.

We believe that our project was particularly challenging in a number of respects, but especially in terms of the multidisciplinary nature of the research and the intensity of the research and training we said that we would undertake. Because of these factors, we have had to continually monitor and evaluate progress on the project to ensure that major milestones did not slip. For the majority of cases, the assumptions we stated held true. There were exceptions to this: 1. just as our project started, Conservation International closed their offices in Botswana, so this organisation could not participate in training. The key contact at CI (Mosopele) however, was employed on our project. However, she subsequently left to join *Biokavango*. All these changes did have an impact on training and research, which we had to compensate for significantly with remaining staff; 2. We were unable to recruit a second MPhil student, which again had an impact on research to be carried out, for which we had to compensate for significantly with remaining staff; 3. On one occasion, fieldsites were not accessible in one region (the Lower Panhandle) due to extensive flooding. See Section 6.1 for details on how we dealt with this.

Given these issues, the main techniques used to M&E the project were by electronic communication (email; Skype) and face-to-face meetings. That we were able to visit Botswana so regularly meant that potentially very difficult problems were dealt with on a regular basis. However, the M&E system was very useful to remind both partners of responsibilities needed to be undertaken.

Aspects of the logframe have been very beneficial in terms of making sure that outputs from the project were produced. For us, several means of verification have still to happen, especially

with respect to the production of scientific publications (several of these are still in preparation). However, equally we have exceeded several measureable indicators, such as the number of sites analysed, number of staff trained and employed on the project.

There has not been any formal external evaluation of the project as a whole, although internal evaluation has been continuous. There has however been external evaluation of the taxonomic work carried out. Dr Helen Dallas from University of Capetown is an expert on macroinvertebrates in southern Africa (including the Okavango Delta). She has helped Mazebedi on taxonomic issues and has provided a link between the Darwin and *Biokavango* projects. Mackay has spent 3 days working with one of Africa's diatom experts (Dr Christine Cocquyt) on taxonomic issues relating to the Delta. This has been especially important given that no diatom flora currently exists for diatoms in Botswana. We now know which diatoms in the Delta are cosmopolitan, which are of African origin, which are rare in their global occurrence, and which are potentially important indicator species for future monitoring of the ecosystem health of the Delta.

6.1 Actions taken in response to annual report reviews

From the last annual report, the reviewer had specific questions that need were required to be addressed in final report:

How were alternative sites sampled when flooding prevented sampling in LPH in 2007? What were the criteria?

- Criteria for all sites was based on flood frequency maps, hydroperiod and accessibility to sites. A subsequent trip to the LPH in October 2007 especially focussed in on collecting samples from sites which could not be visited in May 2007.

How do you plan to use final models and simulations to develop management decisions, and how will these be communicated to the host partner?

- During the final project meeting there was considerable discussion between the members of the Darwin project and members from ODMP and OKACOM about how they should be planning for the future, given the uncertainty in the future predictions of climate change, as revealed during the presentations. It is apparent that there is an incompatibility between scales (spatial and temporal), degree of certainty and level of significance, of what can be supplied by the project (or researchers in general) and what is expected by decision makers. We work at larger scales, are acutely aware of uncertainty and see our work as assisting strategic decisions. ODMP/DWA/DEA work with specific questions and tactical decisions: will there be enough water to recharge boreholes, support fisheries in the next 5 years, how much water can be safely taken from the system etc. To this end, OKACOM have requested representative future hydrological scenarios for incorporation into the development of an Integrated Basin Management Plan.

Is the expectation that the Biodiversity Management Plan will be updated by researchers at HOORC in the future – how confident are you that they will be able to do this?

- Due to limited biodiversity expertise in Botswana, and that HOORC researchers are involved in our project, we do expect the management plan to be updated.

All our report reviews have been discussed with our partners and other collaborators

7 Finance and administration

7.1 Project expenditure

Printing was under-budget, and laboratory costs were over budget. This was principally because we carried out a analyses on a greater number of sites than we originally anticipated (i.e. 120 sites instead of 100). The under-spend in printing was used towards extra laboratory costs.

Master fees were also under-spent by more than 10%, but this is because we were unable to secure a second MPhil student. Darwin were informed of this in Year 2.

7.2 Additional funds or in-kind contributions secured

Luca Marazzi is a self-funding PhD student who started to work on phytoplankton in the Okavango Delta (Sept 2008). He secured funding from the RGS and UCL Graduate School to undertake fieldwork in the Delta, in collaboration with Prof Ramberg.

7.3 Value of DI funding

What has the DI funding enabled the host country and UK partners to achieve that they would not otherwise have been able to do? Collection of all the biodiversity and water chemistry datasets would not have been possible without DI funding. Use of REA to determinate 'best' climate change scenario impacts on the Delta would not have been possible without DI funding. All of the training highlighted would not have been possible without DI funding. In other words, without DI funding, the multidisciplinary nature of the project would not have been possible.

Annex 1 Report of progress and achievements against final project logframe for the life of the project

Project summary	Measurable Indicators	Achievements for complete project	Actions required/planned for next period
Goal: To draw on expertise relevant to biodiversity from within the United Kingdom to work with local partners in countries rich in biodiversity but constrained in resources to achieve • The conservation of biological diversity, • The sustainable use of its components, and • The fair and equitable sharing of the benefits arising out of the utilisation of genetic resources		(report on any contribution towards positive impact on biodiversity or positive changes in the conditions of human communities associated with biodiversity eg steps towards sustainable use or equitable sharing of costs or benefits)	(do not fill not applicable) NA
Purpose Assist in the ability of Botswana to implement CBD in the OD region, through programme of capacity building, training and scientific research.	By end of yr 3: HOORC staff appointed and trained. New knowledge on (i) aquatic ecosystem functioning (ii) hydrological responses to future climate and development scenarios. Key IBIs and predictive models developed. Long-term biodiversity monitoring programme established based on IBIs Inputs to ODMP complete.	5 technicians were appointed. All were trained in fieldwork techniques. One was trained in laboratory chemistry, Four were trained in macoinvertebrate identification; Two were trained in fish identification New knowledge on both ecosystem functioning and hydrological responses to future change have been determined IBIs themselves have not been developed, because our work has shown that there is minimal human impact on the Delta. However, baseline data on aquatic diversity has been characterised from which to monitor future change. Predictive models have been developed using multivariate statistical techniques Long-term monitoring programme has been initiated in conjunction with Biokavango programme	. (Highlight key actions planned for next period) NA

Project summary	Measurable Indicators	Achievements for complete project	Actions required/planned for next period
Output 1. Acquisition of extensive baseline aquatic biodiversity and water quality data across hydroperiod gradients in OD	• Within 1st 6 months of project: Candidate field sites (up to 100) identified from existing 15 year satellite derived flood maps and local knowledge. • By mid Yr 2: Datasets of baseline aquatic biological diversity archived. Contributions to UNDP GEF Wetland Biodiversity project underway		
Activity 1.1: Yr 1: Identification of candidate study sites (up to 100) from historical 15-year satellite derived dataset of flood history, aerial photos and local knowledge. Sampling basin will be range of hydroperiod conditions		• water-level regime modelled from 18 yrs of satellite maps (between 1989-2007 except for 1991; 2003), aerial photographs and flood maps. • over 120 sites were visited; from these, a total of 219 locations were sampled, including 20 'core' locations visited in at least 3 fieldtrips.	
Activity 1.2: Yrs 1 & 2: Data collection from sites, laboratory analysis		Data was collected from all 219 sites on habitat type, macroinvertebrate biodiversity and field-measured limnological variables; Diatoms analysed for 100 sites; macrophytes analysed from 21 locations; full water chemistry dataset measured for 90 locations.	
Output 2. Development of robust Indices of Biological Integrity (IBIs), sensitive to hydroperiod	By end yr 2 IBIs developed and tested, and statistical models relating IBIs to hydrology developed.		
Activity 2.1: Development of IBI and statistical IBI models. Initial prediction of IBIs under hydrological scenarios		For each organism dataset (macroinvertebrates, macrophytes, diatoms) we have used multiple regression techniques to (i) determine significant relationships affecting spatial distribution of species; (ii) model impact of water quality & hydrological variables on species datasets. During analyses it has become evident that the creation of IBIs across a hydroperiod gradient is not possible because human impact on the Delta is simply not strong enough. However, for each of the three organisms we are able to determine indicator species for particular environmental variables and we are able model species responses to their environment. These analyses are detailed in the presentations at the final workshop (and see section 4.3).	

Project summary	Measurable Indicators	Achievements for complete project	Actions required/planned for next period
Output 3. Development of future scenarios of OD flood frequency, extent and duration and biodiversity response	By mid Yr 3: Multiple 20 yr datasets of monthly river discharge and OD flood will be created using hydrological models, from scenarios of climate change/water abstraction. Initial prediction of resulting IBI.		
Activity 3.1: Y2-3: Development of multiple high-resolution climate predictions (for 2030-50) using General Circulation and Regional Climate Models. Multiple 20-year hydrological model simulations over OD conducted, based on various (c 10) climate change and water abstraction scenarios.		High resolution projections of future climate produced using dynamical downscaling with MM5 and Precis RCMs. Coarse resolution projections of climate from an ensemble of GCMs obtained and processed using (i) the Reliability Ensemble Average method (ii) The ClimGen pattern scaling approach. The former produces a weighted ensemble mean. The latter was used to develop a unique set of climate projections for specific prescribed warming values (0.5 – 6°C global mean temperature increase). All these future climate scenarios were used to drive the suite of basin and delta hydrological models to provide a grand ensemble of future flood extent.	
Output 4. Establishment of on-going systematic biodiversity monitoring programme based on identified IBIs	Staff trained. Monitoring equipment procured. In yr 3 monitoring programme initiated	Collaborative biological monitoring will form an important component of current monitoring strategies by HOORC in the Delta, especially in floodplains close to the ORC camp on Chief's Island. This work has recently started.	
Activity 4.1: Yrs 1-3: Training of Batswana staff in taxonomy, field methods, advanced numerical methods, computing and climate analysis.		Training formed a significant component of our project. **One-week advanced level courses in the UK in 2006**: *Macroinvertebrates & meiofauna* (Mrs Mosepele & Mr Mosie) *Introduction to macrophytes* (Mrs Mosepele) *Introduction to diatoms* (Dr Huntsman-Mapila) **Training courses held at HOORC, Maun, 2006-2009** *Darwin fieldwork techniques 2006* (12 participants, HOORC + UCL) *Water quality monitoring of the Okavango Delta 2007* (15 participants, including NWDC; DWNP; *Biokavango*, HOORC, tourist camps) *Numerical analysis of biological and environmental data 2007* (8 participants including DWA, DF, DWNP, HOORC)	

Project summary	Measurable Indicators	Achievements for complete project	Actions required/planned for next period
		*Introduction to the science of climate change and climate modelling 2009 (*13 participants; Met Services, DWA, DWNP, tourist camps, DF, HOORC)	
Output 5. Dissemination of results	Datasets compiled in dual archive at HOORC and UCL, accessible to all. Project website established at UCL. Journal and conference publications submitted (min. 6). Press releases for local and international media		
Activity 5.1: Production of guidelines, training manuals, protocols and web site		Protocols for all techniques used are available on the website. A ECRC Report was produced for method guidelines (Mackay et al. 2008). Project website: http://www2.geog.ucl.ac.uk/~mtodd/accord/index.htm Geo-referenced environmental database: http://www.orc.ub.bw/datacat/darwin.php	
Activity 5.2:.Attendance at conferences		**Oral presentations at National and International meetings** *Climate-Society Interactions - Case Studies from Africa*, 4th Franco-British Seminar, Paris, 2006. (Todd) *British Ecological Society*, Glasgow, UK. September 2007 (Mackay) *Eco-hydrological Processes and Sustainable Floodplain Management*, Lodz, Poland, May 2008 (Wolski) *8th INTECOL International Wetlands Conference*, Cuiaba, Brazil. July 2008 (Wolski) *20th International Diatom Symposium*, Croatia, September 2008 (Mackay) *British Diatom Meeting*, UK. October 2008 (Mackay) UK-Singapore Environment Programme Distinguished Lecture Series, *British High Commission,* Singapore, Dec 2008 (Todd) *NERC QUEST* GSI workshop Quantifying uncertainty in the impacts of climate change and development on freshwater availability, UCL, London, Apr 2009 (Todd) *International Workshop on Mainstreaming Climate Change Adapatation*.	

Project summary	Measurable Indicators	Achievements for complete project	Actions required/planned for next period
		May 2009 (Todd) *Conference Water Resources in Developing Countries: Planning and Management in a Climate Change Scenario*, Trieste, Italy, May 2009 (Todd) **Poster presentations:** Darwin Initiative workshop, 24th Oct 2006, London Zoo	
Activity 5.3: Yr 3: Submission of final results to international publications and media		See Annex 5 for details	
Output 6. Training programme for staff at HOORC/IC & Botswana students completed	Min. 8 HOORC/IC & 4 Government staff trained in key aspects of project science. Min. 2 HOORC academic staff trained in UK. 2 UB Masters by research in Yr 2. UB students trained during HOORC Winter School (up to 10 per yr).		
Activity 6.1: Yr 1. Staff appointed at HOORC, equipment procured		1 RA and 4 technicians were appointed. Equipment was bought at the start of the project, including a combined pH and conductivity meter, a dissolved oxygen meter. All equipment has been left at HOORC for future use.	
Activity 6.2: Yrs 1-3: Training of Batswana staff in taxonomy, field methods, advanced numerical methods, computing and climate analysis.		All were trained in fieldwork techniques. The RA was also registered for an MPhil. Of the technicians, one was trained in laboratory chemistry, while the rest were trained in macoinvertebrate and fish identification. See also Activity 4.1.	
Activity 6.3: UCL staff will visit HOORC to deliver annual 1-week courses on each component, while key HOORC academic staff will visit the UK for specialist training.		See Activity 4.1	
Activity 6.4: Senior undergraduate students from HOORC winter school trained each year.		Each year up to 10 final year undergraduates attended HOORC campus in Maun from the main university in Gaberone.	

Project summary	Measurable Indicators	Achievements for complete project	Actions required/planned for next period
Activity 6.5: Yr 2: 2 UB Masters research projects		We were only able to secure 1 MPhil student (Mazebedi). He was encouraged by HOORC to upgrade to a PhD, but this was unfortunately not successful. He is now due to submit his MPhil thesis by the end of this year, which represents a delay in this deliverable. However, a complete draft is currently waiting on comments from Dr Musundire, and we have put this on our website for consultation by the reviewer.	
Output 7. Relationship of project to CBD established through ODMP initiatives.	Annual/final project reports produced for ODMP. Presentation at meeting with ODMP. Workshops at start and end of project (ODMP and stakeholders). Report submitted to the tri-nation Permanent Okavango River Basin Water Commission (OKACOM).		
Activity 7.1: Yrs 1-3: Submission/presentation to ODMP		There is continuous interaction between HOORC and ODMP on various platforms (e.g. within ODMP proper, a recently developed E-flows project, etc.), ODMP was aware of activities and progress of the Darwin project.	
Activity 7.2: Yr 3: Submission of final results to ODMP & OKACOM		Representatives from the ODMP (Mostumi) and OKACOM (Chonquica) participated at our final project meeting in April 2009.	

Annex 2 Project's final logframe, including criteria and indicators

Project summary	Measurable Indicators	Means of verification	Important Assumptions
Goal: **To draw on expertise relevant to biodiversity from within the United Kingdom to work with local partners in countries rich in biodiversity but poor in resources to achieve** • **the conservation of biological diversity,** • **the sustainable use of its components, and** • **the fair and equitable sharing of benefits arising out of the utilisation of genetic resources**			
Purpose Assist in the ability of Botswana to implement CBD in the OD region, through programme of capacity building, training and scientific research.	By end of yr 3: HOORC staff appointed and trained. New knowledge on (i) aquatic ecosystem functioning (ii) hydrological responses to future climate and development scenarios. Key IBIs and predictive models developed. Long-term biodiversity monitoring programme established based on IBIs Inputs to ODMP complete.	HOORC annual reports. Scientific publications. Joint partner project reports	Government remains committed to CBD, Ramsar, and National Wetlands Policy.
Outputs Acquisition of extensive baseline aquatic biodiversity and water quality data across hydroperiod gradients in OD.	Within 1st 6 months of project: Candidate field sites (up to 100 for contingency) identified from existing 15 year satellite derived flood maps and local knowledge. By mid Yr 2: Datasets of baseline aquatic biological diversity archived. Contributions to UNDP GEF Wetland Biodiversity project underway	Manual of field and lab protocols Data archive of biological and chemical data. Reports	Field sites accessible during periods of flooding.
Development of robust Indices of Biological Integrity (IBIs), sensitive to hydroperiod	By end yr 2 IBIs developed and tested, and statistical models relating IBIs to hydrology developed.	Workpackage report sent to Darwin Initiative. Publications.	HOORC Computing facilities maintained.
Development of future scenarios of OD flood frequency, extent and duration and biodiversity response	By mid Yr 3: Multiple 20 yr datasets of monthly river discharge and OD flood will be created using hydrological models, from scenarios of climate change/water abstraction. Initial prediction of resulting IBI.	Workpackage report completed. Scientific publications.	Matched personnel at UCL will remain in post.
Establishment of on-going systematic biodiversity monitoring programme based on identified IBIs.	Staff trained. Monitoring equipment procured. In yr 3 monitoring programme initiated.	Workpackage report completed and sent to Darwin Initiative.	Botswana government maintains funding for HOORC.
Dissemination of results	Datasets compiled in dual archive at HOORC and UCL, accessible to all. Project website established at UCL. Journal and conference publications submitted (min. 6). Press releases for local and international media.	Data archives documented Copies of all manuals, reports, press releases and publications sent to Darwin Initiative	Computer facilities at UCL are constantly maintained.
Training programme for staff at HOORC/IC & Botswana students completed.	Min. 8 HOORC/IC & 4 Government staff trained in key aspects of project science. Min. 2 HOORC academic staff trained in UK.	Training manuals Training feedback reports Attendance records for	HOORC staff remain in post, and the Winter School continues

	2 UB Masters by research in Yr 2. UB students trained during HOORC Winter School (up to 10 per yr).	training courses Master theses	
Relationship of project to CBD established through ODMP initiatives.	Annual/final project reports produced for ODMP. Presentation at meeting with ODMP. Workshops at start and end of project (ODMP and stakeholders). Report submitted to the tri-nation Permanent Okavango River Basin Water Commission (OKACOM).	Workshop minutes, presentations and feedback compiled and sent to Darwin Initiative.	Reports will positively influence ODMP
Activities	Activity Milestones (Summary of Project Implementation Timetable)		
Research	Yr 1: Identification of candidate study sites (up to 100) from historical 15-year satellite derived dataset of flood history, aerial photos and local knowledge. Sampling basin will be range of hydroperiod conditions. Yrs 1 & 2: Data collection from sites, laboratory analysis. Y2-3: Development of multiple high-resolution climate predictions (for 2030-50) using General Circulation and Regional Climate Models. Multiple 20-year hydrological model simulations over OD conducted, based on various (c 10) climate change and water abstraction scenarios. Development of IBI and statistical IBI models. Initial prediction of IBIs under hydrological scenarios. Yr 1. Staff appointed at HOORC, equipment procured.		
Training	Yrs 1-3: Training of Batswana staff in taxonomy, field methods, advanced numerical methods, computing and climate analysis. UCL staff will visit HOORC to deliver annual 1-week courses on each component, while key HOORC academic staff will visit the UK for specialist training. Senior undergraduate students from HOORC winter school trained each year. Yr 2: 2 UB Masters research projects Yr 1: Production of guidelines, training manuals, protocols and web site		
Dissemination	Yrs 1-3: Submission/presentation to ODMP. Attendance at conferences Yr 3: Submission of final results to international publications, ODMP, OKACOM and media.		
Management	UCL will retain overall responsibility for management of the programme. The establishment of a web site in Yr 1 will facilitate this. Project planning will be finalised at workshop at start of programme (Apr 2006)		

Annex 3 Project contribution to Articles under the CBD

Project Contribution to Articles under the Convention on Biological Diversity

Article No./Title	Project %	Article Description
7. Identification and Monitoring	25	Identify and monitor components of biological diversity, particularly those requiring urgent conservation; identify processes and activities that have adverse effects; maintain and organise relevant data.
12. Research and Training	75	Establish programmes for scientific and technical education in identification, conservation and sustainable use of biodiversity components; promote research contributing to the conservation and sustainable use of biological diversity, particularly in developing countries (in accordance with SBSTTA recommendations).
Total %	100%	Check % = total 100

Annex 4 Standard Measures

Code	Description	Totals (plus additional detail as required)
Training Measures		
1b	Number of PhD qualifications obtained	**1:** Srivatsan Vijayaraghavan (UCL) *Quantifying Uncertainties in Regional Climate Predictions over Southern Africa using nested Regional Climate Models*
2	Number of Masters qualifications obtained	**4:** 1 MPhil student from Botswana is due to submit thesis by end 2009; 3 MSc students graduated 2007: 2 were biological focussed projects while the third linked to stakeholders in the Delta
4a	Number of undergraduate students receiving training	Yr 2 = 7; Yr 3 = 6
4b	Number of training weeks provided to undergraduate students	**12**
5	Number of people receiving other forms of long-term (>1yr) training not leading to formal qualification(ie not categories 1-4 above)	**4**: field and laboratory assistants: Mr Rebaeone Moshongo; Ms. Florah Joshua; Ms. Uanee Kauheva; Mr Laone Pitso
6a	Number of people receiving other forms of short-term education/training (ie not categories 1-5 above) 31	**4** senior staff from HOORC attended 3 advanced-level 1-week courses at UCL (macroinverts, macrophytes, diatoms) **15** people on 1-week biological and water quality monitoring programme at HOORC **8** people on statistics course at HOORC led by Mackay **13** people on climate course at HOORC led by Todd
6b	Number of training weeks not leading to formal qualification	**5.5**
7	Number of types of training materials produced for use by host country(s)	**5** Ordination Practical Guides Darwin Methods report Water quality training video Archived diatom slides (c. 100) Digital images of diatoms on Flickr http://www.flickr.com/photos/ansonmackay/sets/72157603693943090/
Research Measures		
8	Number of weeks spent by UK project staff on project work in host country(s)	Yr1=0; Yr2=12; yr 3=9; yr 4=13

Code	Description	Totals (plus additional detail as required)
10	Number of formal documents produced to assist work related to species identification, classification and recording.	**0**; but informal diatom guide on-line
11a	Number of papers published or accepted for publication in peer reviewed journals	**0** but forthcoming: 5 journal articles
11b	Number of papers published or accepted for publication elsewhere	**1** but forthcoming: 1 book; 1 book chapter
12a	Number of computer-based databases **established** (containing species/generic information) and handed over to host country	**1** orc.ub.bw/datacat/Darwin.php
12b	Number of computer-based databases **enhanced** (containing species/genetic information) and handed over to host country	**1** ODIS will be enhanced
13a	Number of species reference collections established and handed over to host country(s)	**1** set of archived slides containing prepared diatom samples from every fieldtrip
13b	Number of species reference collections enhanced and handed over to host country(s)	**1** enhanced archived macroinvertebrate collection
Dissemination Measures		
14a	Number of conferences/seminars/workshops organised to present/disseminate findings from Darwin project work	**1** final workshop at Maun organised
14b	Number of conferences/seminars/ workshops attended at which findings from Darwin project work will be presented/ disseminated.	**8**
15a	Number of national press releases or publicity articles in host country(s)	**1**
15b	Number of local press releases or publicity articles in host country(s)	**1**
15c	Number of national press releases or publicity articles in UK	**1**
Physical Measures		
22	Number of permanent field plots established	3 Monitoring sites have been established at several locations in the Okavango Delta
23	Value of additional resources raised for project	**c. £4000**
Other Measures used by the project and not currently including in DI standard measures		

Annex 5 Publications

Type	Detail
Book chapter	Todd, M.C. and co-authors., 2008 Integrating climate and hydrological models for water management: Experience from the Okavango River, southern Africa. In Sorooshian, S.; Hsu, K.-l.; Coppola, E.; Tomassetti, B.; Verdecchia, M.; Visconti, G. (Eds.) Hydrological modelling and water cycle. Coupling of the atmospheric and hydrological model, Springer, 291pp ISBN: 978-3-540-77842-4
Report	Mackay, A.W., Mazebedi, R., Wolski, P., Davidson, T.A., Huntsman-Mapila, P. & Todd, M. (2008) Monitoring and simulating threats to aquatic biodiversity in the Okavango Delta: field and laboratory methods. Methods report to Darwin Initiative 162/14/029. ECRC Research Report 129, 35 pp.

Publications in review and forthcoming

Type	Detail
Book chapter	Todd, M.C. and co-authors, Climate change impacts on hydrology in Africa: Case studies of river basin water resources. In Williams, C. and Kniveton, D., (Eds.) African Climate and Climate Change: Physical, Social and Political Perspectives. Springer (in review)
Journal paper	Hughes, D., Todd, MC, Kingston, D., Wolski, P, Taylor, R. Uncertainty in projected environmental flows to the Okavango Delta as a result of climate change. Hydrology and Earth System Science (Special issue, in review)
Journal paper	Todd, M.C and Wolski, P. Climate variability over Southwestern Africa: Interannual to multi-decadal flow variations in the Okavango river system. International Journal of Climatology (to be submitted Sept 2009)
Book	Mendelsohn, J. Editor. (forthcoming). *The Living Okavango*.
Journal paper	Mackay, A.W., Mazebedi, R., Davidson, T., Wolski, P., Huntsman-Mapila, P., Todd, M.C. (forthcoming). Environmental controls on aquatic biodiversity in the Okavango Delta, Botswana: a multivariate approach. Global Change Biology
Journal paper	Mackay, A.W., Davidson, T., Wolski, P. (forthcoming) Patterns in epiphytic diatom diversity in the wetlands of the Okavango Delta, Botswana. Journal of Biogeography
Journal Paper	Mazebedi, R., Mackay, A.W., Davidson, T., Wolski, P (forthcoming) Spatial and temporal characteristics of aquatic macroinvertebrates in the Okavango Delta: assessing the role of water-level regime and habitat type.

Annex 6 Darwin Contacts

Ref No	14-029
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