PROGRAM PROPOSAL - 2010
BIOLOGICAL DIVERSITY OF THE GUIANA SHIELD
(http://botany.si.edu/bdg/index.html)

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PROGRAM SUMMARY

Of all the Grand Challenges that have been mentioned by various organizations over the last few years, perhaps the most important for our survival as a species is "Understanding life on Earth" since that knowledge is essential to preserve life on our ever changing planet. This understanding takes many forms, from studies of discovery to documentation, pattern to process, and genomes to behavior. The Biological Diversity of the Guiana Shield Program (BDG) of the National Museum of Natural History (Smithsonian Institution) operates on a number of levels to increase our knowledge of biodiversity. The goal of BDG is to document, understand, and conserve the biological diversity of the Guiana Shield area. In line with that goal we (BDG and its partners and collaborators) gather and study organisms, publish papers, teach/train, and host websites all based on material from the Shield area of northeastern South America.

The Guiana Shield (the Shield) is a distinct geologic region that is biologically extremely rich (e.g., 23% of Neotropical freshwater fish diversity; 33% of South American bird diversity; 20% of Neotropical plant diversity) but remains poorly known. Because it is an ancient, fairly isolated geological area, the Shield has high endemism (ca. 40% of plants; 54% of amphibians; 40% of reptiles; 8% of birds; 10% of mammals) and many undescribed taxa. Approximately 60-70% of the natural habitat of the Shield remains pristine but these natural areas are now seriously threatened. We must gain an understanding of the Shield biota to inform conservation decisions. In addition, understanding the environment is of utmost importance in order to address current issues such as climate change. Unfortunately, most studies lack the baseline data needed to address such issues, especially in species rich, biologically diverse tropical rainforest biome.

BDG is interdepartmental and inter-unit across the Smithsonian and has worldwide collaborators. Over the past 20+ years we have worked with over 800 people in the course of our research, education/training, and outreach efforts. These efforts have resulted in tens of thousands of new collections that have been used for over 530 papers addressing a variety of questions from basic "What is it?" and "Where does it live/grow?" to synthetic ones such as "What is it related to?", "What are the levels of endemism?", and "Are there adaptive radiations?". From our collaborators and partners we receive data to analyze on a regional level and that they concomitantly can use to address their specific research questions. Past attempts to model the biodiversity were hampered because of the lack of data. Targeted collecting has improved our coverage and now we seek to combine our plant data with that of our vertebrate zoology collaborators to develop a predictable model of biodiversity. To truly understand the Shield biodiversity we need more taxonomic coverage, and thus we plan to expand our proven collecting methods to include select insects. We envision a future BDG program with two main research objectives: 1) *Synthesis of broad biodiversity patterns through Ecological Niche Modeling*. 2) *Expanding biodiversity documentation*, both in poorly known taxonomic groups and unexplored regions. These objectives capitalize on established BDG strengths and extend them in novel and synthetic ways. The program will be overseen by a diverse group of scientists with a broad array of experiences.

Over the 20+ years of its existence BDG has been allocated just over $3 million in Federal Funds (total budget $5 million or $7.5 million with "in kind" contributions), less than a current NSF-PBI grant. Yet it has had a major impact on our knowledge of the Neotropics, produced an amazing amount of scientific research, interacted with hundreds of people and made its information available for conservation efforts and the general public. We believe we are fulfilling the mission of the Smithsonian Institution as was set out by James Smithson when he left his fortune to establish "An institution for the increase and diffusion of knowledge…"

(***1.) Introduction and Overview***

The goal of the Biological Diversity of the Guiana Shield Program (BDG) is to document, understand, and conserve the biological diversity of the Guiana Shield area (the Shield). In line with that goal we (BDG and its partners and collaborators) gather and study organisms, publish scientific papers and books, as well as items for more general use, and assist in the training and education of staff and students from the Shield area of northeastern South America and around the world. We interface with other bureaus at SI, and collaborate with over 800 people around the world. Major outreach efforts are centered on making our data available to the academic community and the public and working with conservation organizations. Specific questions addressed in the publications vary greatly depending on our knowledge level in that group of organisms. We usually begin with the two basic questions of Systematics, "What is it?" and "Where does it live/grow?" and move on to more synthetic ones such as "What is it related to?", "What are the levels of endemism in the biota of the Shield?", "Are the species in a genus the result of an adaptive radiation across the Shield?, "How much species turnover do we have along latitudinal gradients?", "What is the estimated species diversity of the Shield area?", "Where should we collect to get the most new material?", etc. From our collaborators and partners we receive data that we can analyze on a regional level. They, in turn, are able to address questions specific to their research. This year we have begun a major effort in ecological niche modeling, a new and growing field sometimes referred to as "Phylogenetic Beta Diversity", incorporating phylogenetic information with measures of data diversity to look at evolutionary relatedness of communities. This effort will coordinate efforts to examine all available data for plants, birds, and mammals and possibly ants, odonates, amphibians and reptiles. Other Entomological groups need a more intensive collecting strategy for a number of years before enough data will be available for such analyses. At this point our strategy is three fold, to immediately begin to analyze the available data in plants, birds and mammals, to quickly sample the necessary areas for ants, odonates, amphibians, and reptiles so they can be analyzed by the end of six years, and to undertake a broad scale collecting effort in selected groups in Hymenoptera over a six and possible 12 year time frame with a view to the future of adding those data to the analyses.

Why the Guiana Shield Area? - The Shield is a distinct geologic region that underlies Guyana, Suriname, French Guiana, parts of Venezuela and Brazil and a very small part of Colombia. The Shield is biologically extremely rich (e.g., 23% of Neotropical freshwater fish diversity; 33% of South American bird diversity; 20% of Neotropical plant diversity) but poorly known. Because it is an ancient, fairly isolated geological area, the Shield is rich in endemic plants and animals (Plants ca. 40%; 54% of amphibians; 40% of reptiles; 8% of birds; and 10% of mammals). Species accumulation curves indicate that many more species new to science are likely to be discovered (e.g., 102 new plant species in the last 4 years) (Hollowell and Reynolds 2005, Feuillet 2009). In addition, because this area has been long neglected by biologists, it is often an area of "inadequate information" for many biodiversity analyses.

Unlike other regions of South America, approximately 60-70% of the natural habitat of the Shield remains pristine due to historically low population and economic pressures. These natural areas are now seriously threatened by logging, gold and bauxite mining, hydroelectric dams and wildlife exploitation. It is important that we gain an understanding of the flora and fauna of the Shield so that decisions can be made on critical areas that have high priority for conservation and so data can be collected from areas that might ultimately be destroyed. In addition, understanding the environment is of utmost importance in order to address current issues such as climate change, conservation and biodiversity assessment. Unfortunately, most studies lack the baseline data needed to address these imminent issues, especially in the species rich, biologically diverse tropical rainforest biomes. Many current studies rely heavily on museum specimen label information for baseline data used for

biogeographical and taxonomic studies (Beck and Kitching 2007, Clarke and Funk 2005, Graham et al. 2004, Clarke et al. 2001, Ponder et al. 2001), conservation (Tobler et al. 2007, DeWalt et al. 2005, Ferrier et al. 2004, Meier and Dikow 2004, Peterson et al. 2004, Schlick-Steiner et al. 2003) and decision making (Golding, 2004). However, a common caveat is that they are hindered by the incomplete, non-systematic historical sampling bias (Rowe 2005; Schmidt et al. 2005, Rasmussen and Prys-Jones, 2003, Reddy and Dávalos, 2003, Smith et al. 2003). Most early collections are concentrated about villages, roads, airstrips, rivers and other easily accessible areas. Using historic data to make predictions about biodiversity, species richness and distributions can be useful but must be strengthened and "require repeated surveys at the same locations" and expanded geographic coverage (Tingley and Beissinger 2009). However, historical data can be used to ascertain collecting efforts and target areas that have little or no data (Funk and Richardson, 2005).

What is now the BDG program began over 20 years ago (see History in Appendix 7) as a flora project in the three Guianas (Guyana, Suriname, French Guiana) but evolved into a biodiversity program that eventually covered the Shield region. Collecting efforts and data management have been aimed at gaining an understanding of the biodiversity of the area (see Prior Accomplishments) and providing collections and information for scientific study. Attempts to model the biodiversity (Funk and Richardson 2002) met with limited success because of the lack of data. Survey gap analysis was useful in plants and birds to indicate where we should be collecting to gather the most new information (Funk et al. 2005) and we have targeted those areas. Now we seek to combine our data with those of our vertebrate zoology collaborators to develop a predictable model of biodiversity. However, vertebrates and plants are not sufficient to truly understand the diversity of an area, and we plan to expand our proven collecting methods to include insects. Plants and vertebrates are not good predictors of diversity for one another but it is expected that insects may be better (Funk and Richardson, unpublished data).

Relevance to Institutional Objectives. Our program will advance the NMNH Strategic Plan for 2010-2015 by directly embracing the key theme of discovery and understanding life's diversity (p. 4). We do this by enabling the documentation of that diversity with collections-based data and enhancing the research on the origins, evolution and ecology of a tropical forest biota. We will build partnerships and strengthening collaborations both within NMNH and with universities and other institutions. Similarly, our program addresses numerous points (p.11) in the SI Strategic Plan for 2010-2015 including leveraging SI research through national and international partnerships, strengthening collections and their documentation, and understanding ecosystems.

Research Objectives

We envision a future BDG program with two main research objectives: 1) *Synthesis of broad biodiversity patterns through Ecological Niche Modeling (ENM)*. For groups of organisms where we already have sufficient data due to past activities of the BDG program, we would analyze the data from BDG and its partners. For most insect groups, we will initiate or intensify field data collection, with the goal of incorporating these data into future ENM studies. 2) *Expanding biodiversity documentation*, both in unexplored regions and across taxonomic groups that are poorly known. These objectives capitalize on established BDG strengths and extend them in novel and synthetic ways.

Objective 1 – Synthesis of broad biodiversity patterns through Ecological Niche Modeling

The use of GIS-based ENM to predict species potential distributions has become a powerful research tool in recent years. This suite of approaches has found diverse application in studies of species responses to climatic change (Hijmans and Graham 2006, Fitzpatrick et al. 2008), conservation and reserve planning (Anderson and Martínez-Meyer 2004, Costa et al. 2009, Kremen et al. 2008), species invasions (DeVanney et al. 2009, Anderson et al. 2006), phylogeography (Carstens and Richards 2007,

Waltari et al. 2007), species delimitation (Raxworthy et al. 2007), patterns of biodiversity (Carnaval and Moritz 2008), and other areas (see Kozak et al. 2008 for a review of the uses of ENM in evolutionary biology). ENM algorithms require two kinds of input data: 1) georeferenced occurrence records for the species, and 2) environmental data (especially regarding climate) for the study region. Ideally, the occurrence records are vouchered and correspond to museum or herbarium specimens. Various presence-absence approaches from spatial ecology and wildlife modeling have existed for many years, but they require information regarding the presence of the species as well sites where the species is absent; such absence data are rare in biodiversity repositories for the overwhelming majority of taxa on and regions. Fortunately, more recently developed presence-only techniques do not require absence information; instead, the most successful among them compare the environmental characteristics of sites of known presence to the overall environmental conditions available in the study region. They also can integrate information regarding the sites that have been sampled for a given group, using this information to correct for the sampling biases in geographic and environmental space that consistently plague both planned and opportunistic biodiversity surveys.

The BDG database of vouchered occurrence records assembled through many years of field surveys, systematic research, and data capture from historical specimens has enormous untapped potential to inform many areas of biodiversity science via ENM. It includes recent records based on BDG fieldwork as well as historical specimens, the latter often from regions where such surveys no longer are possible (either because of political hindrances or human modifications of the environment). The large number of records from many different data sources facilitates modeling because better models generally can be made with larger numbers of records, and because complementary data sources (e.g., many museums rather than just one) typically provide a truer sample of a species' environmental requirements. Finally, the collective information regarding records of many species that all belong to a single "target group" (e.g., vascular plants, small non-volant mammals, etc.) can serve as a surrogate for sampling effort, allowing researchers to correct for sampling bias and evaluate the adequacy of sampling in regions predicted suitable for a species but lacking records of it (Heyer et al. 1999, Anderson 2003, Phillips et al. 2009).

Currently, we envision three stages to the ENM component of the proposed research: 1) a pilot project with two small, well-known clades of plants; 2) a workshop to facilitate coordination among the various parties; and 3) a much larger series of parallel projects in various taxonomic groups, producing concrete predictions of the geographic distributions of many species. These predictions will be used to guide field surveys, provide synthetic overviews of patterns of richness and turnover in the Guianas for academic and conservation-related uses, and form the basis of studies of speciation in selected groups for which phylogenies exist. The NMNH funding requested here will be leveraged in NSF proposals to realize the third stage fully. The primary ENM algorithm to be used is Maxent, developed by Anderson and colleagues (Phillips et al. 2006; http://www.cs.princeton.edu/~schapire/maxent), which has performed especially well and is widely used in the field (Elith et al. 2006, Hernandez et al. 2006, Warren et al. 2008, Wisz et al. 2008, Rebelo and Jones 2010).

The pilot phase of modeling (2010) focuses on two endemic Guiana Shield genera, *Stenopadus* (Asteraceae) and *Elizabetha* (including *Paloue*; Fabaceae). While the species of these groups occupy rather different climatic and elevational ranges within the Shield, available phylogenetic data indicate that they each speciated in-situ (Bruneau et al. 2008, Funk et al. 2009) and are sister to respective taxa found outside the Shield. Although user-friendly Maxent software is freely available, research on Anderson's current NSF grant has shown the utility of, and indeed the need for, species-specific settings (Anderson and Raza, in press; Radosavljevic et al., in ms; Anderson and Gonzalez, in ms; Anderson and Shcheglovitova, in ms; the latter three nearing submission). Essentially, "custom" models for each

species provide geographic predictions far superior to those made based on default settings of Maxent. The additional effort to produce high-quality models by customizing the study region for modeling and conducting experiments to tune model settings (e.g., control overfitting by an approach similar to AIC/BIC) will greatly increase the utility of the models in predicting species occurrences on the ground and accurately representing and forecasting complex biodiversity patterns. Semi-automated protocols ("supervised" for each species by input from specialists at critical junctures when biological knowledge is needed) developed in this phase will greatly facilitate later work on other taxa (Phase III). In addition, the work on these two plant genera will include processing of environmental datasets that can be used for other groups as well (e.g., remotely sensed precipitation data for the Shield, which should be more realistic than currently available data interpolated from weather stations; http://www.worldclim.org/)

A workshop will be held in September 2010 (and each subsequent year) involving all of our partners (see #5 below). The workshop will have two goals: 1) to coordinate our efforts across the Shield and 2) to determine the best ways to standardize data (regarding species occurrence records) and use the predicted geographic distributions to guide field surveys and compare patterns among plants, birds, mammals, reptiles, and amphibians. Before the first meeting we will probably add a theoretical macroecologist to our collaborator list but this requires some input from our partners.

Objective 2 – Expanding biodiversity documentation Previous efforts of BDG have especially focused on plants and vertebrates. Over the next six, and possibly 12, years BDG will continue to fill in holes in the data for plants and will expand its focus to also document and analyze patterns of biodiversity for four hyperdiverse insect groups: Formicidae (ants), select Parasitica (i.e., primarily parasitoid Hymenoptera), Apoidea (bees), and Odonata (dragonflies).

PLANTS - Plant collecting methods are well established (see Prior Accomplishments) and the way forward is clear. We intend to continue to send 1-3 expeditions a year (depending on external funding) to areas targeted as critical new areas to survey. In the past, these areas have been determined based on the survey gap analysis by Funk et al. (2005), however the methods used are now outdated and we intend to rerun the analyses with a dataset that includes all the new collecting information involving the whole Shield. We will identify areas holding concentrations of predicted but undocumented biodiversity, likely either new populations or new species (cf., Raxworthy et al. 2003). By focusing our collecting efforts, we can potentially save a great deal of time and money, and increase the scientific and conservation-related products of the fieldwork. In addition, we are now as a matter of routine also sampling for genetic resources and gathering geo-tagged images and these efforts will continue on future trips.

INSECTS - There have been a number of prior invertebrate collecting trips (e.g., butterflies, shore flies, Hymenoptera, micro-Lepidoptera, Odonata, spiders, and water beetles) but no overall organization of the sampling efforts. Except for ants and butterflies, the collecting was limited in nature. During the next six years, BDG will design and implement an integrated sampling scheme for two selected groups of invertebrates, Hymenoptera (ants, bees, parasitoid wasps) and Odonata (dragonflies and damselflies). The Hymenoptera portion of this program will be based on mass collecting using a system of litter sampling, pitfall traps, pan traps, and Malaise traps maintained by locals. Many other groups of invertebrates also will be collected in these traps; they will be sorted to order and distributed to specialists working on those groups (i.e., Homoptera, spiders). The Odonata must be collected individually with nets and so require a different collecting scheme.

HYMENOPTERA – Hymenoptera (ants, bees, and wasps) is one of the largest insect orders with >115,000 described species (Gaston 1993) and estimates of true global richness ranging from 300,000–3 million species (Gaston et al. 1996, Grissell 1999). Hymenoptera is an excellent focal taxon for biodiversity sampling because they (i) are hyperdiverse; (ii) are easily sampled by replicable, quantitative methods; and (iii) occupy a diverse range of trophic levels. The design of the integrated Hymenoptera sampling protocol proposed here would result in the single most intensive effort (in both time and space) for Hymenoptera ever attempted in the Neotropics. Our sampling scheme (see Appendix 7), which includes ants, bees, and wasps, will encompass the broad range of trophic levels.

ANTS – Litter-dwelling ants are model organisms for biodiversity assessment (Spector and Forsyth 1998, Agosti et al. 2000b) because of their high diversity and biomass, ecological importance at a range of trophic levels, ease of sampling, and well-understood community dynamics (Tobin 1994, Andersen and Sparling 1997, Davidson et al. 2003, Russell et al. 2009). The standardized "ALL" (Ants of the Leaf Litter) protocol (Agosti et al. 2000b) will continue to be employed to collect thousands of quantitatively comparable samples in diverse localities across the globe (Fisher et al. 2000, Agosti et al. 2000a, Ward 2000, Delabie et al. 2000, LaPolla et al. 2007), generating data for assessing biodiversity measures such as relative species richness and diversity, species overlap, and species uniqueness (endemism) across localities (Longino 2000). In addition to providing data about biodiversity of the Guiana Shield, the ant-sampling data will be integrated with those of the dozens of myrmecological colleagues also collecting leaf-litter ant data, using comparable methods, in other localities in South America (e.g., Vasconcelos for Manaus, Delabie for Atlantic Forest, Brandão and Vasconcelos for cerrado, Longino for Central America) (Agosti et al. 2000b, Longino 2000, Longino et al. 2002) and the world (Fisher et al 2000).

PARASITOID HYMENOPTERA – Parasitoid Hymenoptera are a hyperdiverse assemblage of organisms that complete their development on or in other organisms (usually insects and/or plants), in most cases killing the host. Parasitoids are unquestionably critical to biological control of pest insects, and they help maintain high diversity in other organisms (LaSalle and Gauld 1991). Despite their overwhelming numerical, biological, and morphological diversity, they remain little studied. Parasitoid Hymenoptera are unique bioindicators as they represent a broad spectrum of arthropod host niches (Sharkey 2007). They are sensitive to ecological perturbations, especially pesticides, so that investigators should see fluctuations in parasitoid populations well before they are observed in their host populations (LaSalle 1993). This sensitivity makes them ideal candidates for conservation studies.

Parasitoid wasps are poorly known in the Neotropics (Gauld and Hanson 1995). The results of a recent biodiversity survey illustrate the paucity of baseline data for Neotropical parasitoid wasps. For example, only 55 species of Doryctinae (Braconidae) were known in Costa Rica prior to the establishment of Instituto Nacional de Biodiversidad (INBio) in 1989. Marsh (2002) described 119 new species from Costa Rica, a ~216% increase, primarily using specimens from INBio's sampling efforts. Only 10 species of Doryctinae are known from Guyana. We expect a greater level of increase in dorcyctine species for Guyana due to its larger size and relatively undisturbed ecosystems. Similar increases in species richness are expected for other focal taxa within Hymenoptera. The acquisition of baseline data to address broader questions of parasitoid wasp biodiversity, such as how parasitoid wasp diversity varies with latitude and the effects of climate change, requires a spatially and temporally intensive sampling strategy using multiple sampling methods as described in this proposal. Species discovery and description of this particular group of insects also has impact beyond that of understanding global species diversity patterns: parasitoid Hymenoptera represent the single most influential force shaping the population dynamics of terrestrial arthropods worldwide. These species are commonly used in agriculture for regulating pest species population levels, yet this success rests

critically on the ability to identify parasitoids species. Hence, understanding the diversity in nature dovetails directly into understanding species diversity within a human context.

BEES – Bees, as herbivores and pollinators, are involved in complex symbioses with flowering plants (Danforth 2007, Michener 2007). Many plant groups in tropical lowland forests are predominantly bee pollinated (Bawa 1990). Some bee species are generalist pollinators, while others are specialists on one or few plant taxa. Bees are completely dependent on their plant hosts for nutrition. This intimate relationship between bees and flowering plants establishes the expectation that their diversity may be correlated, especially in cases of extreme floral specialization. Our sampling will obtain data on bee species richness that will be analyzed within the context of already-established baseline plant data from Guyana, allowing the examination of floristic and other factors associated with bee distributional patterns. Furthermore, it is commonly argued that bee diversity is greater in temperate and xeric habitats compared to the tropics (Michener 2007), though this may reflect sampling bias (e.g., Melo and Alves dos Santos 2003). The bee data gathered through BDG, especially in conjunction with the ENM analyses, will provide a major source of additional information and theoretical focus to this outstanding issue.

OTHER GROUPS OF INSECTS AND SPIDERS FROM THE HYMENOPTERA SAMPLING – In the course of sampling for Hymenoptera we will also collect many other groups of insects. We plan to train local participants in basic methods of sorting, identifying and preparing other insects, e.g., students and staff at the University of Guyana working at the Biodiversity Centre. We will hold in-country training seminars to teach students and faculty to sort and identify material at least to order. Once there is an initial sorting of material, specimens can be quickly sent to various experts who have expressed interest in seeing material from the Guiana Shield region.

ODONATA – Odonata comprise roughly 5000 species, and are generally good dispersers, with large population ranges compared to many terrestrial insects. In contrast to other insects being sampled as part of BDG, dragonflies and damselflies have much higher levels of dispersal, and their diversity is only just beginning to be studied and understood (Claustiner et al. 2009). Some species are migratory or semi-migratory, while others have more restricted ranges. Our broader goals for sampling Odonata in the Shield are to uncover the diversity of the region, for taxonomic and systematic work. Ongoing studies by Claustiner et al. (2009) aim to assess the global threat level for Odonata, and our work in the Shield will fill in much needed data about species distributions and abundance (for example, 32% of Neotropical species are considered "data deficient").

Data from our Partners:

BIRDS - There have been many BDG expeditions to Guyana to collect birds (see Prior Accomplishments). The BDG program has the data from those collections along with all the specimen data from NMNH (courtesy of the Bird Division) and some data from BM and AMNH. Thus, we are well-positioned to include the birds from Guyana in the ENM analysis at no additional field costs. For the wider Shield region we plan on collaborating with Gary Graves (NMNH) and his co-author Carsten Rhebeck (Copenhagen) who have accumulated a large data set for all of South America.

MAMMALS - The mammals are collected and studied by collaborators at the Royal Ontario Museum who report that the largest taxonomic gaps are within the large mammals such as carnivores, primates, and edentates. They plan to continue their ongoing mammal surveys in Guyana and Suriname and target poorly collected regions such as the Llanos savanna of Venezuela and French Guiana to study the biogeography of the tepuis and savannas in relation to more typical lowland forest. They have a large database with information on Shield mammals housed in institutions around the world; these data will be available for the ENM studies.

REPTILES AND AMPHIBIANS - The knowledge of the herpetofauna is still far from complete, because many species are cryptic or have restricted distributions. More collecting, through general surveys or taxon-specific collections, is needed. Collaborating with BDG will leverage the funds for additional fieldwork and enable analyses that provide a much clearer picture of the makeup and distribution of the Shield herpetofauna. The herp data will be included in the preliminary ENM analysis.

FISHES – AUM, ROM, UG-CSBD, and ULL have recently submitted an NSF grant for the Pakaraima Mountains. (Guyana), and if funded, the main areas of focus in the near future would be the Rewa and Corantinjne Rivers. The fish checklist of Vari et al. (2009) is being developed further at AUM by re-identifying all Guyana fishes and developing an online pictorial guide. Several papers are planned including a reevaluation of the interpretations of Eigenmann's fish distributions. Likewise there are ongoing projects in Suriname and French Guiana (Vari, pers.com.). The fish occurrence data are incomplete; however, we will include it in preliminary ENM analyses to test its usefulness.

Publication goals:

PLANTS - For 2010 the goals are clear and many diverse papers will be published. Central to this proposal is a "proof of concept" ENM paper to be submitted in late 2010 for the pilot plant project (see **Research Plans**). There is a large botanical monograph, many new species, at least one of the "collector series", an issue of the Contributions from the Centre, and more already scheduled. For 2011-2015 the publication flow will continue unabated including several papers from the niche modeling as well as some addressing radiations across the Shield and species turnover rates.

HYMENOPTERA (minus ants) - There will be many entomological publications from the BDG team members and a few are listed here: The Doryctinae (Hymenoptera: Braconidae excluding *Heterospilus*) of Guyana, with a comparison of temperate and tropical species diversity, will include a key to species of the Shield, descriptions of new species, and a comparison of doryctine species diversity across a latitudinal gradient covering ~5,000 km. A comparison of the doryctine fauna at sites with high levels of endemism in North, Central, and South America will be completed using the research proposed herein coupled with surveys of Konza Prairie, Kansas (Kula, in prep.) and Costa Rica (Marsh 2002). Publication goals using the bee data involve hypothesis tests of floristic and environmental influences on bee diversity, new species descriptions based on morphological and molecular data, web-based identification keys, statistical comparison to other standardized bee surveys conducted by co-PI Brady (e.g., Cuba) and colleagues, and the inference of phylogeographic and community phylogenetic patterns within the Shield using next-generation sequencing approaches currently being developed by Brady with a UMD/SI seed grant.

ANTS - For ants we envision that several ongoing monographic works will benefit from BDG collecting, including for Attini, *Brachymyrmex*, *Discothyrea*, *Nylanderia*, and *Solenopsis*. As for a more theoretical paper, we continue work on putting together a database for analysis of leaf litter ant diversity patterns. Co-PI LaPolla has a graduate student who is analyzing the 2006 survey results to compare whether or not the fauna in rotten wood differs significantly from that found in leaf litter. Despite the high frequency of leaf litter ant surveys, there has been little attempt to quantify microhabitat differences that might impact the manner in which such surveys are conducted.

ODONATA - Over the next six years we will produce a *Field Guide and checklist to the Odonata of the Guyana Shield*. There will be several papers on the systematics of the Corduliidae, with a taxonomic emphasis on South American taxa and a study of the *Odonate larvae of the Guyana Shield: behavior, morphology and taxonomy.*

AMPHIBIANS AND REPTILES - A major milestone for our knowledge of the amphibians and reptiles of Guyana will be the completion of a several hundred page monograph by Charles J. Cole, who

worked with the BDG for many years before he retired, and collaborators. This work is a detailed checklist of the ca. 315 species of herpetofauna known from Guyana and includes keys, an account for each species, maps, color photographs, and artwork. Co-PI Noonan plans a series of descriptive publications as well as one describing the diversity across the Shield.

MAMMALS - Co-PI Lim is preparing a work on bats of the Shield for an edited volume on *Diversity, systematics and conservation of South American bats* (*in* Tavares et al.), and a more theoretical work on adaptive radiation of bats in savanna: Guiana Shield forest as a stable core area for speciation.

Funding goals: A program with the scope of BDG cannot be funded on internal money alone. We have consistently sought to leverage additional funds and "in kind" contributions from traditional and non-traditional sources (see Appendix 5). Currently, we have two grant proposals pending:

1. *Plants of the Guiana Shield: Inventorying using a comparative approach* was submitted to NSF ($860,115) in January 2010. It covers five years of field work and research to establish a large plot in Guyana (in collaboration with the Brazilians).
2. *Biodiversity of the Guiana Highlands: Botanical exploration of Mount Tulameng* ($14,000) was submitted to the National Geographic Society in March 2010.

In addition, during 2011 we plan to submit three large NSF proposals: One is a resubmission of a RevSys proposal to monograph a large and complicated legume genus that has radiated in the Neotropics. A second proposal will go to BS&I and will focus on the entomological collecting effort (especially Hymenoptera) and on a much smaller scale additional collecting in plants and vertebrates. The final proposal will go to the New Dimensions Macroscale Ecology program and will focus on analyzing data from plants, birds and mammals. There is a possibility that before the end of the six years we will have sufficient data from ants, odonates, reptiles and/or amphibians.

New Partners:
BDG is a natural fit with the Global Genome Initiative (GGI), one of the new NMNH "Big Ideas". A fundamental goal of this initiative is to conduct new field expeditions to obtain genomic-grade specimens that will form a synoptic collection from the Tree of Life. The BDG program can serve as a key enabling partner for this activity, and we hope to coordinate expeditions with the GGI beginning in 2011. Co-PI Brady is a major participant in the GGI, which will facilitate this interaction. In addition, this program fits well with the goals of the new SI Consortium "Understanding and Sustaining Life on a Biodiverse Planet" in that in order to understand biodiversity we must first document it.

(2) Description and justification of research plans, component projects, and milestones for the six-year period and how these will be integrated to advance the central objectives of the program.
Description, justification, and integration of research plans are discussed above.

Major Milestones (see **Goals** for details and other milestones)
2010: Completion of first paper on niche modeling using two test groups; publication of one "collectors" volume; publication of one botanical monograph; publication on ant diversity; opening in July of enhanced Centre Library using new metal shelving courtesy of BDG; Ant expedition to CI concession; launching of the Odonata collecting effort; planning for 2011 Hymenoptera collecting effort; plant expedition to Mt. Tulameng; one USA MS student trained in field work; one USA PhD student trained in field work; several Amerindians and undergraduates from UG trained; one short course taught at the

Centre; website updated with "miscellaneous collectors". In September we will host the first of our annual PI meeting/workshop at NH.
2011: Publications on plant radiations across the Shield; publication on species turnover; two "collectors" volumes; additional publications on ant diversity; launching of Hymenoptera collecting program by setting up first field site; Odonata and ant expeditions; one plant expedition to area selected by survey gap analysis and one outside of Guyana, perhaps to Brazil on the southern slopes of Neblina; students and staff at UG trained to sort insects to order; additional education and training.
2012: Numerous publications determined by research of PIs and collaborators; one paper on niche modeling; one on species richness estimates or other theoretical aspect of data analysis; Hymenoptera group sets up second site and continues with first one; one Odonata expedition; one ant expedition; one plant expedition inside Guyana and one elsewhere on the Shield; insect specimens are processed in Guyana; training and education continue.
2013: Same as 2012 except Hymenoptera group sets up third site and continues with first two; first Odonata publications should come out; administration of BDG transfers to Entomology. From this point forward the Botany portion of program is reduced to one trip per year and maintenance of backlog (any additional activities to be funded outside of BDG).
2014: Same as 2013 except Hymenoptera group sets up fourth site and continues only with second and third sites.
2015: Same as 2014 except Hymenoptera group sets up fifth site and continues only with third and fourth sites.
2016 and beyond: A 6^{th} and final site will be set up in Guyana and by 2017 (should the program continue to be funded for another six years) sites will be set up elsewhere in the Shield region.

(3). Discussion of relevant collections and how the program will strengthen and enhance NMNH collections. BDG will bring to NMNH, our hosts and partners numerous high quality specimens from relatively unknown areas across the Shield and these will be distributed to hundreds of specialists. Duplicates are used for exchange with sister institutions to increase the diversity of our holdings

Collection goals:
2010: 3 field trips are planned with 5 taxonomic groups represented: One six week **plant** collecting expedition (Redden and Wurdack) will be sent to Mt. Tulameng in June-August 2010. An initial Odonata sampling trip will be undertaken by Jessica Ware and Karen Redden, in June 2010. This trip serves two primary purposes: it will determine what is needed to set up a sampling strategy and it will build the logistical framework for future trips (permits, etc). In August 2010 an **ant** expedition will visit the CI concession in southern Guyana. One of the other Entomology team members (bees or parasitic Hymenoptera) may go along as far as Rewa village to investigate the possibility of setting up a long term **general entomology** collecting program there. Wayne Mathis will do a short trip to SW Guyana to collect **shore flies** that he needs to complete a paper.
2011 and beyond: Beginning in 2011 the organized collecting program for Hymenoptera will be established using a variety of traps, which will be monitored throughout the year at a minimum of six localities. A large Odonata sampling effort will be undertaken on a four week trip during 2011, which will involve both larval and adult sampling and documenting oviposition and flight behavior by Jessica Ware and graduate students from Rutgers University (she will provide outside funding for their participation). Both damselflies (Zygoptera) and dragonflies (Anisoptera) will be also targeted for work on population genetics and higher level taxonomic studies.

Our combined plan includes joint expeditions when possible, a shared in-country manager to monitor continuous year-round trapping and sampling, and two Hymenoptera Unit lab managers to oversee a large group of interns who will process, sort, and prepare the anticipated large volumes of specimens. Shared matching-funds measures to reduce costs to BDG will include continuing our proven history of graduate student assistantships (e.g., paid by Towson University), unpaid internships (e.g., NMNH Internship Program), and vigorous fundraising from outside grant sources from which we have previously obtained funds (e.g., NSF and National Geographic).

Plant Backlog and importance of funding for base line activities. - The BDG program has been collecting plant specimens since 1985. Each collection number represents a specimen and each specimen usually has duplicates. One sheet of each number is sent to a specialist for identification and once identified the duplicates of that specimen are sent as exchange to herbaria worldwide. Processing of specimens is ongoing but there remains a backlog of unidentified material representing approximately 59,000 sheets or 26% of the specimens collected (mostly recent collections). Funding for these base line activates is crucial to the ongoing success of the program and would leave a huge burden on NMNH if funding was eliminated abruptly.

(4). Broader impacts - Goals

Education, training and outreach, both in the USA and abroad, is imperative if we hope to achieve and sustain our goals to document, understand, and conserve the biological diversity of the Guiana Shield area. Our mission necessitates interactions with all constituencies (scientific, local, Amerindian and the public). Because BDG interacts with such a large, diverse audience, it is difficult to cover all aspects and interactions concerned with education, training and outreach separately because each category is interconnected in the context of our program. For example, BDG data are used in teaching biodiversity courses, form the baseline information for numerous studies including dissertations and checklists, and are the basis for the BDG website that is used in education, training and outreach! Furthermore, an individual's relationship with BDG usually shifts categories over time. For instance, some individuals have started with training, moved to education, and then on to conservation careers or off to graduate school elsewhere.

Education Goals (Appendix 2) - *USA Education:* In keeping with its track record, BDG will continue to support and mentor interns, undergraduate, graduate and post-doctoral students in the USA. For example, in summer 2010 BDG will be sponsoring two *University of the District of Columbia* interns, one supported by the UDC-STEM program and one supported by the SI-STEP program. If successful, the program will be expanded and will utilize these students throughout the year. In addition we would add two undergraduates from City College of New York (likely minority) in a program similar to the UDC ones. Also, BDG and Northwestern University-Chicago Botanic Garden will be co-sponsoring one doctoral student who will explore ecological niche models using BDG specimen data to map species distribution across the Shield. This will then be used to explore patterns of diversification and radiation on the Shield, community composition, evolutionary relationships and conservation strategies.

International Education: BDG will continue to assist and sponsor UG graduates in attaining advanced degrees and also sponsor Guyanese faculty, students and Amerindians to participate in SI courses, workshops and symposia offered in the USA. Currently, we are collaborating with Dr. Godfrey Bourne, a professor at the University of Missouri-St. Louis who established and manages the CEIBA research center in Guyana. Dr. Bourne has taught a number of biodiversity undergraduate and graduate courses at CEIBA and Karen Redden co-taught with Bourne in January 2010. A two-week course on

rainforest biodiversity of Guyana will be offered in June 2010 to students from George Washington University (GWU). This course will be paid for by student tuition, which will also support one University of Guyana student to participate in the course. If it is successful it will be offered every year and opened for enrollment to the other Consortium Universities in the Washington-Metropolitan area.

Training Goals - We have defined "training" here to mean hands-on, skill-based learning with the caveat that these types of skills are also part of education and outreach. BDG is uniquely positioned to provide training opportunities and knowledge transfer to the Shield, such as through parataxonomy classes which we will continue to offer in collaboration with the Biodiverstiy Centre at UG. Also, every expedition includes at least one UG student, and a number of local and Amerindian counterparts who are extensively trained in the area of expertise. When expeditions transverse Amerindian territories, the participants conduct workshops and give presentations to the villagers. These talks highlight research interests, expedition findings, and the importance of the rainforests. Entomology will rely heavily on local communities participation for their long-term research projects and will give comprehensive workshops on collecting, sorting and preserving the various insect groups.

Conservation Goals - BDG data can be used to generate community composition and species lists of different areas and we expect this need to increase with continued development and natural resource use across the Shield. The data are critical to objectively guide decisions concerning conservation areas, hotspots, and areas of concern or special interest. For example, during 2010 our data will be used for the Amaila Falls Hydroelectric project and at the CI Concession.

Outreach Goals - The *Centre for the Study of Biological Diversity* (Biodiverstiy Centre or *CSBD*) was formally established in 1992. It is largely autonomous now but continues to rely on international collaborators to assist in achieving its goals. BDG has supported and will continue to support CSBD with numerous endeavors including, but not limited to, fundraising, training, education, advising, grant writing, publications and supply procurement; however, on a much smaller scale than in the past. BDG assists with the *Contribution to the Study of Biological Diversity* publication series that documents the current research efforts of the University of Guyana's students and faculty. Researchers and staff of BDG have presented numerous lectures on a wide range of topics including phylogenetics, conservation, GIS techniques, parataxonomy and skill-based techniques. Each BDG-supported researcher is required to present a public seminar at CSBD explaining their current research project.

Public Outreach: BDG website: The BDG program has an active and informative website. Our most important goal is to maintain we have and continue to update the site as new information (e.g., identifications) becomes available. Currently we are spending most of our time on the project *Georeferencing Plants of the Guiana Shield.* Four phases have been completed except for one small section (Prior Accomplishments). There is a **Phase 5** that is planned but so far unscheduled. In addition to the BDG collections mentioned, we have databased nearly 100,000 specimens in the US National Herbarium (referred to as historical specimens) that we would also like to make available on line. However, the time and funds required to verify locations and identifications and to georeference those without coordinates are not available at this time. We will begin this project in the summer of 2010 with volunteers but expect such an approach to take years to complete. **Phase 6** is in the "dreaming" stage. It has the goal of scanning one representative specimen of each species to go on our website. Plant expeditions during the last five years have had two new goals, a photo and genetic resources for each collection made. So, if we were to have the scan of the herbarium sheet we would also have thousands

of photos to match up with the scan. During the next year we will develop a plan and seek outside funding for both of these phases.

Many of the people associated with the program give public lectures each year. These are way too numerous to list (Appendix 3).

(5). A discussion of program team. The people listed below have worked with BDG for several years, with the exception of Anderson. They all have a strong commitment to studying organisms in the Shield area as is evidenced by their publication and collecting records. Anderson has indicated a strong interest in working with BDG and has agreed to attend the September 2010 workshop and collaborate on an NSF proposal. [see Biographical Sketches: ** = PI; * = co-PI's]

Botany: Christian Feuillet. **Vicki A. Funk, Kaslyn Holder-Collins, Carol L. Kelloff, Karen Redden, *Kenneth Wurdack, Charles Zartman

Ecological Niche Modeling: *Robert P. Anderson, Aleksandar Radosavljevic

Entomology: *Seán G. Brady, *Matthew Buffington, Michael William Gates, Robert R. Kula, *John S. LaPolla, *Ted R. Schultz, Jeffrey Sosa-Calvo, *Jessica Ware

Ichthyology (Fishes): *Jonathan W. Armbruster, *Richard P. Vari, Calvin Barnard

Herpetology (Reptiles and Amphibians): *Ross D. MacCulloch, *Brice P. Noonan, R. P. Reynolds

Mammals: Mark Engstrom, *Burton Lim

(6). Management Plan

Management of the BDG program requires several people working together. Currently Funk is the Director, Kelloff is the Assistant Director, Redden is the Field Trip Coordinator, and Holder is the Guyana in-country coordinator. Funk and Kelloff have FTEs and require receive no funds from the program. Redden gets summer salary ($4,000-10,000) full or partial depending on how many trips she organizes. Holder receives an honorarium of $1000 and is responsible for paying for permits, etc. as well as helping with in-country logistics. The six years of this grant will see a gradual transition from the current management team in Botany to one in Entomology since the majority of the field work funded by the BDG program will be in that department. In 2010 funds are managed by the Botany group. In 2011-2012 the funds for the Entomology work will be transferred to that Department in one lump sum for them to manage but Redden will continue to help organize the field work and will get summer salary for her year-around work. In 2013-2015 the management of the program should move to Entomology; Botany will receive a lump sum from Entomology (Redden and Holder may or may not continue to help organize field work depending on their situations and the needs of Entomology). Christian Feuillet is French and lived in French Guiana for many years. He helps any group that wants to collect in French Guiana and usually goes there on one expedition a year. Charles Zartman is on staff at IMPA in Manaus and he is helping coordinate field trips in Brazil. All of the co-PIs will meet in September each year at SI. Trips to Suriname and Venezuela are organized on a "one at a time" basis in conjunction with the appropriate colleagues in those countries.

PRIOR ACCOMPLISHMENTS (5 pages of text)

Five pages is insufficient space to examine over 20 years of research, specimen collecting, and outreach activities (Appendices 1-3). We will therefore rely heavily on the Appendices and on our website to summarize the full breadth of our accomplishments. In addition, a pdf of the BDG Annual Reports from 2003-onwards can be found on our website (http://botany.si.edu/bdg/program.html). These reports provide more detailed lists of activities and highlights for each year. Our accomplishments can be grouped into three categories: Research, Collecting, and Outreach. A brief history of the program, from the time it began as a floristic project though it current form as a biodiversity program, can be found in Appendix 7.

Summary of Research

All of the research in the BDG program is focused on understanding the biological diversity of the Guiana Shield area. The resulting **531** scientific publications include monographs, checklists, new species descriptions, travelogues, phylogenies and theoretical papers that have been written by the co-PI's and/or by our collaborators. Most are based on the material collected by BDG or by our collaborators. There are many additional publications that have used our material but which we have not been able to track and the list will grow quickly as we catalog them. We were requested to single out five titles that illustrate the impact and diversity of research publications from BDG:

Funk, V. A., and K. Richardson. 2002. Biological Specimen Data in Biodiversity Studies: Use it or lose it. *Systematic Biology* 51: 303–316.

Funk, V. A., K. S. Richardson, and S. Ferrier. 2005. Survey-gap analysis in expeditionary research, where do we go from here? *Biological Journal of the Linnean Society* 85: 549–567.

Schultz T. R., and S. G. Brady. 2008. Major evolutionary transitions in ant agriculture. *Proceedings of the National Academy of Sciences, USA* 105: 5435–5440.

Robbins, M. B., M. J. Braun, and D. W. Finch 2003. Discovery of a population of the endangered Red Siskin (*Carduelis cucullata*) in Guyana. *The Auk* 120: 291-298.

Vari, R. P., C. J. Ferraris, Jr., A. Radosavlejevic, and V. A. Funk. 2009. Checklist of the freshwater fishes of the Guiana Shield. *Bulletin of the Biological Society of Washington*, no. 17, 95 pages.

There are of course numerous other articles that could be selected including Kelloff and Funk (2004) which looks the biogeography of the plants of the Kaieteur Falls area, Braun et al. (2005) which examines Avian speciation, or any of the checklists that have generated so much research interest and local use (Hollowell and Reynolds 2005, Braun et al 2007, Funk et al. 2007), etc. However, we selected the five listed above to show the diversity of our work. The first one (Funk and Richardson 2002) represents an early attempt to use presence-only data from a tropical area to model species distributions. While the results were interesting they made clear that additional data were needed. Funk et al. (2005) used new methods to determine the location of future expeditions to maximize our collecting efforts and those have since guided our plant collecting. Schultz and Brady (2008) used critical material they collected in Guyana to examine the evolution of ant agriculture, a novel social insect behavior. Robbins et al. (2003) reported the discovery of an endangered bird in Guyana that has had conservation and economic impact. Finally, Vari et al. (2009) is a checklist list of the fishes that has color photographs and some data synthesis. As with all checklists there is an immediate reaction from scientists working in the area to improve our knowledge especially in areas that are found to have fewer species than the others!

Starting in 2002, BDG initiated a long-term effort to apply quantitative leaf-litter ant sampling protocols to a diversity of ecological habitats of the Shield. Biodiversity analyses of a large part of the Guyana material are reported in LaPolla et al. (2007), of the Suriname RAP in Sosa-Calvo (2007), and of the 2006 samples from the Acarai Mountains of southern Guyana in Schultz and Sosa-Calvo (2008). For example, the cluster diagram in Figure 1 indicates the relative similarities, in terms of species composition, of eight areas in Guyana and identifies Mt. Ayanganna as an area of high endemism (LaPolla et al. 2007). In addition to biodiversity data, the samples have generated abundant taxonomic information (LaPolla 2004, LaPolla and Cover 2005, LaPolla and Sosa-Calvo 2006, LaPolla 2006, Sosa Calvo et al. 2006, Feitosa and Brandão 2008, Sosa-Calvo et al. 2010).

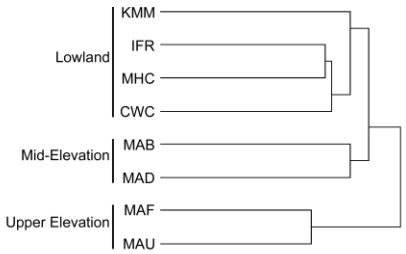


Figure 1. Cluster diagram of Guyana localities based on species overlap using the Jaccard Index. Abbreviations of localities: Calm Water Creek (CWC); Iwokrama Forest Reserve (IFR); Kanuku Mountains (KMM); Base Camp, Mt. Ayanganna (MAB); Upper Forest, Mt. Ayanganna (MAU); *Dicymbe* Camp, Mt. Ayanganna (MAD); Falls Camp, Mt. Ayanganna (MAF); Mabura Hill Camp (MHC). This and other analyses identify Mt. Ayanganna (MAF and MAU) as a center of endemism.

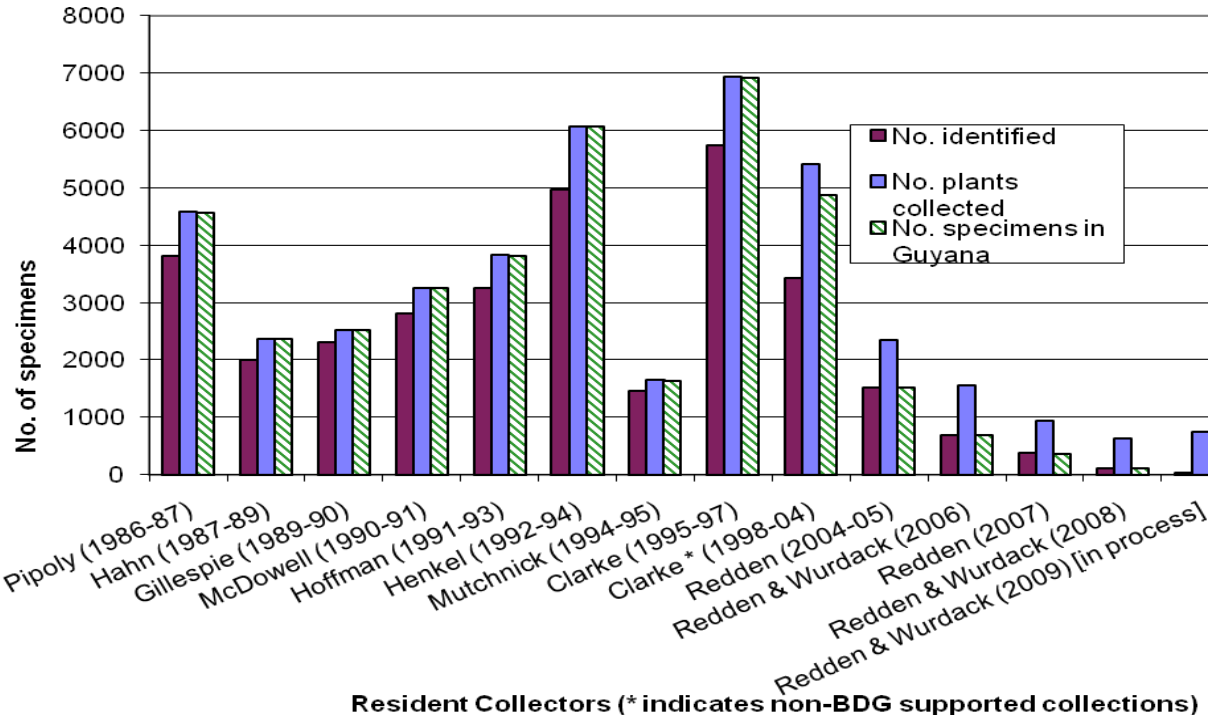
There have been more than a dozen bird collecting expeditions resulting in more than 6000 specimens, including many species new to Guyana, and the first tissue samples and anatomical specimens of numerous Shield endemics. Comparative avifaunal analyses and checklists have been published (Braun et al. 2000, 2003, 2007; Robbins et al. 2004, 2007), as well as more detailed studies of noteworthy taxa (Braun et al. 2005, Robbins et al. 2005), including discovery of an unknown population of the Red Siskin (Robbins et al. 2003). The tissue samples have been especially valuable, and have been used in dozens of genetic studies on the phylogeny, systematics and biogeography of Neotropical birds.

Summary of collecting activity

Biological specimens provide the foundation of molecular and morphological characters that are crucial to understanding life on earth. Identified vouchers are an irreplaceable resource as they provide the only reliable, verifiable record of life and are the basis for all studies of biodiversity and evolution. When the Smithsonian Institution decided to work in northeastern South America it was one of the least known areas in the world. As a result, from its inception, a major focus of BDG has been its collecting efforts. From 1986 to 2004 BDG had a resident plant collector in Guyana. Consistent budget reductions made it impossible to continue that practice. In 2005 we sponsored a six month butterfly collector and in 2006 a six month bird collector as well as a part-time plant collector. After 2005 we have planned only 1-3 expeditions per year. Details of expeditions up through 2007 are available on line (see below). Two recent expeditions will be made available after more of the collections are identified. BDG expeditions and collaborators have significantly expanded and improved our Neotropical collections at NMNH. Many of the resulting collections become types for new species (e.g., 102 new plant species in the last 4 years) or document significant new range records (i.e., species new to Guyana). Termite expeditions increased our knowledge of termite species from 90 to 135. Collecting and research on Mammals, Fish, Amphibians, and Reptiles is largely accomplished through our collaborators. New activities that have

originated in the last few years are the collecting of leaf samples in silica gel (suitable for molecular studies) and increased photographic records because of digital technology. As a result we now have leaf material and photos of nearly all plants we collect. These are distributed to collaborators around the world and have been used in numerous papers (Appendix 1).

Beginning in 1994, BDG sponsored a long-term survey of the avifauna of Guyana by NMNH ornithologists. This survey has benefited from fruitful collaboration with the University of Kansas, has leveraged many tens of thousands of dollars in matching NMNH research funds and external grants, and has spun off research projects in phylogenetics, community assembly and endangered species recovery that continue today. More than a dozen collecting expeditions have resulted in more than 6000 specimens, including many species new to Guyana, and the first tissue samples and anatomical specimens of numerous Shield endemics. Among the notable finds was the rediscovery by the birds expeditions of a healthy population in Guyana of the Red Siskin (*Carduelis cucullata*) which was previously believed to be extinct in the wild.



BDG Collection statistics (numbers do not include the specimens residing in other collections):
Plants: **54,987** numbers resulting in approx. **220,000** sheets including ca. 110,000 specimens for exchange. Approximately **75%** of the collections have been processed and are filed in the herbarium. The remaining **25%** are mostly more recently collected specimens that are awaiting identification. All BDG collections are databased and geo-referenced and most data are available on line. Plant collections from the Shield already present in the U.S. National Herbarium at the beginning of the BDG program (= historical collections): ca. **90,000** (82% are georeferenced). Of those that are not georeferenced, 4040 have almost no locality information and it is unlikely we will ever figure out exactly where they were collected.
Birds: over **6,000** specimens; **5,928** tissue collections (15-20% of the Bird Division's frozen tissue collections)
Mammals: **870** specimens, all georeferenced

Herpetological: **52** frogs, **3** lots of tadpoles, **23** lizards, **1** turtle, **8** snakes
Termites: ca. **2,000** specimens, **135** species
Dung beetles: ca. **500**
Aquatic insects: ca. **7,600**
Butterflies and moths: **8,235** (most of which are pinned and databased)
Microleptodoptera: ca. **4,800**
Ants: **75,000** individuals- from 44 genera and 230 species
Spiders: ca. **6,000**

Processing and Georeferencing – Collection processing is essential if their data are to be consequential rather than remaining "invisible". Plant collection processing is done by part-time contractors supervised and assisted by Dr. Carol Kelloff (Assistant Director of BDG) and using space and supplies provided by the Department of Botany. The animal collections are either processed by the NMNH department of the collector or by the collaborating institution. The entomology collections are processed by the department or by a part time contractor paid for by BDG. Specimen processing involves tasks that are critical to the success of the program and require a certain skill level but can be tedious and time consuming. A "Plant Pathway" (Appendix 7) that explains collection processing can be found on the BDG website. The georeferenced plant collections have allowed us to map previous collecting localities and to make decisions for future expeditions to fill in our knowledge of the plant diversity. Birds, mammals, amphibians, reptiles are already databased and ready to combine with the plant data. The bird collections are processed and georeferenced. The databasing of the Ant collections is in progress and should be completed by the end of the six year grant period.

Outreach (see Appendix 2)

Education - totals
Science meeting in Guyana, 2001 (see Appendix 7)
BDG has participated in a many short courses run by universities; the most recent was a two week course from the University of Missouri, St Louis, held in Guyana in January 2010. One additional course is scheduled for 2010.
Interns and Undergraduates (non-Guyanese): 25
Guyanese who traveled to NMNH for internships: 11
Masters degrees: 8
PhD degrees: 15
Postdoctoral Fellows: 4

Training - BDG has trained numerous students, scientific officers and others at CSBD on collections management, preservation, and maintenance at the Centre. The program has sponsored parataxonomy classes, which included techniques in ornithology, mammalogy, botany, herpetology, and fungal diversity. Amerindians, UG students, forest rangers, and many others have attended these courses. Expeditions have typically included at least one UG student, and a number of local and Amerindian counterparts who are extensively trained in the area of expertise. For example four Amerindians received training and assisted with the 2009 Redden/Wurdack expedition. In 2009 a mini-training course was conducted on the use of the new BDG website at three locations: the Biodiverstiy Center (UG), Conservation International-Guyana, and the Office of Amerindian Affairs.

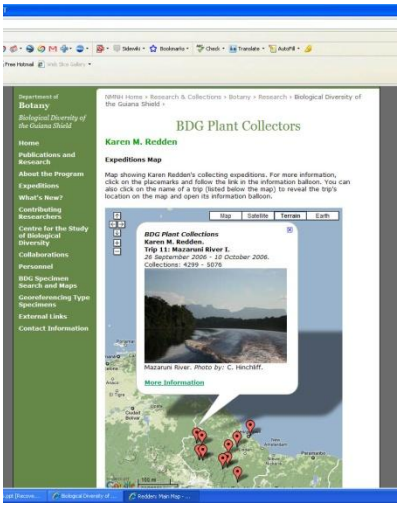
PUBLIC - In October of 2009 we developed a Google Earth video tour about the biodiversity of the Guiana Shield and about the BDG program. It was posted on the *Google Earth Outreach Showcase* and selected by *GE Sightseer* in its "Top Content" for October. But most important is that the tour has generated comments on the *GE Blog* which shows that it is being viewed and discussed by the public.

Google Earth Outreach program:
http://earth.google.com/outreach/showcase.html#kml=Biological_Diversity_of_the_Guiana_Shield_Program
Google Earth Sightseer (monthly newsletter) top content October 2009:

Google earth Blog (unofficial, but very influential):
http://www.gearthblog.com/blog/archives/2009/09/loop_links_biodiversity_and_the_law.html

Website

We made great progress on our website during 2009 as a result of our efforts to make our information more available to colleagues and the public. Most of the work was accomplished by a contractor, Eduardo Garcia-Milagros, and our part-time webmaster Sara Alexander with help from the Department of Botany IT Unit: Ellen Farr and Sylvia Orli. We also appreciate the assistance we have received from the NH-OIT office, especially from Denis Hasch, Dan Cole, and Tom Hollowell. As with all big data rich projects, getting everything organized and in an appropriate condition to go on line is a big job, it really "takes a village" and we have had encouragement and help from many sources.



All of the sites mentioned below can be found under our "What's New" link, http://botany.si.edu/bdg/whatsnew.html .

Georeferencing Plants of the Guiana Shield

Phase 1: *Georeferencing Plants of the Guiana Shield: US Types,* began in October of 2007 and was completed in July of 2008. It includes ca. 3400 TYPE collections from the Shield that are housed at the U.S. National Herbarium. BDG updated the records by checking locality data and adding coordinates so these specimens could be mapped using Google Earth. In 2009 a paper was submitted on how Google Earth can be used to improve georeferencing and why taking the time to do this is important to ecology and conservation biology.

Phase 2: *Georeferencing Plants of the Guiana Shield: Mapping the BDG Expeditions*, focused on making the data from the BDG funded expeditions available on-line. During 2008-2009 all but one of our resident collectors were added. This site allows the visitor to travel along with the collector, read their journal entries, view photos of the places and plants and animals they experienced; the user can see what a collecting expedition is really like.

Phase 3: *Georeferencing Plants of the Guiana Shield: Images*, is progressing with each collectors images being put on line after the expeditions are available.

Phase 4: *Georeferencing Plants of the Guiana Shield: Providing public access to the collecting information from the BDG Expeditions* went on line in December 2009. Most of the plants collected by the BDG program are now searchable by genus and species and have interactive maps using *Google Maps API* trace. This has proved to be very popular with our fellow scientists.

Conservation – BDG has been involved in many Conservation efforts over the years including collaborative efforts with the World Bank, Conservation International, UNDP, USAID and other groups. Some of the larger efforts include the original plant survey of the Iwokrama Reserve (Clarke and Funk 2001, 2005), a plant diversity study of Kaieteur National Park (Kelloff 2003, 2008), a mangrove study of Shell Beach, the turtle nesting area (Hollowell 2009) and numerous interactions with CI. In addition, all BDG data is publically available and can be used to generate community composition and species lists of different areas. The data are critical to guide decisions concerning conservation areas, hotspots, and areas of concern or special interest. BDG floristic data has been used for a number of Conservation International's (CI) Rapid Assessment Programs (RAPs) including Mt. Roraima, the Kanaku Mountains, and areas along the Essequibo River. Two BDG sponsored botanical expeditions have been conducted in the CI Upper Essequibo Concession to document floral composition in an effort to protect this region from timber and mineral exploration. Additionally, the program helped set up the Environmental Impact Assessment studies for a current major hydroelectric dam project.

REFERENCES CITED

Agosti, D., J. Majer, L. Alonso, and T.R. Schultz (Eds.). 2000a. *Sampling Ground-dwelling Ants: Case Studies from the Worlds' Rain Forests.* Perth, Australia: Curtin School of Environmental Biology Bull. No. 18. 75 pp.

Agosti, D., J. Majer, L. Alonso, and T.R. Schultz (Eds.). 2000b. *Ants: Standard Methods for Measuring and Monitoring Biodiversity.* Washington, D.C.: Smithsonian Institution Press. 280 pp.

Anderson, R. P**.** 2003. Real vs. artefactual absences in species distributions: tests for *Oryzomys albigularis* (Rodentia: Muridae) in Venezuela. *Journal of Biogeography,* 30:591-605

Anderson, R. P., and A. Raza. (in press) The effect of the extent of the study region on GIS models of species geographic distributions and estimates of niche evolution: preliminary tests with montane rodents (genus *Nephelomys*) in Venezuela. *Journal of Biogeography*.

Anderson, R. P**.** and E. Martínez-Meyer. 2004. Modeling species' geographic distributions for conservation assessments: an implementation with the spiny pocket mice (*Heteromys*) of Ecuador. Biological Conservation, 116:167-179.

Anderson, R. P., A. T. Peterson, and S. L. Egbert. 2006. Vegetation-index models predict areas vulnerable to purple loosestrife (*Lythrum salicaria*) invasion in Kansas. Southwestern Naturalist, 51:471-480.

Andersen, A.N., and G.P. Sparling. 1997. Ants as indicators of restoration success: relationship with soil microbial biomass in the Australian tropics. *Restoration Ecology* 5: 109-114.

Bawa, K.S. 1990. Plant-Pollinator Interactions in Tropical Rain Forests. *Annual Review of Ecology and Systematics* 21: 399-422.

Beck, J., and I. J. Kitching. 2007. Estimating regional species richness of tropical insects from museum data: a comparison of a geography-based and sample-based methods. *Journal of Applied Ecology* 44: 672-681.

Braun, M. J., D. W. Finch, M. B. Robbins and B. K. Schmidt. 2007. *A Field Checklist of the Birds of Guyana, 2nd Ed.* Smithsonian Institution, Washington, D.C.

Braun, M. J., D. W. Finch, M. B. Robbins, and B. K. Schmidt. 2000. *A Field Checklist of the Birds of Guyana.* Biological Diversity of the Guianas Program, Smithsonian Institution, Washington DC.

Braun, M. J., M. L. Isler, P. R. Isler, J. M. Bates and M. B. Robbins. 2005. Avian speciation in the Pantepui: The case of the Roraiman Antbird (*Percnostola[Schistocichla] "leucostigma" saturata*). *Condor* 107: 329-343.

Braun, M. J., M. B. Robbins, C. M. Milensky, B. J. O'Shea, B. R. Barber, W. Hinds and W. S. Prince. 2003. New birds for Guyana from Mts. Roraima and Ayanganna. *Bull. Brit. Orn. Club* 123: 24-33.

Bruneau, A., M. Mercure, G.P. Lewis, and P.S. Herendeen. 2008. Phylogenetic patterns and diversification in the caesalpinioid legumes. *Canadian Journal of Botany* 86: 697–718.

Carnaval, A. C. and C. Moritz. 2008. Historical climate modelling predicts patterns of current biodiversity in the Brazilian Atlantic forest. Journal of Biogeography, 35 (7): 1187-1201.

Carstens B.C. and C. L. Richards. 2007. Integrating coalescent and ecological niche modeling in comparative phylogeography. *Evolution* 61, 1439-1454.

Clarke H.D., V.A. Funk. 2005. Using checklists and collections data to investigate plant diversity. II: An analysis of five florulas from northeastern South America. *Proceedings of the Academy of Natural Sciences of Philadelphia* 154: 29-37.

Clarke, H. D., V. A. Funk, and T. Hollowell. 2001. Using checklists and collections data to investigate plant diversity. *In:* A comparative checklist of the plant diversity of the Iwokrama Forest, Guyana. *SIDA Misc.* 21: 1-86.

Clausnitzer, V., V. J. Kalkman, M. Ramc, B. Collen, J. E. M. Baillie, M. Bedjanic, W. R. T. Darwall, K. D. Dijkstra, R. Dowf, J. Hawking, H. Karube, E. Malikova, D. Paulson, K. Schütte, F. Suhling, R. J. Villanuevam, N. von Ellenrieder, and K. Wilson. 2009. Odonata enter the biodiversity crisis debate: The first global assessment of an insect group. *Biological Conservation* 142: 1864–1869.

Costa, G. C., C. Nogueira, RB Machado, and G.R. Colli. Sampling bias and the use of ecological niche modeling in conservation planning: a field evaluation in a biodiversity hotspot. Biodiversity and Conservation, 19:883-899, 2010.

Danforth, B. N. 2007. Bees - a primer. *Current Biology* 17: R156-R161.

Davidson, D. W., S. C. Cook, R. R. Snelling and T. H. Chua. 2003. Explaining the abundance of ants in lowland tropical rainforest canopies. *Science* 300: 969–972.

Delabie, J.H.C., B.L. Fisher, J.D. Majer, and I.W. Wright. 2000. Sampling effort and choice of methods. Pp. 145-154 in *Ants: Standard Methods for Measuring and Monitoring Biodiversity* (D. Agosti, J. Majer, L. Alonso, and T.R. Schultz, eds.). Washington, D.C.: Smithsonian Institution Press.

DeVaney, S.C, K.M. McNyset, J.B. Williams, A.T. Peterson, E.O. Wiley. 2009. A Tale of Four "Carp": Invasion Potential and Ecological Niche Modeling. PLOS ONE, 4(5):e5451.

DeWalt, R. E., C. Favret, and D. W. Webb. 2005. Just how imperiled are aquatic insects? A case study of stoneflies (*Plecoptera*) in Illinois. *Ann. Entomol. Soc. Amer.* 98: 941-950.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudík, S. Ferrier, A. Guisan, R. J. Hijmans, F. Huettmann, J. R. Leathwick, A. Lehmann, J. Li, L. G. Lohmann, B. A. Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J. M. Overton, A. T. Peterson, S. J. Phillips, K. Richardson, R. Scachetti-Pereira, R. E. Schapire, J. Soberón, S. Williams, M. S. Wisz, and N. E. Zimmerman. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography, 29:129-151

Feitosa, R.M., C.R.F. Brandão. 2008. A taxonomic revision of the Neotropical myrmicine ant genus *Lachnomyrmex* Wheeler (Hymenoptera: Formicidae). *Zootaxa* 1890: 1-49.

Ferrier, S., George V.N. Powell, K.S. Richardson, G. Manion, J.M. Overton, T.F. Allnutt, S.E. Cameron, K. Mantle, N.D. Burgess, D.P. Faith, J.F. Lamoreux, G. Kier, R.J. Hijmans, V.A. Funk, G.A. Cassis, B.L. Fisher, P. Flemons, D. Lees, J.C. Lovett and R.S.A.R Van Rompaey. 2004. Mapping more of terrestrial biodiversity for Global Conservation assessment: A new approach to integrating disparate sources of biological and environmental data. *BioScience* 54: 1101-1109.

Feuillet, C. 2009. Checklist of the plants of the Guiana Shield. 1. An update to the Angiosperms." *Journal of the Botanical Research Institute of Texas* **3**(2): 799-814.

Fisher, B.L., A.K. Malsch, R. Gadagkar, J.H.C. Delabie, H.L. Vasconcelos, and J.D. Majer. 2000. Applying the ALL protocol: Selected case studies. Pp. 207-214 in *Ants: Standard Methods for Measuring and Monitoring Biodiversity.* (D. Agosti, J. Majer, L. Alonso, and T.R. Schultz, eds.). Wash, D.C.: Smithsonian Institution.

Fitzpatrick MC, A.D. Gove, N.J. Sanders, and R.R. Dunn. 2008. Climate change, plant migration, and range collapse in a global biodiversity hotspot: The *Banksia* (Proteaceae) of Western Australia. Global Change Biology, 14: 1337-1352.

Funk, V. A., A. A. Anderberg, B.G. Baldwin, R.J. Bayer, J.M. Bonifacino, I. Breitwieser, L. Brouillet, R. Carbajal, R. Chan, A.X.P. Coutinho, D. J. Crawford, J. V. Crisci, M.O. Dillon, S.E. Freire, M. Galbany-Casals, N. Garcia-Jacas, B. Gemeinholzer, M. Gruenstaeudl, H.V. Hansen, S. Himmelreich, J.W. Kadereit, M. Källersjö, V. Karaman-Castro, P.O. Karis, L. Katinas, S.C. Keeley, N. Kilian, R.T. Kimball, T.K. Lowrey, J. Lundberg, R. J. McKenzie, M.E. Mort, B.

Nordenstam, C. Oberprieler, S. Ortiz, P.B. Pelser, C.P. Randle, H. Robinson, N. Roque, G. Sancho, J.C. Semple, M. Serrano, T.F. Stuessy, A. Susanna, M. Tadesse, M. Unwin, L. Urbatsch, E. Urtubey, J. Vallès, R. Vogt, S. Wagstaff , J.M. Ward and L. E. Watson. 2009. Compositae metatrees: the next generation. (in) *Systematics, Evolution, and Biogeography of Compositae* (Funk, V.A., A. Susanna, T. Stuessy and R. Bayer, eds). IAPT, Vienna. 747-777.

Funk, V. A., and K. Richardson. 2002. Biological specimen data in biodiversity studies: Use it or lose it. *Systematic Biology* 51: 303-316.

Funk, V. A., K. S. Richardson, and S. Ferrier. 2005. Survey-gap analysis in expeditionary research, where do we go from here? *Biological Journal of the Linnean Society* 85: 549-567.

Gaston, K. J. 1993. Spatial patterns in the description and richness of the Hymenoptera, pp. 277–293. *In* J. LaSalle and I. D. Gauld, eds. Hymenoptera and Biodiversity. CAB International, Walingford.

Gaston K. L., I. Gauld, and P. Hanson. 1996. The size and composition of the hymenopteran fauna of Costa Rica. *Journal of Biogeography* 23: 105–113.

Gauld, I. D. and P. E. Hanson. 1995. 1.2 The order Hymenoptera, pp 4–6. *In* P. E. Hanson and I. D. Gauld, eds. The Hymenoptera of Costa Rica. Oxford University Press, New York.

Golding, J. S. 2004. The use of specimen information influences the outcomes of Red List assessments: the case of southern African plant specimens. *Biodiversity and Conservation* 13: 773-780.

Graham, C. H., S. Ferrier, F. Huettman, C. Moritz and A.T. Peterson. 2004. New developments in museum-based informatics and applications in biodiversity analysis. *TRENDS in Ecology and Evolution* 19: 497-503

Grissell, E. E. 1999. Hymenopteran diversity: Some alien notions. *American Entomologist* 45: 235-244.

Hernandez, P. A., Graham, C. H., Master, L. L. and Albert D. L. 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography* 29: 773-785.

Heyer, W.R., Coddington, J., Kress, W.J., Acevedo, P., Cole, D., Erwin, T.L., Meggers, B.J., Pogue, M.G., Thorington, R.W., Vari, R.P., Weitzman, M.J. and Weitzman, S.H. 1999. Amazonian biotic diversity and conservation decisions. *Ciência e Cultura,* 51: 372–385.

Hijmans R.J. and C.H. Graham. 2006. The ability of climatic envelope models to predict the effect of climate change on species distributions. Global Change Biology, 12: 2272-2281.

Hollowell, T. and R. Reynolds. 2005. Checklist of the Terrestrial Vertebrates of the Guiana Shield. *Bulletin of the Biological Society of Washington* 13: 1-98.

Hollowell, T. H. 2009. Plant community structure, fire disturbance, and recovery in mangrove swamps of the Waini Peninsula, Guyana. *Contributions to the Study of Biological Diversity*,University of Guyana. **3**:1-162.

Kelloff, C. L. 2003. The use of biodiversity data in developing Kaieteur National Park, Guyana for ecotourism and conservation. Contributions *to the Study of Biological Diversity,* University of Guyana **1**:1-44.

Kelloff, C. L. 2008. Structure and diversity of a riparian forest at Kaieteur National Park, Guyana. *J.Bot. Res. Inst. Texas* **2**:521-545.

Kelloff, C., and V. Funk. 2004. Phytogeography of the Kaieteur Falls, Potaro Plateau, Guyana: floral distributions and affinities. *Journal of Biogeography* **31**:501-513.

Kremen, C. A., A. Cameron, A. Moilanen, S. J. Phillips, C. D. Thomas, H. Beentje, J. Dransfield, B. L. Fisher, F. Glaw, T. C. Good, G. J. Harper, R. J. Hijmans, D. C. Lees, E. Louis Jr., R. A. Nussbaum, C. J. Raxworthy, A. Razafimpahana, G. E. Schatz, M. Vences, D. R. Vieites, P. C. Wright, M. L. Zjhra. 2008. Aligning conservation priorities across taxa in Madagascar with high-resolution planning tools. *Science* 320: 222–226.

Kozak, K. H., C. H. Graham, and J. J. Wiens. 2008. Integrating GIS data into evolutionary studies. *Trends in Ecology and Evolution* 23:141–148.

La Salle, J. 1993. Parasitic Hymenoptera, biological control, and biodiversity. In: La Salle, J. and I. D. Gauld. (eds). *Hymenoptera and Biodiversity*. CAB International, Wallingford, UK. pp. 197-215.

La Salle, J. and I. D. Gauld. 1991. Parasitic Hymenoptera and the biodiversity crisis. *Redia* 74: 315-334.

LaPolla, J.S. 2004. *Acropyga* (Hymenoptera: Formicidae) of the world. *Contributions of the American Entomological Institute* 33: 1-130.

LaPolla, J.S. 2006. *Pheidole neoschultzi*: replacement name for *Pheidole schultzi* LaPolla, 2005 (Hymenoptera: Formicidae), a junior homonym of *Pheidole schultzei* Forel, 1910. *Transactions of the American Entomological Society* 3+4: 427.

LaPolla, J.S., and S.P. Cover. 2005. New species of *Pheidole* (Hymenoptera: Formicidae) from Guyana, with a list of species known from the country. *Transactions of the American Entomological Society* 131: 1-11.

LaPolla, J.S., and J. Sosa-Calvo. 2006. Review of the ant genus *Rogeria* (Hymenoptera: Formicidae) in Guyana. *Zootaxa* 1330: 59-68.

LaPolla, J.S., T. Suman, J. Sosa-Calvo and T.R. Schultz. 2007. Leaf litter ants of Guyana. *Biodiversity and Conservation* 16: 491-510.

Longino, J. 2000. What to do with the data. Pp. 1866-203 in: *Ants: Standard Methods for Measuring and Monitoring Biodiversity* (D. Agosti, J. Majer, L. Alonso, and T.R. Schultz, eds.). Washington, D.C.: Smithsonian.

Longino, J. T., J. Coddington, and R. K. Colwell. 2002. The ant fauna of a tropical rain forest: Estimating species richness three different ways. *Ecology* 83: 689–702.

Marsh, P. M. 2002. The Doryctinae of Costa Rica (excluding the genus *Heterospilus*). *Memoirs of the American Entomological Institute* 70: 1–319.

Melo, G. A. R., and I. Alves dos Santos (eds.). 2003. *Apoidea Neotropica*. Criciúma, Brazil: UNESC

Meier, R., and T. Dikow. 2004. Significance of Specimen Databases from Taxonomic Revisions for Estimating and Mapping the Global Species Diversity of Invertebrates and Repatriating Reliable Specimen Data. *Conservation Biology* 18: 478-488.

Michener, C.D. 2007. *The bees of the world*. 2nd ed. Johns Hopkins University Press, Baltimore, MD.

Peterson, A. T., E. Martínez-Meyer, C. González-Salazar, and P. Hall. 2004. Modeled climate change effects on distributions of Canadian butterfly species. *Canadian Journal of Zoology* 82: 851-858.

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling, 190:231-259

Phillips, S., J. Elith, M. Dudik, C.H. Graham, A. Lehmann, J. Leathwick and S. Ferrier. 2009. Sample selection bias and presence-only models of species distributions: implications for selection of background and pseudo-absences, Ecological Applications, 19: 181-197

Ponder, W. F., G. A. Carter, P. Flemons and R. R. Chapman. 2001. Evaluation of museum collection data for the use in biodiversity assessment. *Conservation Biology* 15: 648–657.

Rasmussen, P. C., and R. P. Prys-Jones. 2003. History *vs* mystery: the reliability of museum specimen data. Pages 66-94 *in* N. J. Collar, C. T. Fisher, and C. J. Feare, editors. Why Museums Matter: Avian Archives in an Age of Extinction. British Ornithologists' Club, Green Park, Aston Clinton, and Natural History Museum, Tring, UK.

Raxworthy, C.J., Martinez-Meyer, E., Horning, N., Nussbaum, R.A., Schneider, G.E., Ortega-Huerta, A., and Peterson, A.T. (2003). Predicting distributions of known and unknown reptiles species in Madagascar. Nature. 426: 837-841.

Raxworthy, C.J., Ingram, C. Rabibisoa, N. and Pearson, R. 2007. Applications of Ecological Niche Modeling for Species Delimitation: A Review and Empirical Evaluation using Day Geckos (*Phelsuma*) from Madagascar. Systematic Biology 56 (6): 907-923.

Rebelo, H., and G. Jones. 2010. Ground validation of presence-only modelling with rare species: a case study on barbastelles Barbastella barbastellus (Chiroptera: Vespertilionidae). *Journal of Applied Ecology* 47: 410–420.

Reddy, S., and L. M. Dávalos. 2003. Geographical sampling bias and its implications for conservation priorities in Africa. *Journal of Biogeography* 30: 1719-1727.

Robbins, M. B., M. J. Braun and D. W. Finch. 2003 Discovery of a population of the endangered Red Siskin (*Carduelis cucullata*) in Guyana. *The Auk* 120: 291-298.

Robbins, M. B., M. J. Braun and D. W. Finch. 2004. Avifauna of the Guyana southern Rupununi, with comparisons to other savannas of northern South America. *Ornitologia Neotropical* 15: 173-200.

Robbins, M. B., M. J. Braun, C. J. Huddleston, D. W. Finch, and C. M. Milensky. 2005. First Guyana records, natural history, and systematics of the White-naped Seedeater (*Dolospingus fringilloides*). *Ibis* 147: 334-341.

Robbins, M. B., M. J. Braun, C. M. Milensky, B. K. Schmidt, W. Prince, N. H. Rice, D. W. Finch and B. J. O'Shea. 2007. Avifauna of the upper Essequibo River and Acary Mountains, Southern Guyana. *Ornitologia Neotropical* 18: 339-368.

Rowe, R. J. 2005. Elevational gradient analyses and the use of historical museum specimens: a cautionary tale. *Journal of Biogeography* 32: 1883-1897.

Russell, J. A., C. S. Moreau, B. Goldman-Huertas, M. Fujiwara, D. J. Lohman & N. E. Pierce. 2009. Bacterial gut symbionts are tightly linked with the evolution of herbivory in ants. *Proceedings of the National Academy of Sciences, USA* 106: 21236-21241.

Schlick-Steiner, B. C., F. M. Steiner, and S. Schödl. 2003. A case study to quantify the value of voucher specimens for invertebrate conservation: ant records in Lower Austria. *Biodiversity and Conservation* 12: 2321-2328.

Schmidt, M., H. Kreft, A. Thiombiano, and G. Zizka. 2005. Herbarium collections and field data-based plant diversity maps for Burkina Faso. *Diversity and Distributions* 11: 509-516.

Schultz, T.R., and S.G. Brady. 2008. Major evolutionary transitions in ant agriculture. *Proceedings of the National Academy of Sciences* 105: 5435-5440.

Schultz, T.R., and J. Sosa-Calvo. 2008. Ants of southern Guyana – a preliminary report. Pp. 31-32 and p. 72 in A rapid biological assessment of the Konashen community owned conservation area, southern Guyana (L.E. Alonso, J. McCullough, P. Nasrecki, E. Alexander, and H.E. Wright, eds.). *RAP Bulletin of Biological Assessment* 51. Washington, D.C.: Conservation International.

Sharkey, M. J. 2007. Phylogeny and classification of Hymenoptera. *Zootaxa* 1668: 521-548.

Smith, G. F., Y. Steenkamp, R. R. Klopper, S. J. Siebert, and T. H. Arnold. 2003. The price of collecting life: Overcoming the challenges involved in computerizing herbarium specimens. *Nature* 422: 375-376.

Sosa-Calvo, J, T.R. Schultz, and J.S. LaPolla. 2010. Review of Dacetini (Hymenoptera: Formicidae) in Guyana. *J. Hym. Res*. 19: 12-43.

Sosa-Calvo, J. 2007. Ants of the leaf-litter of two plateaus in Eastern Suriname. Pp. 92-98 in A Rapid Biological Assessment of the Lely and Nassau Plateaus, Suriname (with additional information on the Brownsberg Plateau) (L.E. Alonso, L.E. and J.H. Mol, eds.). *RAP Bulletin of Biological*

Assessment 43. Washington, D.C.: Conservation International.

Sosa-Calvo, J., S.O. Shattuck, and T.R. Schultz. 2006. Dacetine ants of Panama: New records and description of a new species (Formicidae: Myrmicinae: Dacetini). *Proceedings of the Entomological Society of Washington* 108: 814-821.

Spector, S. and A. B. Forsyth. 1998. Indicator taxa in the vanishing tropics. Pp. 181-210 in *Conservation in a Changing World* (A. Balmford and G. Mace, eds.). Cambridge: Cambridge University Press.

Tingley, M. W., and S. R. Beissinger. 2009. Detecting range shifts from historical species occurrences: new perspectives on old data. *Trends in Ecology & Evolution* 24: 625-633.

Tobin J. 1994. Ants as primary consumers: Diet and abundance in the Formicidae. *In*: *Nourishment and Evolution in Insect Societies*, J.H Hunt and C.A. Nalepa, eds. (Westview Press, Boulder, CO), pp 279–308.

Tobler, M., E. Honorio, J. Janovec, and C. Reynel. 2007. Implications of collection patterns of botanical specimens on their usefulness for conservation planning: an example of two neotropical plant families (Moraceae and Myristicaceae) in Peru. *Biodiversity and Conservation* 16: 659-677.

Vari, R. P., C. J. Ferraris, Jr., A. Radosavljevic, & V. A. Funk. 2009. Checklist of the freshwater fishes of the Guiana Shield. *Bulletin of the Biological Society of Washington* 17: 1-93.

Waltari, E., S. Perkins, R. Hijmans, A. T. Peterson, Á. Nyári, and R. Guralnick. 2007. Locating Pleistocene refugia: Comparing phylogeographic and ecological niche model predictions. *PLOS ONE* 2:e563.

Ward, P.S. 2000. Broad-scale patterns of diversity in leaf litter ant communities. Pp. 99-121 in *Ants: Standard Methods for Measuring and Monitoring Biodiversity.* (D. Agosti, J. Majer, L. Alonso, and T.R. Schultz, eds.). Washington, DC: Smithsonian Institution Press.

Warren, D.L., R.E. Glor, and M. Turelli. 2008. Climate niche identity versus conservatism: quantitative approaches to niche evolution. *Evolution* 62: 2868–2883.

Wisz, M., R. Hijmans, J. Li, S. Phillips, A. Peterson, C.H. Graham and the NCEAS Species Distribution Modeling Group. 2008. Effects of sample size on the performance of species distribution model. *Diversity and Distributions* 14: 763–773.

BUDGET AND JUSTIFICATIONS

(Budget follows Suggested Reviewers section)

There are three parts to the budget. The 2010 budget is a combined Botany-Entomology budget that is managed by Botany. There are two budgets for 2011-2015, one for Botany and one for Entomology. The Excel file has three sheets that correspond to the three budgets.

Unique costs

In FY 2010 Library Shelving (and shipping) for the Centre was $11,469. We have been trying for years to find funds for these shelves (and the shipping) submitting half a dozen proposals to a variety of funding agencies. Since this is the last thing needed to finish the new addition to the Centre we decided to fund it when a field trip was cancelled. Over the years the staff at the Natural History Museum has donated thousands of books to the Centre and it is time the library was functional. The Main Library at the University of Guyana has agreed to unpack, catalogue, and staff the library.

The "Big Ticket" items

In all three budgets most of the funds are expended on two things: Expeditions and Contracts (for specimen processing - data base management – outreach)

Expeditions – After over 20 years of working the Guiana Shield Area we are confident of our ability to estimate the cost of an expedition. It varies from $7,000 to $20,000 depending on two things, how many people you are flying in from other countries and how you are getting to your field site. Air charters are expensive, sometimes as much as $1,000-1500 per flight as are flights from the USA especially if you are in the country for over 30 days. The prices we have used in the budget reflect an average cost for "land" transport trips or "air" transport trips. In addition, the field work is greatly assisted by the advice and ground work of Dr. Karen Redden who has conducted field work all over the Shield. We have requested summer salary for her work in helping set up the trips, this is critical, especially for the Entomological work. Likewise we depend on Kaslyn Holder, a Science Officer at the Centre, to take papers around to different offices and expedite permits. For the Entomology mass collecting sites there is a need for a person who will be responsible for picking up the vials and storing them properly.

Contracts – In order for the material collected on the expeditions to be useful, it must be processed which can be time consuming (Plant Pathway in Appendix 7 as an example). From the beginning all plant collecting information has been databased and this has proved invaluable as we have moved to web based dissemination methods. Likewise our new Google Earth interface needs to be completed so it continues to be current. All of this costs money, on the average of $25,000 a year for the digital work and $15,000 for the sorting and plant mounting.

"In Kind" Contributions

Ants - The collecting methods proposed would generate, for Year 3 through Year 6, 300 samples of ants per year. For each sample it takes an expert preparator a minimum of 20 hours on average to initially process ("Stage 1" sorting), which consists of extracting the specimens from the associated debris, sorting the specimens to morphospecies, and mounting an example of each morphospecies. Thus, the 300 samples projected for Years 3-6 will require a minimum of 6000 person-hours (or 150 person-weeks) to process. This does not include also time-intensive "Stage 2" processing, wherein morphospecies are checked and identified. Obviously, the cost of accomplishing the sorting is prohibitive (at $10/hr, Stage 1 sorting of 300 samples would require $60K), and thus can only be

accomplished through the creative use of unpaid interns and work-study students. We propose to accomplish this through lab managers (preferably grad students on assistantships) who will manage a volunteer labor force for the entire Hymenoptera Guiana Shield effort. Based on current stipend rates, the cost of a one-year grad assistant ranges from $18K (Towson University, through LaPolla) to $24K (Univ. Maryland). Stage 2 processing will be carried out at no cost to this proposal by the co-PIs and by myrmecological colleagues to be enlisted (e.g., MacKay for *Camponotus*, Longino for *Pheidole*).

In addition to generating biodiversity data about ants, we propose to create a web-based resource, The Ants of the Guiana Shield. This resource, combined with web-based keys, would accelerate our ability (and, indeed, the abilities of South American researchers working outside of the Guiana Shield) to identify leaf-litter ants. We have tried in the past to secure funding from various sources (e.g., EOL) for this resource, so far without success. See http://entomology.si.edu/ants/guianaants.html for a sample page. We estimate the cost of generating the required images to be $3800 (500 specimens x 30 minutes per specimen at $15/hour). The creation of the keys will be carried out by the co-PIs.

Other Hymenoptera - On average, we estimate that processing one raw sample to fully curated collection-ready specimens requires 15 hours, thus the samples from Years 3-6 alone will require 28,080 person-hours and cost $280,800 (using $10/hour). The intern/work-study worker protocol set forth in the ant-sampling section applies here.

Plants – The Botany Department furnishes the time of Funk and her Research Assistant, Dr. Carol Kelloff both of whom spend about half of their time on BDG matters.

Odonata – Students of Ware will be use to process the collections.

Recent Proposals and their fate as an example of external fund raising efforts:

NSF-REVSYS Proposal: *Biogeography, phylogenetics and taxonomic revision of the Neotropica genus* Macrolobium *(Leguminoseae, Caesalpinioideae)* Redden, Funk & Herendeen submitted in July 2009, $416,718 [Reviewed well but was not funded, the reviewers asked for additional preliminary data we think this one has a good chance when we resubmit it in July 2010]

A Smithsonian Women's Committee proposal was submitted for $24,000 to pay for the shelving in the library at the Centre in Guyana. This proposal was considered but not funded in the final cut.

Scholarly Studies/Endowment Proposal to investigate adaptive radiation across the Guiana Shield in two lineages one in the Compositae and one in the Leguminoseae: $40,000 would have paid for field work and half time salary for a postdoc. This was declined and we have never received any comments on why.

NSF BS&I Proposal: *Plants of the Guiana Shield: Inventorying using a comparative approach,* submitted January 2010, $860,115. A five year project to establish a large plot in Guyana (in collaboration with the Brazilians) [pending]

National Geographic Society proposal, for field work in Guyana, submitted April 2010, $14,000 [pending]

FACILITIES, SPACE AND OTHER RESOURCE NEEDS (MAJOR EQUIPMENT)

SI - NMNH, and the **Departments of Botany and Entomology** in particular, possess the resources to undertake the collections research and care needed by BDG. These include world-class curated collections of specimens, support libraries, and necessary equipment for specimen preparation and identification. Office space is provided by both departments and is sufficient for the needs of the program. Compound and dissecting microscopes with digital imaging capabilities are available. NMNH core facilities relevant to biodiversity research include the Scanning Electron Microscope Laboratory (with three SEMs) and the Laboratory of Analytical Biology (LAB). LAB occupies 7500 sq. ft., consisting of three laboratory spaces, computer rooms and office space at MSC and NMNH. The combined facilities are fully equipped for the high through-put sequencing and state of the art analysis of molecular data (e.g., for phylogenetic, population, and DNA barcoding studies).

The **United States National Herbarium** is a major resource within the Department of Botany. This worldwide collection of ca. 5 million specimens (including over 100,000 types) provides coverage for all plant groups and ranks among the richest and most complete in the world. The U.S. National Herbarium houses a premier collection of South American plants. Because of its history of work in South America and over 20 years of collecting efforts of the BDG program, the herbarium maintains one of the best representative collections of the Guiana Shield. Associated with the herbarium is the combined **Botany and Horticulture Branch Library** which houses over 60,000 volumes, including both books and journals. Emphasis is on all aspects of plant biology, including systematics, palynology, molecular evolution, classification, identification, nomenclature, cladistics, floristics, and conservation. Other related subjects are botanical history, especially of North and South America, ethnobotany, plant exploration, and botanical illustration. Geographical coverage is world-wide, with a special emphasis on the Neotropics. Other resources available at NMNH-Botany that may be utilized by BDG include an extensive **digital photography lab** and **computer graphics center** for digitizing the specimens if necessary. The Digital Studio runs a digitizing operation using a LightPhase digital camera back on a Hasselblad camera body supported by high end studio lighting systems and two computers (to process images and derivatives in a room optimized for digital photography).

The BDG program has the ability to sort and store large collections of plants. The Sort Center is located at the **Museum Support Center (MSC)** in Suitland, MD, in room E1102. It occupies 757 sq. ft. of space equipped with 14 tall herbarium cases and 10 counter top cases. In this room specimens brought in from the field are first sorted for the specialists that receive one sheet for identification. After identifications are reported, the remaining duplicates are sorted for distribution to various collaborating institutions as exchange. Specimens pending identification are stored in the "pod", a large collections storage space at MSC. The BDG Program shares this area with other departments and has over 100 cases available to hold specimens during various stages of the processing. The Sort Center also has the capacity to pack and ship specimens.

The **U.S. National Entomological Collection** ranks as probably the largest accessible insect collection in the world with approximately 35 million specimens (including over 110,000 types). The Hymenoptera Collection is very rich, consisting of about 3 million specimens and over 15,000 types. The **Entomology Library** contains over 23,000 volumes, on insect systematics, ecology, behavior, and related areas. The collection is especially rich in the areas of taxonomy and anatomy of insects and related arthropods, especially arachnids.

NON-*SI* - **Centre for the Study of Biodiversity of Guyana (CSBD), Guyana.** The University of Guyana has drying and sorting facilities in the CSBD. The climate-controlled herbarium of ca. 50,000 specimens is in the newly constructed annex to the original building, and has a full time scientific officer and support staff. Compound and dissecting microscopes, industrial freezers, extra herbarium cases for

specimen storage and ample room to sort, identify and process specimens are available. Computers, printers and scanners are all housed at CSBD (Appendix 7 for details). The **Herbaria** at INPA in **Manaus (**Brazil), **Cayenne (**French Guiana), **Paramaribo** (Suriname), and **Guynare** (Venezuela), are frequent collaborators and partners in our expeditions in their countries.

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