Frederick W. Edwards Lecture in Insect Natural History
Natural History Museum
London, June 1, 2005

Title Slide
Good afternoon. It is my honor to have been invited to deliver the 2005 Frederick W. Edwards Lecture in Insect Biology. Edwards remains in the esteem of his peers after more than 60 years for the high quality, insight, and quantity of his work. During his relatively short life of just 52 years he described more than 2500 species of flies, 2300 of which remain valid today. This monumental achievement speaks volumes about the nature of insect diversity itself, and also mirrors the major theme of my presentation today.

Slide 2
Because the taxonomic subject matter of my presentation relates exclusively to the Heteroptera, and more particularly to the family Miridae, I would like to begin with a brief introduction to this large and diverse hemimetabolous taxon, as a way of giving the non-specialists in the audience some perspective on the biology and current state of classification within the group.

The Heteroptera are currently divided into 7 infraorders, comprising 85 families and about 40,000 species. Among them we find insect predators, plant sap feeders, seed feeders, meristematic tissue feeders, and 3 lineages of vertebrate blood feeders. They live in a great variety of habitats and are unique among insects in including species that pass their entire life cycle on the surface of the open ocean.

Slide 3
The currently recognized phylogenetic relationships of the infraorders are portrayed in this slide, with the unique-headed bugs of the infraorder Enicocephalomorpha, here portrayed by a bright red species, representing the sister-group of all other true bugs. They are followed by the Dipsocomorpha, tiny, mostly tropical bugs with elaborate asymmetrical male genitalia in most species, then by the Gerromorpha, the semiaquatic bugs, all of which can walk effortlessly on the water surface film. The Nepomorpha, or true water bugs were once thought to the sister group of all remaining bugs, but are here shown in a more derived position, in part by virtue of their possession of a true hemelytron. Next we come to the Leptopodomorpha, shore bugs and their relatives, a group with only 300 described species, but nonetheless of considerable phylogenetic significance. An finally the “land bugs” and the appearance of phytophagy in the Heteroptera, comprising the species rich and biologically diverse Cimicomorpha with feeding habits including insect predation, vertebrate blood feeding, and phytophagy, and the Pentatomomorpha, most of whose members feed either on plant sap or seeds.

Slide 4
The Miridae, or plant bugs, the taxonomic focus of this presentation, belong to the infraorder Cimicomorpha. They are the largest family of true bugs, with 1350 valid genera and more than valid 10,200 species being currently recognized. Although some species are specialized insect predators, most are phytophagous, and many of those are highly host specific. At least 8 lineages spread across 4 subfamilies are strongly myrmecomorphic. A few lineages contain mostly aposematic species.

Slide 5
Linnaeus, in the *Systema Naturae*, not only established the foundations for modern zoological nomenclature, but also attempted to catalog and describe zoological diversity on a world basis. His classification for the Heteroptera was uncomplicated by modern standards, with only four genera. Of the hundred or so included bug species, 17 were Miridae. The numbers of specimens on which the 10^{th} edition was based would appear to be quite small.

Slide 6
Although Linnaeus in many ways set the stage, no location for the discussion of the subject of documenting biological diversity could be more appropriate than London, because it was here that some of the most monumental zoological surveys ever conducted were organized, financed, and published. In this regard we might first consider the *Biologia Centrali America*, a work that has achieved almost iconic status. The range of taxonomic coverage in the *Biologia* has seldom been attempted. But, the number of specialists involved in producing the taxonomic treatments was small by comparison to what anyone might attempt today. Nonetheless, the work was completed in a period of 35 years, documenting anthropological subjects, as well as 50,000 species of plants and animals, 18,000 of them being described as new. The colored plates that graced the *Biologia* continue to attract collectors to these volumes, and cause librarians to treat them as rare. Evidence to the legendary status of the Biologia series can now be seen in the availability of the entire series on the World Wide Web.

Slide 7
But the *Biologia* was not the end. Before it was finished, volumes in the Fauna of British India series began to appear. As was the case with the *Biologia*, most of the work on the Heteroptera was done by W. L. Distant. Distant provided in these two volumes an outline for diversity in two areas of the world that were previously known in only the most fragmentary way.

Slide 8
Finally, I would like to mention the *South African Animal Life* series, a faunistic treatment based primarily on fieldwork conducted by Hanstrom, Brinck, and Rudebeck from Lund University. This monumental effort, influenced greatly not

only our knowledge of the South African fauna, but also in a very real way the course of my career as a systematic zoologist.

These above-mentioned works and others like them, to a great degree, have offered the historical model for how large survey projects might be conducted. But, we know now that it was not only Linnaeus who fell far short of his lofty goal.

Slide 9
Before proceeding with the description of a 21st century approach to documenting biological diversity on global basis, I would like to provide some background on the historical acquisition of knowledge for the two large, world-wide, Miridae subfamilies Orthotylinae and Phylinae. Here we see a graphical presentation of the description of species over time. These curves suggest several things:

> **First**, the description of taxa from most areas continues and appears not to be complete.
> **Second**, the Northern Hemisphere is at least better known that the Southern Hemisphere, or the latter is less diverse.
> **Third**, that for the Nearctic, Ethiopian, and Oriental regions, a few large works introduced a very large amount of the available knowledge regarding species diversity. And,
> **Finally**, that Australia, of all areas, remains with the least described species diversity.

Slide 10
If we examine the Australian situation in greater detail, we see that as of 1994 there were 180 described species of Miridae representing about 1.8 percent of the world fauna, about 25,000 specimens in collections representing approximately 500 species, and that there were 35 published host records. The total Miridae fauna for Australia was estimated at 650 species in the *Insects of Australia*, published in 1991.

Slide 11
At this point I would like to introduce my colleague **Gerry Cassis** from the Australian Museum, Sydney. Most of what I have to say from now on represents a collaborative effort between him and me, that began in 1995.

Slide 12
In that year, Gerry and I began a series of expeditions to various regions in Australia, in an attempt to determine the true nature of diversity in the Miridae for this biotically remarkable continent. Here you see plotted more than 400 localities we visited on 7 expeditions carried out between 1995 and 2002.

Slide 13

The results of our efforts can here be seen in contrast with the situation as of 1994.

The number of described species of Miridae has increased slightly to 210.
The estimated numbers of species in collections has increased dramatically to about 1500.
The numbers of specimens available for study has risen by at least 4 times.
The number of documented hosts has risen at least 40 times.

These data suggest clearly that all prior resources and estimates for evaluating diversity in Australian Miridae were grossly inadequate.

Slide 14
Let us now turn to the concept of Planetary Biodiversity Inventories, as represented by a program first funded by the US National Science Foundation in 2003. The guidelines required that the taxon under study be worldwide and monophyletic. Projects were funded for a period of 5 years and include the taxa:

Eumycetozoa (slime molds): 1000 species
Solanum (Solanaceae): 1500 species
Miridae (plant bugs) (Heteroptera: Orthotylinae and Phylinae): 5000 species
Siluriformes (cat fishes): 2500 species

Slide 15
Introducing the Miridae with our project logo, shown here, I will provide a bit more detail on the groups under study.

Slide 16
The Plant Bug Planetary Biodiversity Inventory, which from here onward I will refer to as **the PBI**, deals exclusively with the subfamilies Orthotylinae and Phylinae. They comprise 8 recognized tribes, 485 described valid genera, and 3900 described valid species. Our estimates suggest that 90 or more genera remain to be described and that there are at least 1200 undescribed species in existing collections.

Slide 17
Some exemplar members of these two subfamilies can be seen in this slide, including the aposematic *Daleapidea ornata* from Baja California on the left, followed by the myrmecomorpic *Myrmecoridea* from Australia, the myrmecomorphic female of a *Tuxenella* sp. From Chile, *Larinocerus balius* from western North America with its unusual antennae, and finally the strongly myrmecomorphic *Pilophorus kathleenae* from tropical Asia.

Slide 18

The goals of the Plant Bug Planetary Biodiversity Inventory project can be summarized as follows:

To describe more than 1000 new species
To produce an improved classification for the world fauna
To update the systematic catalog to include at least 5000 species
To produce a digital library of more than 27,000 pages
To produce a specimen database of more than 500,000 specimens
To voucher in excess of 3500 host plants, and
To produce and make available more than 20,000 habitus, morphology, host, and habitat images.

Slide 19
Achieving of these goals will require the use of several tools and approaches, which I will now quickly review before describing each in somewhat greater detail. They include:

Internet dissemination of information
On-line Systematic Catalog
Specimen Databasing
Georeferencing
Unique specimen identification
Species Pages
Processing of Existing Collections
Digital Imaging
Field Work/Specimen Processing
Host Documentation

Slide 20
Untold amounts on information are now being transmitted over the Internet, yet there are a limited number of models for dealing with data from systematics. Here we see in graphical form a scheme as proposed for the PBI project. The modular nature of this approach allows for the construction of the individual elements in a progressive fashion.

Slide 21
The PBI Homepage offers a brief description of the project and allows access to all other elements, including participants, activities, and accomplishments, as well as research data and other sources of information such as a glossary.

Slide 22
Institutional participants for the PBI project include:

American Museum of Natural History, which focuses on training, specimen processing, and research products.
Australian Museum, which focuses of training, field support, and research products.
Smithsonian Institution, which focuses on delivery of collection data and research products.

Zoological Institute, St. Petersburg, which focuses on delivery of collection data.
Canadian Nation Collection of Insects, Ottawa, which focuses on delivery of collection data and research products.

Slide 23
Individual participants for the project include four senior scientists in the top row, including Thomas Henry from Washington, DC and Michael Schwartz from Ottawa, in addition to Gerry Cassis and me.

Our 4 postdoctoral trainees are shown in the second row, with the 2 doctoral trainees in the third row. Other participants shown include those involved in administrative support, technical support, and information technology support.

Slide 24
An on-line systematic catalog developed in the form of a relational database, serves as the primary access point for delivery of all data related to nomenclature, literature, and specimens. The main features of the catalog include:

- Up to date nomenclature and classification.
- Annotations to the relevant literature.
- Host and geographic information from the literature.
- Portal to other databases and website features, including:
- Specimen Database
  - Species mapping
  - Host data from specimens
  - Digital Library
  - Image Database
  - Species pages
  - Web-based aids to identification

Slide 25
Access to information via the systematic catalog is gained through an intuitive interface that currently allows for query of information relating to insect names, host names, and author names, on the left. Alternatively, one can “drill down” via the taxonomic hierarchy on the right, using the green arrows to move to the next-lowest level in the hierarchy. Names themselves serve as links to references. This functional approach to accessing information is repeated throughout the catalog application.

Slide 26
Upon entry of a generic name, for example, one is presented with a classificatory listing, including senior as well as junior names.

Slide 27

Choosing one of the names takes the user to references to that name in the literature, and associated host information, seen in the bottom part of the panel. At this point one may gain access to the digital library by clicking on the page or volume icon.

Slide 28
Sample digital library page.

Slide 29
Produce a map for the species using information currently available in the specimen database. Data from which the map was produced can be down-loaded to a file for further use.

Slide 30
A prime PBI objective is to acquire as much actual specimen data as possible, and allow those data to be used for making inferences concerning species distributions, host associations, accuracy of identifications, and the like. The primary functions of the database then, are to:

- Capture specimen data
- Incorporate unique specimen identification
- Serve data over the Internet

Possible approaches to achieving these functions include the use of:

- Off the shelf vs. newly developed application
- Browser-based vs. program-based access
- Open source vs. proprietary software
- Stand-alone vs. network-based usage

Side 31
The PBI project has developed a specimen database with the following attributes:

- Tailored to invertebrate collections
- Browser based
- Open source software
- Data entry over Internet to central server
- Efficient data entry
- Batch loading of unique specimen identifiers
- Multiple modes
    - Museum Mode
    - Field Mode
    - Identification Mode
    - Edit Mode

Slide 32
Entry of specimen data is one of the most important, yet most tedious and time-consuming of all activities associated with a project of this type, especially

when one considers that more that 0.5 million specimens are involved. This data entry form is designed for use with typical museum specimens. It presents information organized in a hierarchic manner, beginning with taxonomic information in the top-most panel, followed by locality data, date and collector, data regarding the individual specimen, such as sex, institutional depository, and type status, and finally host association. Each part of the form can be cleared individually, so that if specimens are properly organized at the outset, the effort required to record specimen information is reduced to a minimum. Furthermore, the entire form can be navigated---top to bottom---solely through the use of the keyboard, a feature that facilitates speed of data entry.

Slide 33
Specimen label data acquires greatly enhanced utility through georeferencing, which allows the data to be plotted in an interactive fashion on the web, for use in print publications, or for further analysis through the use of geographic information systems technology. Georeferencing, like specimen data entry itself, can be a tedious process. The quality of the product will always depend on the quality of the underlying gazetteer. We have successfully used a program called GEOLocate to georeference large numbers of localities in North America. GEOLocate has the following desirable features:

Stand alone program
Easy to use
Allows individual and batch processing
Has manual correction capability

Its limitations are:

Ineffective parsing of some locality names
Still under development

Slide 34
The GEOLocate interface appears as follows, showing a map of georeferenced localities in the upper screen panel, and a database of those localities in the lower panel. Locality data can be processed on a record-by-record basis or in batch mode.

Slide 35
Map layers of greater detail can be accessed for correction of individual plots, as shown in this slide.

Slide 36
Unique specimen identification, long a staple of vertebrate zoological and paleontological collections, has not been widely used in terrestrial arthropod collections. Nonetheless, it greatly facilitates specimen tracking, and has therefore been incorporated into the PBI project, and most particularly into the design of the specimen database.

When used in conjunction with a database, a unique specimen identification system should possess the following attributes:

- Machine readability, using either
  - Bar codes
  - Matrix codes
- Human readability
- Small size of code-bearing labels
- Ease of integration into existing collection practices

Here we see the use of matrix-code labels bearing 17 character alpha-numeric codes. The matrix of less than 1 cm square is capable of encoding approximately 20 million such labels.

Slide 37
Specialized printers such as this one, often hidden under places like airline check-in counters, will produce labels bearing a wide variety of codes. Specialized software allows for label design and incremental numbering of labels.

Slide 38
This particular approach to applying the labels to the specimens allows them to be read by machine or by eye without the need to remove the specimens from the box.

Slide 39
What I will call **species pages** have long been used in taxonomic publications. In their original form they contained some or all of the following information:

- Nomenclatural history
- Descriptions/diagnoses
- Figures
- Distributional summaries
- Biological data

Such an approach has served well for nearly at least 200 years, but use of the Internet offers the potential for substantially expanded capabilities, including:

- Dynamic updates
- Dynamic mapping
- Improved access
- Links to additional resources

Slide 40
As an example of an early species page, we might consider this original description of *Capsus pilicornis* from Panzer's *Fauna Insectorum Germanicae* of 1805.

Slide 41

In contrast, we see here this mock-up of a species page which can be assembled in real time from Internet-accessible databases, and which will be available in the near future on the PBI website.

Slide 42
With more than 0.5 million specimens to be examined, the processing of existing collections must be undertaken in a purposeful and efficient manner. The PBI project has identified the following approaches which it attempts to implement whenever possible:

- Select specimens that:
  - Increase taxon numbers
  - Extend geographic coverage
  - Extend host coverage
- Groups of taxonomists sort specimens to:
  - Minimize handling
  - Speed processing
- Sort specimens according to the following hierarchy:
  - Taxon
  - Geography
  - Sex

Slide 43
Yet, not all collections are organized such that these approaches can be readily applied. Difficulties most frequently encountered include:

- Historical organization of collections
- Specimens pinned directly into boxes/drawers
- No sorting to family-rank taxa and below
- Lack of web-based inventories

Possible solutions to overcoming these impediments include:

- Systematic organization of collections
- Movement to drawer and unit system
- Sorting to family-rank taxa and below
- Use of unique specimen identification
- Creation of web-based inventories

Slide 44
With regard to the physical presentation of collections, we can see here the differences between collections:

- Pinned directly into specimen boxes
- Pinned into larger specimen drawers
- Organized in **units trays**

The use of **unit trays** with foam pinning bottoms, greatly facilitates the handling of specimens, reduces specimen damage through handling, and facilitates reorganization of collections.

Slide 45
The major collection resources available for the PBI project are located in a limited number of institutions, with an equivalent number of smaller collections also possessing valuable material. By our estimates, this modest number of collections houses:

555,000 specimens relevant to the PBI project
327,000 of those specimens have been studied in some way
143,000 have been databased in some way

Slide 46
Digital imaging technology has advanced tremendously in the last few years, with costs coming down precipitously while image quality has been improved substantially. One objective of the PBI project is to deliver over the Internet high quality images of authoritatively identified specimens for as many taxa as possible. We have chosen to use a Microptics-USA system, which possesses a number of desirable attributes, including:

Unique lighting
High depth of field
Real-time focusing
Rapid image acquisition
High resolution

Slide 47
This slide shows the quality of image that often can be achieved with a single exposure. Such images will greatly facilitate the process of taxon recognition and specimen identification by end users, including taxonomic specialists, as well as those involved in more practical endeavors such as agriculture or port inspection.

Slide 48
Even though existing collections offer a wealth of information, as we have already seen for areas such as Australia, the PBI project will be a success only because it includes a large fieldwork component. We have chosen focus our fieldwork with an eye on the following objectives:

Apply taxon-focused techniques
Maximize discovery of new taxa
Extend geographic coverage
Maximize biological information
Maximize specimen quality
Maximize specimen numbers

Slide 49
Equipment used in the field by our team members includes, among others items such as global positioning devices, those illustrated in this slide. Most important is the specially designed net that is particularly well adapted to

collecting specimens of Miridae from woody plants. A beating stick, aspirator, and small killing tubes used to accept specimens from individual host plants, completes the tool kit. The following short film clip demonstrates the use of these tools in the field.

Slide 50
[film clip of collecting techniques]

Slide 51
Because the PBI project will generate on the order of 100,000 new specimens for study, it is important that these collections be processed in an efficient and uniform fashion. We have chosen to implement the following practices, which make specimens of greatest value over the long run and which greatly facilitate the process of specimen databasing.

Centralized mounting and labeling
Label copy derived directly from locality database
Centralized rough sorting after host labeling
Unique specimen identifiers added as part of rough sorting process

Slide 52
All specimens collected during the PBI project bear labels of the type shown here, with both the locality and host labels bearing complete data associated with the specimen, including:

A complete description of the geographical location
Latitude and longitude coordinates
Date of collection
Collectors names, and
Project locality number

Host labels bear:

Host family name
Host name and author
Host identifier when available
Voucher number, and
Project host number

These labeling procedures assure that the provenance of all specimens can be determined without recourse to the project database.

Slide 53
Early in this presentation I mentioned the high degree of host specificity found in the Orthotylinae and Phylinae. This histogram portrays the situation graphically, indicating that for species where hosts are recorded, the great majority of species are known from a single host, approximately one-third that number are known from 2 hosts, and so forth. This high host fidelity makes a

compelling case for a rigorous approach to determining host associations and securing host identifications.

Slide 54
PBI procedures for host documentation and vouchering include the following:

- Vouchers are collected, pressed, and tied to their insect associates
- Vouchers are photo-documented
  - In the field using a SLR digital camera
  - As herbarium specimens using a flat-bed scanner
- Vouchers are identified by botanical specialists
- Vouchers are deposited in recognized herbaria and receive voucher numbers
- Voucher data are included as part of insect labeling

This approach offers an assessment of host identity independent of the host collector and allows for future recourse to host specimens if necessary.

Slide 55
Here doctoral student Dimitri Forero and I can be seen processing host voucher material for final drying and subsequent identification by the staff of the Compton Herbarium at the Kirstenbosch Gardens, Cape Town.

Slide 56
I would now like to return to the documentation of diversity in the field, beginning with South Africa, and in the process show you representatives of plant-bug taxa and their hosts. The Western Cape Region of South Africa, including Namaqualand, the Little Karoo, and the *fynbos*, was identified as a PBI target area because of the:

- Extreme plant diversity and endemism
- Unique biotic affinities
- Limited prior sampling
- Limited number of publications and described taxa
- Fauna unstudied by classical & modern authors
- Absence of local specialists

Slide 57
If we look at the history of study of this area we see the following:

As of 1961, as recorded in the *South African Animal Life* treatment of the fauna, for all of South Africa there were:

- 12 described species of Orthotylinae and Phylinae
  - no documented hosts
- ~ 250 specimens had been studied

In 1974, after completion of my dissertation dealing with the fauna, there were:

- ~ 100 described species

~ 50 documented hosts
~ 2000 specimens studied

Even though this advance in knowledge represented a more than 800 percent increase in the number of known species, most of the taxa were from the eastern part of the continent, with very few coming from the Western Cape, the area of greatest floristic diversity.

Slide 58
In order to test the presumption that diversity of Miridae in the Western Cape must to a degree be proportional to plant diversity, we have mounted two collecting expeditions to the area, 2003 shown here in blue and 2004 in red, with a total of more than 120 localities represented, and for which 420 host vouchers were collected.

Slide 59
Although we have not yet mounted, labeled, and identified all of the material, a conservative estimate suggests that we now have examples of at least:
250 species, for an increase of 250 percent
350 documented hosts, for an increase of 700 percent, and
20,000 specimens, for an increase of 1000 percent.

One thing is absolutely certain: Diversity of Miridae in the Western Cape is substantial, even though all prior existing collections contain only the smallest fraction of that diversity at both the generic and the species level.

Slide 60
In this panoramic view of southern Namaqualand, looking west from Vanrhyns Pass, we see a low elevation, arid landscape that is dominated by succulent and semi-succulent vegetation, with surprising species diversity.

Slide 61
Some 200 kilometers to the north near Kamieskroon the land is much higher, rising to more than 1000 meters, and is underlain by a huge dome of granitic rock.

Slide 62
Here I am collecting in the bush just east of Kamieskroon, in an area dominated by asteraceous shrubs.

Slide 63
The Phylinae are clearly the most diverse group of Miridae in the Western Cape, inhabiting a wide variety of hosts. Here we see one of the 5 species of the cupressaceous genus *Widdringtoniola*, a part of the *fynbos* flora, and an associated species of *Widdringtoniola*. You see here the male genitalia of *Widdringtoniola*, offering some indication of the complexity of structural detail.

Slide 64
Here we see a thorny shrub in the solanaceous genus *Lycium*, with its mirid associates in the genus *Karoocapsus*. This bug species demonstrates strong sexual dimorphism and conspicuous ant mimicry, particularly in the female, shown below. The male genitalia differ markedly from those seen in *Widdringtoniola*.

Slide 65
The genus *Pelargonium*, in the family Geraniaceae, is remarkably diverse in the Western Cape, with hundreds of species. Here we see a large species with purple flowers, with its phyline associate. The color matching of the bug and the flower are better in life and in these photos.

Slide 66
The plant family Aizoaceae is represented by more than 1000 species in the Western Cape. Here we see a representative of the genus *Lampranthus*, with its mirid associate in the genus *Eminoculus*. And the male genitalia of *Eminoculus*. As of 1974, *Eminoculus* was know from 2 species and a handful of specimens, most of them collected on one ornamental planting in the city of Pretoria. We now have several thousand specimens, representing many species, with hosts documented from a large number of widely scattered localities.

Slide 67
Papilionoid legumes, or peas, are another group demonstrating remarkable diversity in the Western Cape. Here we see *Lebeckia sericea*, host to a species of *Pseudosthenarus*, a group occurring on a wide variety of papilionoids, and certain to show diversity much greater than what is presently known. Before the advent of PBI field work, no hosts were known for the 5 presently described species of *Pseudosthenarus*. The male genitalia of this group are absolutely distinctive.

Slide 68
And finally for South Africa, the family Asteraceae, a group of truly remarkable diversity in the region. Here we see a species of *Leysera*, an annual known for its profuse flowering in wet years, and which attracts botanically oriented tourists from around the world. We discovered for the first time in 2004 this strongly dimorphic phyline mirid associated with *Leysera* spp.

Slide 69
Returning to Australia, the reasons for choosing this grossly understudied continent as a PBI target area are very similar to those for South Africa. They include:

High plant diversity and endemicity, especially in west and southwest
Limited sampling

Few publications and described taxa
No local specialists historically

Habitats in Australia are remarkably varied, but 3 types that have been shown to be especially rich for the Miridae include:

Slide 70
Open woodlands, often dominated by species of *Acacia*, with woody shrubs as an understory, as in this scene from South Australia

Slide 71
Sand dunes, frequently rich in *Grevillea* spp. and other taxa adapted to this specialized soil type, as in this scene near the Kalbarri Park in Western Australia, and

Slide 72
Heathlands, usually with a white sand substrate, as in this scene near Esperance on the south coast of Western Australia. A representative sample from these and other habitats in Australia includes:

Slide 73
The monocot family Xanthorrhoeaceae, here represented by a species in the genus *Lomandra*, host of a recently described species of *Kirkaldyella*.

Slide 74
The monocot family Restionaceae, a family restricted to Australia and Southern Africa, and showing substantial diversity in both areas. Here we see *Hypolaena humilis* and an undescribed member of the Phylinae, with its male genitalia. Several species of this undescribed bug group have been collected in Australia. Associates of the Restionaceae in Africa, although similar in general appearance, are members of the subfamily Mirinae.

Slide 75
The parasitic family Loranthaceae, here represented by a species of *Amyema*, is diverse in both Africa and Australia, and host in both areas---as well as southeast Asia and the Malay Archipelago---to members of the genus *Hypseloecus*, all of whose numerous Australian species remain to be described; and the distinctive male genitalia.

Slide 76
The signature transantarctic family Proteaceae, most diverse in Australia and South Africa, here represented by the genus *Conospermum*, with its color-matching undescribed phylinae, and the distinctive genitalia.

Slide 77

The proteaceous genus *Grevillea*, with nearly 100 species in Australia, here represented by the “honey *Grevillea*”, named for its profuse production of nectar, and the 3 species of phyline Miridae that simultaneous inhabit the host.

Slide 78
The proteaceous genus *Adenanthos*, with its inconspicuous flowers and foliage that looks for all the world like that of a species of *Larix* from the Northern Hemisphere, with one of the tiniest mirids yet collected in Australia, and the distinctive male genitalia.

Slide 79
The family Myrtaeceae, immensely diverse in Australia and best know for the nearly 1000 species in the genus *Eucalyptus*, here represented by the very diverse genus *Melaleuca*, producer of ti oil, and an undescribed phyline whose numerous congeners appear restricted to *Melaleuca*; and the distinctive male genitalia.

Slide 80
The Chenopodiaceae, ubiquitous on saline soils, are here represented by a species of *Rhagodia*, host of an undescribed species of Phylinae from the Lake Eyre Basin.

Slide 81
The Casuarinaceae, a distinctive Australasian flowering plant group with approximately 100 species in Australia. Although appearing as less than desirable hosts for their dry, non-succulent foliage, the species of Casuarinaceae serve as host to a legion of Miridae species in at least 3 subfamilies. Her we see a myrmecomorphic species in the orthotyline tribe Austromirini.

Slide 82
The mimosoid legumes, represented by approximately 800 species of *Acacia* in Australia, are host to many species of Miridae, here represented by a species of *Austromiris*, one of the “green monsters”.

Slide 83
And finally the Asteraceae, not nearly so diverse in Australia as Africa, but with some surprises nonetheless, as with *Waitzia acuminata*, a straw flower from Western Australia, host to this remarkable yellow species of “Wallabicoris”; and the male genitalia.

Slide 84
After this whirlwind tour of plant bugs from the Southern Hemisphere, I would like to provide some summary remarks.

With regard to accomplishments of the plant bug Planetary Biodiversity Inventory, we have registered:

- 20% increase in available specimens
- 20% increase in known species diversity
- Continental-scale increases in geographic coverage
- > 500% increase in host-documented specimens
- > 1000% increase in host vouchers

Slide 85

Comparing the PBI approach with classical faunistic studies, we might conclude the following:

- World vs. local collection resources
- World vs. regional perspective
- Broad-scale vs. narrow taxonomic conclusions
- All-inclusive phylogenetic theories as opposed to those based on a limited geographic sample
- Broad-scale vs. narrow biogeographic conclusions
- The production of broad-scale vs. regional taxonomic tools
- One-stop biodiversity information shopping on the Internet

Slide 86

Several ideas receive strong reinforcement from our studies:

- **First** is the continued need for study of basic insect taxonomy.
- **Second** is the need to improve biodiversity knowledge on a global scale, rather than on a regional basis.
- **Third** is the need to improve knowledge of insect biology

It takes little reflection to realize that all of these themes are no less true today than they were for Frederick Edwards more than 60 years ago. If the Miridae are any indication, a tremendous amount of work remains to be done.

Slide 87

Finally, I want to thank the many colleagues, family members, and institutions who have helped to make the PBI project a success, and without whose assistance I would not have been able to deliver this presentation.