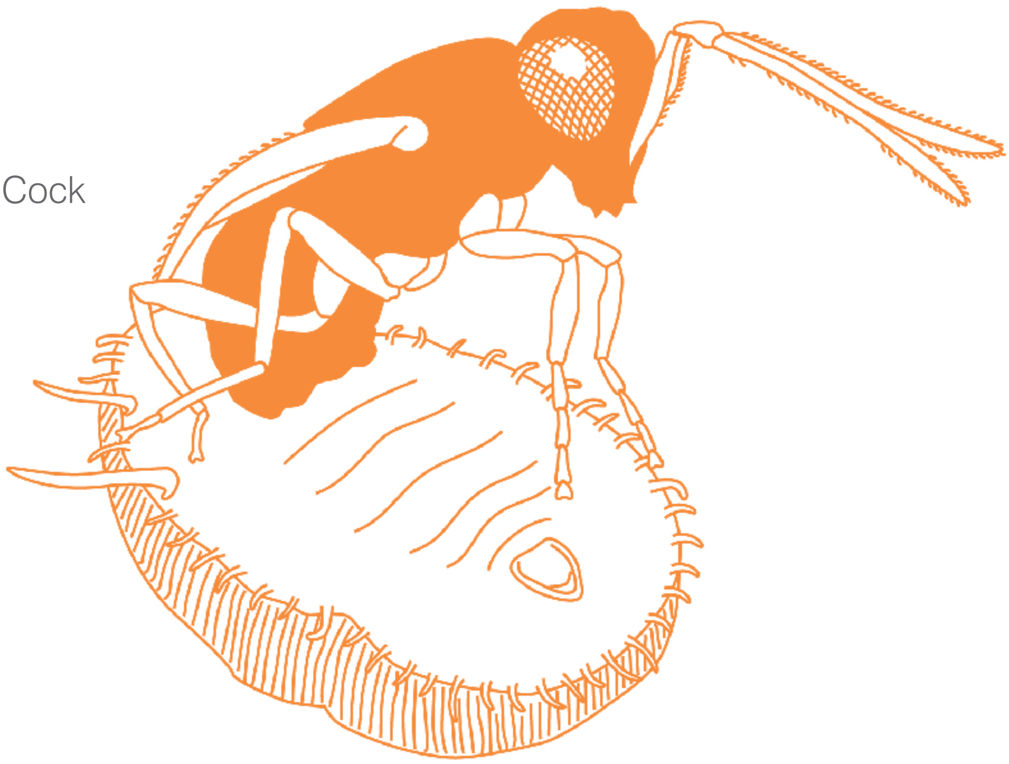
CABI WORKING PAPER 3

funding taxonomic support to agriculture in developing countries

April 2011



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Preparation of the October 2010 report "Strategic entry points for funding taxonomic support to agriculture in developing countries", on which this CABI Working Paper is based, was supported in part by the European Commission through an Environment and Natural Resources Thematic Programme (ENRTP) project with the BioNET International Secretariat. The contents can under no circumstances be regarded as reflecting the position of the European Union.

This Working Paper may be referred to as:

Cock, M.J.W. 2011. Strategic entry points for funding taxonomic support to agriculture in developing countries. CABI Working Paper 3, 32 pp.

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Executive Summary

This paper on taxonomy and agriculture in developing countries is based on an unpublished report intended to identify strategic and funder entry points for taxonomy in support of agriculture, particularly in relation to a possible Global Taxonomy Partnership Fund (GTPF) currently being considered, and the activities of BioNET INTERNATIONAL (BioNET). The dominant needs from agriculture that have been recognized are for identifications and various products based on identifications as well as access to what is known about the species. Taxonomic research is occasionally needed to help answer specific questions, or to clarify the taxonomy of groups of organisms that cannot otherwise be identified. Taxonomy of crop plants and related taxa is an important need of agriculture, but is serviced by different mechanisms.

Although taxonomic inputs are important, sometimes critical, for aspects of agriculture, particularly relating to pest management, there is no international process to ensure that this support is available to those who need it in developing countries. In-country support is variable, and generally correlates with the degree of development or affluence of the country. The only global identification service was that offered by CABI, covering insects, fungi, nematodes and animal parasites, but this was not sustainable once charging was introduced, and now only a reduced capacity to identify fungi and bacteria affecting plants remains.

At some point in the future, DNA barcoding could provide a simple, cost-effective alternative to in-country identification capacity, and developing countries should be supported in using this technology.

There are many other ongoing initiatives that include taxonomic elements relevant to agriculture. Many are still at an early stage of development, but offer great promise for the future. In terms of the requirements for taxonomic capacity to support agriculture (i.e. taxonomists, equipment, finances, reference collections, literature and information), the area where there is least progress, and where if anything global capability is in decline, is capacity in trained and experienced taxonomists who are able to reliably identify species and recognize and solve taxonomic issues in their specialist groups. Developed and transition-economy countries invest in taxonomy far more than the less-developed countries. Hence, mechanisms to develop taxonomic human capacity and to share and network regional taxonomic expertise will be especially important to address this key bottleneck in less-developed countries.

New initiatives in agricultural research and development (ARD) are mostly taking taxonomy for granted. This may mean that resources will be allocated as and when needed, or it may mean there is a planning and/or capacity gap. BioNET should explore the scope for integration of taxonomic activities for agriculture with the CGIAR (Consultative Group for International Agricultural Research) Mega Programs, IPPC (International Plant Protection Convention) capacity building, and GFAR (Global Forum for Agricultural Research).

It would be appropriate for multilateral and bilateral donors concerned with agriculture to support capacity building and the provision of services in taxonomy. However, these donors are focussing their attention on the Millennium Development Goals (MDGs) and opportunities to have direct and measurable impact on these. Taxonomy, while an important underpinning for aspects of agriculture, cannot be shown to directly support the MDGs. Taxonomy can be incorporated into large, focussed proposals where there is a specific need, or commissioned as needed in large initiatives such as the CGIAR Mega Programs, but substantial donor interest in a global support mechanism for taxonomy (or even just identifications) for agriculture is unlikely.

Corporate sponsors working through their philanthropic foundations are unlikely to find support to agricultural taxonomy or identifications charismatic enough to feel that they will gain the profile they want by supporting such activities. Corporates in the field of agriculture will support global initiatives that are relevant to agriculture. If taxonomy can be presented as helping agricultural production, e.g. through improved crop protection, then corporate support from the large agricultural companies is certainly feasible.

The same is generally true of foundations. Certainly some foundations will support taxonomy in the context of biodiversity, but none have yet been identified that would support taxonomy and identifications in agriculture. This is not to say there are none, but to find such foundations amongst thousands would require substantial effort.

Conclusions

1. In the context of agriculture, it is very difficult to justify donor funding for taxonomy in isolation for the developing world.
2. To meet the recognized needs, taxonomy must be seen to be directly supporting activities which will achieve direct impact, e.g. in terms of the MDGs.
3. This means that in the majority of cases, taxonomy will be in support of specific pest and SPS (sanitary and phytosanitary) issues.
4. In order to be supported by the agricultural sector, GTPF or BioNET will need to be seen to be clearly supporting a global initiative that will have relevant impact. Two possible examples are the CGIAR programme and CABI's Plantwise initiative.
5. The CGIAR programme is moving towards focussed Mega Programs, so although they should be encouraged to participate in the GTPF and BioNET, there is unlikely to be general support from this system.
6. Therefore, with regard to activities in agriculture, it is recommended that BioNET further explore how it and the GTPF can support CABI's Plantwise initiative.

Introduction

This paper on taxonomy and agriculture in developing countries is based on an unpublished report intended to identify strategic and funder entry points for taxonomy in support of agriculture, particularly in relation to a possible Global Taxonomy Partnership Fund (GTPF) currently being considered, and the activities of BioNET INTERNATIONAL (BioNET). Funders considered include bilateral and multilateral donors, corporates and foundations.

The first part of the paper (Sections 1–4) contributes to the development of a case for support for a new public–private partnership, the GTPF, although the conclusion of this paper is that substantial support for such a fund is unlikely in the context of those who fund agriculture for developing countries. The second part of the paper (Section 5) contributes to the BioNET strategic planning process involving the network (Locally Owned and Operated Partnerships or LOOPs), Secretariat and Secretariat host organization (CABI) by identifying and reviewing strategic options for taxonomic support to agriculture.

In this paper, agriculture refers primarily to farming and forestry, with an emphasis on food security, and taxonomy includes taxonomic and reference collections and other support needed for taxonomists, applications of taxonomy (identifications, identification guides, checklists, etc.), taxonomic research and networking of taxonomists.

The work complements other activities that assess the scope for support for a GTPF from the business and biodiversity sectors. Selected documentation provided by the BioNET Secretariat and other relevant sources was reviewed (Sections 1–3), an analysis of the strategies/ priorities of selected strategically important agencies in agricultural research for development (ARD) and related funding sources was made (Section 4), and a one-day workshop at CABI Europe – UK (E-UK) was organized to engage other expertise within CABI.

1. Overview of agriculture's need for taxonomy

In this section I examine the main demands and need for taxonomic support to agriculture and agricultural research, with a food security viewpoint to the fore. For a broader analysis see Lyal *et al*. (2008) and relevant 'Why Taxonomy Matters' case studies (www.bionet-intl.org/why).

An overarching objective of taxonomy is to produce a stable set of scientific names for all species. Unfortunately, in order to achieve this, there is ongoing instability as errors are corrected, new classifications are introduced, taxonomists interpret species differently, etc. The net result is that collections and publications contain many old, incorrect names that have been replaced, misidentifications, names which are applied to different species by different authors, species groups which are treated as a single species by one author, but as a complex of different species by another, and so on. The result is that there are plenty of pitfalls for the unwary. To work with extension staff and farmers, local names will also be needed, and these too need careful interpretation, as there is not necessarily a direct correlation between taxonomic species and local names for species, the latter often applying to symptoms or at the genus or a higher level (Bentley *et al*., 2009). Those working with scientific names and information linked to these names need to be aware of these problems, and how to check names for accuracy and the use of different interpretations. This is where a taxonomist's opinion or viewpoint will normally be useful. In most of the following applications, it is important to be aware of such synonyms, alternative taxonomic interpretations and local names to obtain all useful information.

1.1 Diagnoses and identifications

Most of the demand for taxonomic support in agriculture is centred around identifications of crop-related biodiversity and the tools and information that can be generated based on identifications. Sometimes more than identification is needed, perhaps a degree of characterization. Conversely, a significant demand, particularly at the farm level, is only for diagnoses and advice based on diagnoses.

The difference is perhaps not obvious, and an analogy may be useful. If you go to a doctor with an infection, she may diagnose that you have a bacterial infection and prescribe an antibiotic. The doctor might also take a sample of the infected material and send it away for identification (which would provide a name for the species of bacteria) and characterization (which might show that this particular strain of bacteria was resistant to certain antibiotics, which could cause the doctor to change her prescription).

In an agricultural setting, a farmer might find a ‘bug’ on his crop, which he takes to a specialist (perhaps at a plant clinic) and asks for advice. The specialist might be able to say, this is a reduviid bug, all of which are ‘friends of farmers’ as they eat other insects, not crops, so you need take no action. In this situation, all the farmer needed was the diagnosis (this is a friend) and the advice (don’t worry about this bug).

On the other hand, the specialist might recognize the bug as a defoliating caterpillar, but not know which species. If the farmer had also noted lots of feeding damage to leaves or other crop parts, this may well be what was causing damage. The specialist could suggest the use of a preparation of *Bacillus thuringiensis*, knowing that this would kill defoliating caterpillars, but have little impact on other insects in the crop. The specialist could then send the caterpillar away for identification. (This is not straightforward as the identification of caterpillars is not well advanced, and often depends on rearing it through to obtain the adult moth or butterfly. Maybe there is a caterpillar identification guide available for this crop. In the future identification is likely to be possible using molecular markers, an approach that works equally well for different life stages of the same organism.) Let us assume that the caterpillar is identified. This in itself does not help directly, but based on the identification it is now possible to consult the literature and characterize the food plants, pest status, control options, etc., for this species. This might show that the caterpillar does not feed on the crop in question, or that it normally only does minor damage to old leaves, so that the prescription could change.

There is a further complication: although for many purposes identification at the species level is sufficient, in many cases identification at below the species level is needed for pest management purposes, i.e. at the subspecies, strain or biotype level. This is particularly true when dealing with fungi, bacteria and other disease causing agents. For example, national agricultural systems monitoring the spread of Ug99 wheat rust (*Puccinia graminis* f. sp. *tritici* Race TTKSK) need to know whether their samples are of a strain already established and under effective management in their country, or the new strain which causes severe damage in the areas to which it spreads. These infraspecific entities are frequently defined by biological characteristics or cross-breeding experiments, but identifications at this level increasingly use molecular-based methods such as DNA barcoding (Section 5.2).

Hence, it is clear that the level of diagnosis, identification or characterization needed will depend upon the actual situation. Taxonomy inputs would primarily be concerned with identification, but diagnosis depends on previous work, including taxonomic research, and identification is a necessary prerequisite for characterization.

Sometimes, newly introduced species will be found, which cannot usually be reliably identified locally; these will have to be referred to an expert at a centre of (taxonomic) excellence. Sometimes, species will be found which are new to science, and they will need to be described and named (by a taxonomist).

In order to be able to make authoritative identifications, it is necessary to have a competent taxonomist (often specialized in a few groups), access to relevant key literature (including taxonomic revisions, keys, field guides, check-lists, etc.), an equipped taxonomic laboratory (the level of complexity and cost depending to some extent on the groups to be identified), and a reference collection of reliably named specimens, for visual comparison. This can be developed at the research centre level, the national level, the regional level, or the international level, but in all cases it will be a long-term commitment and investment. Increasingly, for many groups of organisms, such resources can be made available digitally, although some taxonomic groups are better suited to this approach than others. For example, images of herbarium sheets can be used to rule out many possible names, but it would often be difficult to make an affirmative identification without representative images of the microsculpture of different parts of the plant.

1.2 Sanitary and phytosanitary issues

In order to move planting materials and agricultural produce between countries, sanitary and phytosanitary (SPS) requirements to minimize the risk of transferring pests are critical. Planting materials and agricultural produce have traditionally been a major pathway for the introduction of exotic pests (and beneficial species) between countries and continents, causing on occasion devastating damage and loss of food security.

The different aspects of SPS, including black-lists of pests that must not be imported, pest risk assessments for any trans-border movement, border inspections and interceptions, reporting, etc., all depend on taxonomy, e.g. to define key pests and their current distributions, recognize which pests may be imported in association with a particular pathway, and identification of contaminants found during border inspections.

Taxonomic support is essential to support SPS requirements, and without it countries will find it difficult to meet the requirements of international trade, particularly trade in agricultural produce. Developing countries need to be able to address this to export their produce. The link to food security is not so direct, but if internationally traded agricultural materials and produce are not adequately regulated, new pests will be introduced which will have an impact on food production and food security. Indeed, food aid itself needs to meet SPS requirements of the receiving country. More than one exotic pest is thought to have been introduced into Africa in food aid, ultimately causing far more loss of agricultural production than the food which the aid replaced. Taxonomic support alone might not have successfully prevented this, but without it, there is no way to prevent it.

1.3 Derivatives from identifications

Another important demand from agriculture is for what are here called 'derivatives from identifications', i.e. products which depend upon someone having first identified pests and/or beneficials in a particular situation. The types of things considered here include:

- Field identification guides for pests, natural enemies and pollinators in a particular crop or region;
- Distribution maps;
- Check-lists of pests present in a region or country;
- Black-lists of alien species of quarantine concern for a country;
- Lists of pest interceptions by SPS services;

i.e., tools of value to SPS, as well as crop production.

1.4 Access to information

The name of a species is the key to finding out what is known about it – where it is found, what crops it attacks, what damage it does, when it does the damage, what natural enemies it has, how effective they are at controlling the pest, what methods have been used to control the pest, how effective they have been, what the economic threshold is for a pest management, etc., etc. Based on this information, advice can be developed for farmers or extension workers. In order to review the available information on a species, whether in a text book, in a database or on the Internet, the starting point is the scientific name.

1.5 Climate change

Understandably, a major concern in all aspects of life today is climate change and its implications. This is certainly true in agriculture, where quite apart from impact on crop growth, it is anticipated that climate change will result in changes in pest distribution. Any attempt to predict this depends upon knowing what the eco-climatic needs are of a particular pest. This can be estimated by time consuming and expensive experimental means, or it can be derived from accurate distribution data for that pest under the current climatic regime, linked to geographic climate data. The best places to obtain this information are from taxonomic revisions, distribution maps, and collections of reliably named material properly labelled with location data – these are all outputs of taxonomic research.

1.6 Biological control and integrated pest management

Biological control by the introduction of exotic natural enemies is a specialized science best undertaken by specialists working with government agencies. Today, particular attention is required to assess the risk that an introduced biological control agent may pose to non-target species, whether of economic value or purely as part of the indigenous biodiversity. Because of this, biological control by the introduction of biological control agents from one country to another is particularly demanding in terms of taxonomic inputs, most of which will need to be targeted with research, e.g.:

- To provide identification and often genetic characterization/differentiation of biological control agents (predators, parasitoids and pathogens of pests).

- To provide phylogenies to identify non-target risks. In assessing the safety of biological control agents being introduced to new areas, tests are conducted to check whether these will attack species most-closely related to the target pest species, as these are more likely to be attacked than less-closely related species. Taxonomy can generate classifications of species related to the pest (or better, a phylogeny of related species), which can be used to identify which non-target species are most at risk, so as to include them in the testing programme.
- To support practical aspects of research and implementation, e.g. day-to-day identification and checking of biological control agents, recognition of hyperparasitoids, assess host specificity from the literature, etc.
- To identify possible non-target species to be monitored in pre- and post-release studies.

Biological control, through the action of indigenous natural enemies, is the basis of most integrated pest management (IPM) systems. In many cases, these indigenous natural enemies already keep many crop pests under control, but this may only become apparent when misuse of pesticides kills the natural enemies, eliminating their control of what would have been minor pests, which then become very damaging (so-called secondary pests). Manipulation of the agro-ecosystem (e.g. intercropping, multiple cropping, flower-rich strips and margins, etc.) can make indigenous natural enemies more effective in controlling the key pests. However, to establish such systems and generate recommendations, research and monitoring are required to establish what natural enemies are normally present and how they act to reduce potential pests, i.e. it is necessary to be able to identify the natural enemies to at least family level, but often to genus or species, to understand which groups of potential pests they act upon.

1.7 Agricultural and forestry production for biodiversity

There are a variety of certification schemes regarding how agricultural and forestry produce (usually for export) is grown. This niche market is growing rapidly as it provides a way for consumers in developed countries to positively influence production methods in developing countries. Given that one of the intentions of these schemes is to protect and encourage biodiversity, it may be anticipated that monitoring of biodiversity is required – with corresponding taxonomic support.

One prominent example is the Rainforest Alliance (www.rainforest-alliance.org), which works to conserve biodiversity and ensure sustainable livelihoods by transforming land-use practices, business practices and consumer behaviour. The Rainforest Alliance's agriculture programme supports the international secretariat of the Sustainable Agriculture Network (SAN), a coalition of leading conservation groups that links responsible farmers with conscientious consumers by means of the Rainforest Alliance Certified seal of approval. SAN is made up of environmental groups in Brazil, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras and Mexico, with a watchdog group in Denmark and many associated academic, agriculture and social responsibility groups around the world. SAN seeks to transform the environmental and social conditions of tropical agriculture through the implementation of sustainable farming practices. The conservation and rural development groups that manage the certification programme understand local culture, politics, language and ecology and are trained in auditing procedures according to internationally recognized guidelines.

Similarly the Rainforest Alliance’s forestry programme provides independent third-party certification, which assures consumers that the wood products they purchase come from well-managed forests. They were one of the founders of the Forest Stewardship Council (FSC), the most respected standard-setter in the world, and are now the largest FSC-accredited certifier, having certified the greatest number of community and indigenous operations to FSC standards.

However, as yet there is a “near absence of studies directly addressing the effects of certified forest management on biodiversity” (van Kuijk *et al*., 2009). Hence, it is not surprising that indicators for certification and assessing impact are based on surrogates for actual biodiversity measurements, e.g. for certified forests: area of forest designated as strict reserves, area of forest designated as ‘High Conservation Value Forest’, and length of streams protected (Newsom, 2009). So, although in the future taxonomic support may be needed to certify such schemes, at the moment, it remains a research gap that will need to be addressed.

1.8 Other beneficial species

All the arguments made about pests and natural enemies apply more or less directly to other beneficial groupss such as endophytes, pollinators and non-pathogenic soil organisms. Taxonomic support is needed to support research, facilitate access to the literature, and enable practical management advice to be generated.

1.9 Crop plants and related taxa

Plant breeders in particular need to understand, recognize, characterize and develop a terminology for infraspecific populations of crop species and their related taxa. This discipline is technically taxonomy, but has traditionally been dealt with separately from pests and beneficials found in agro-ecosystems, and does not form part of the current BioNET programme. Some current initiatives will be briefly discussed below which suggest that there is no open niche in this area for BioNET.

1.10 Taxonomic research

Throughout the foregoing discussion, the emphasis has been on identifications, as this is the primary demand made on taxonomy by those involved in agriculture. However, the ability to make identifications depends upon earlier taxonomic research, and assumes that the pest species are sufficiently well known that they can be identified by experts. This is not necessarily the case: there are still a significant number of taxonomic groups where research is needed before identifications can be reliably and consistently made. These include the important disease groups such as *Phytophthora*, *Fusarium*, viruses and phytoplasmas (E.R. Boa, pers. comm., 2010) as well as beneficial groups such as parasitic Hymenoptera and Tachinidae (see also discussion of cryptic species in Section 5.2).

In addition to research to enable identification, any intensive study of an organism relevant to agriculture is going to generate research question which taxonomists can address, e.g.: What are the species most closely related (and what is their biology, etc.)? Are there differentiated populations of this organism in different parts of its range, or within different climate regions of the same country? How much individual variation is there within the species with regard to size, markings, phenology, host range? And so on.

Summary

The dominant needs from agriculture that have been recognized are for diagnoses and identifications and various products based on identifications as well as access to what is known about the species. Taxonomic research is occasionally needed to help answer specific questions, or to clarify the taxonomy of groups of organisms that cannot otherwise be identified. Taxonomy of crop plants and related taxa is an important need of agriculture, but is serviced by different mechanisms.

2. Existing/emerging mechanisms and gaps

In this section, the existing mechanisms that provide taxonomic support to agriculture are examined. Given the conclusions of the previous section, particular attention is paid to the provision of identifications. The worst gaps are highlighted in the discussion at the end of the section.

2.1 In-country limitations

Developed countries already invest substantially in taxonomists and collections to maintain some capacity to identify organisms of agricultural importance (Sections 2.9 and 2.10). Even so, relatively few if any are able to fully cover all major groups of organisms. While the developed countries have yet to catalogue all organisms in their countries, most are well advanced in this task, but the constant shortage and erosion of taxonomists means that the ability to name species is deteriorating. New techniques, such as DNA barcoding, will make identifications possible in more places more rapidly, but depend on expert taxonomists and reference collections for their development and to provide ongoing back-stopping.

In comparison, most developing countries are a long way behind, in terms of collections, reference materials, sophisticated techniques and, above all, competent, experienced taxonomists. The exceptions are those developing and emerging economies that have taken significant steps to invest in taxonomy, for instance Brazil, Malaysia and China, and former socialist-block countries with a strong history of taxonomic science such as Russia, Ukraine and Cuba. Therefore, developing countries need to strengthen their own capability, especially for dealing with routine identifications, and network with regional and international groups to gain access to critical expertise and resources not available in-country.

The Internet offers a mechanism to address several important aspects of taxonomic support discussed below, not just in developing countries but throughout the world. Until broadband access is available to taxonomists in developing countries, they will not be able to benefit from these opportunities on the same scale as developed countries. On the other hand, many of the initiatives that will provide critical taxonomic support are still at an early stage of development.

Internet access to literature

One area that is rapidly improving is local access to critical taxonomic information and publications through the Internet. The Biodiversity Heritage Library (www.biodiversitylibrary.org/) is making the taxonomic literature prior to 1922 available via the Internet.

Other groups are making important taxonomic reference material available, such as the Smithsonian Institute, which *inter alia* provides an Internet version of the huge *Biologia Centrali-Americana* (www.sil.si.edu/DigitalCollections/bca/), and the University of Goettingen's AnimalBase (www.animalbase.uni-goettingen.de) which is digitizing many of the older works published in Europe.

Depending on the taxonomic group, Internet resources may include most of the relevant literature, but for most groups, there is still a significant gap after 1922, which will need to be filled one way or another. Various initiatives such as the Scientific Electronic Libraries on line (SciELO, e.g. SciELO Brasil; www.scielo.br/) are making local journals available open access, and there is a growing trend towards open access publications, although as yet most archive volumes are not yet available. In the developing world, key agricultural journals are available open access via AGORA (Access to Global Online Research in Agriculture; www.aginternetwork.org/en/), but many taxonomic journals are missing from this. In spite of these riches, one must remember that literature in isolation is not very helpful; competence in taxonomy will almost always be needed to interpret it.

Internet access to names

There are important Internet-based initiatives to document the valid names of taxa. Several initiatives provide information (sometimes conflicting) on the valid names of major groups, e.g. The Global Lepidoptera Names Index (Beccaloni *et al*., 2003) and Lepidoptera and Some Other Life Forms (Savela, 2010), or all groups, e.g. The Tree of Life Web Project (Maddison and Schulz, 2007), Catalogue of Life (Bisby *et al*., 2010), Encyclopedia of Life (www.eol.org/), Global Names Architecture of the Global Biodiversity Information Forum (www.gbif.org/informatics/name-services/global-names-architecture/) and Wikipedia (http://species.wikimedia.org/wiki/Main_Page). In time some of these will be supported by illustrations of types or named material.

Internet access to specimen images

In most groups, identifications are based on visual examination of specimens, ideally in comparison with reliable reference material. Depending on the group, examination may be by eye, hand lens, microscope, compound microscope or scanning electron microscope. The most authoritative reference specimens are the types, and various initiatives are underway to make images of type specimens available via the Internet. This works quite well with groups such as Lepidoptera, although often dissection and photographs of the genitalia are needed for confirmation, but for most groups, more detailed photographs of microsculpture from a standard angle will be needed, or the preparation of microscope slides for comparison. Another complication is that fresh or living material may not obviously resemble the dead preserved material, for example herbarium material. Nevertheless, the increasing availability of illustrations of types and reliably named material will make identifications possible, where before they would not have been, but will also make misidentification easy in the hands of inexperienced or untrained individuals. As yet, the availability of images is far from comprehensive, and mostly provided by individual museums. As a result, some museums with smaller holdings are taking something of a lead, while the major repositories are yet to make much progress on what for them will be a huge task. So, for the immediate future, taxonomists will continue to need to visit the major museums to see key material for all groups.

Internet access to specimen data

As already shown, the Internet has great advantages handling and making available large amounts of information. Another ambitious project, the Global Biodiversity Information Forum (GBIF; www.gbif.org/) of the CBD (Convention on Biological Diversity), is compiling specimen information for all biodiversity and making it available via the Internet to enable countries to share data on biodiversity. Information can be searched taxonomically, geographically or by who provided it, but as yet coverage is still too limited in most cases to be useful to taxonomists and thus for making identifications

Internet help with identification

Another area where the Internet can significantly help is the provision of easily used keys such as the Lucid suite of software and its application to IdentifyLife (www.identifylife.org/) by the Centre for Biological Information Technology (www.cbit.uq.edu.au/). Lucid is a flexible and powerful knowledge management tool that helps users make an identification or diagnosis, using the information available without the rigidity of the traditional key structure. Under IdentifyLife, keys to all life are being developed to help people find the name of an organism and hence access relevant information. As yet it is very early days, but once more keys are available and they have been tested and validated, this should enable those working with inadequate support resources to make more reliable identifications (cf. Section 2.9). Facilitating the creation and dissemination of keys to end users is a task well suited to BioNET. There is significant scope for making existing keys more available, adapting them to local needs and training more people to produce them.

2.2 Access and benefit sharing

One challenge that may arise following anticipated adoption and ratification of a legally binding access and benefit-sharing protocol under the CBD is national legislation with regard to access and sharing benefits from the use of genetic resources. It is necessary to establish routine procedures to send specimens abroad for identification, whereas some countries are introducing legislation which inadvertently or otherwise makes this almost impossible. However, more generally, one might anticipate that legislation of this type will require authoritative identification of genetic resources so that their movement and use can be tracked; taxonomy will have a role in this, whether capacity building, or verification of identification of material. Equally, it may be that trusted, formal networks such as BioNET will have a role in facilitating movement of material for identification. In this regard, see discussion of regional identification networks below (Section 5.1).

2.3 Current practice in agriculture

At the moment, there is not a common practice, rather a variable response. At one extreme, where a new pest is recognized as causing substantial damage, one way or another material will get to those competent to identify it and advise on the implications. This may be through international groups such as the CGIAR (Consultative Group for International Agricultural Research) and CABI's Global Plant Clinic, or through personal contacts, but it will happen, although not necessarily as quickly as it could.

At the other extreme, an extension worker with inadequate taxonomic support available will try and relate any particular sample to the pests already known and make a diagnosis and recommendation based on this. Sometimes this will result in suitable advice being given, but sometimes not. In between these extremes, the national agricultural research systems (NARS) and universities will do the best that they can with whatever resources are available. This means that often pests will be misidentified, pest complexes will be treated as one species, and new pests will not be recognized as such until their damage becomes so great it cannot be overlooked. Scientific outputs based on this level of identification, if they can be published, will often be unreliable and include errors of identification. Once in the literature, these errors will be perpetuated.

Studies of natural enemies will be worse hit than studies of pests. This is because there are more species of natural enemies and because the state of knowledge of their taxonomy is generally less advanced (see discussion of parasitoids in Section 5.2), so that taxonomic research is often needed to understand what species are involved. Increasingly, there is little or no capacity available to agriculture to identify natural enemies beyond family or sometimes genus. Thus, research outputs on natural enemies can still be useful, but they are of little value for comparing different situations or places, and lack the essential reproducibility of good science. However, studies based on identification of natural enemies only to the family level may be adequate to develop and support IPM approaches. On the other hand, for the development of biological control interventions this will not suffice and identification to the species level will be needed.

2.4 What support is appropriate?

At a minimum, each country should have a diagnostic capability to be able to identify the damaging stage of the main pests of the main crops. Even so, certain groups will be lumped together if they have similar appearance and damage symptoms, and while this will often be adequate for pest management purposes, it will not suffice for SPS lists. Identification information on key pests should be disseminated with simple identification guides, and extension staff trained in their use. Even this is challenging for diseases and micro-insects, but much could be achieved with a competent and experienced entomologist and mycologist, each with a reference collection of reliably identified material and photographs.

However, most countries would want to identify most pests on most crops, and distinguish the main natural enemy groups. To comply with IPPC (International Plant Protection Convention) commitments, and to participate effectively in world trade, countries will need to establish and maintain lists of known pests (Section 3.7). The quality of most lists for developing countries today is very poor.

Only in developed countries do aspirations extend to cover all pests (and all biodiversity in agro-ecosystems, and even all biodiversity), and most of these are finding it challenging, or beyond their capacity.

Obviously, to be sustainable, in-country diagnostic ability will need to be paid for by each country. Except for the poorest countries, there is scope for regional collaboration to share taxonomic resources, ideally paid for in-country. External support is needed to develop national capacity, establish regional cooperation, and maintain links between national and regional mechanisms and international centres of excellence, e.g. the world's museums, identification services, etc. This is a niche that BioNET was established to fill.

2.5 CBD Global Taxonomy Initiative

The Global Taxonomy Initiative (GTI) was developed by the Parties to the CBD to:

- Identify taxonomic needs and priorities;
- Develop and strengthen human capacity to generate taxonomic information;
- Develop and strengthen infrastructure and mechanisms for sharing of and access to that information;
- Provide taxonomic information needed for decision-making regarding the conservation of biological diversity, sustainable use of its components, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources (the three objectives of the CBD).

The Programme of Work consists of 18 planned activities grouped under five operational objectives. The operational objectives and the planned activities relevant to each objective are listed below; *those most relevant to BioNET are in italics*.

1. Assess taxonomic needs and capacities at national, regional and global levels for the implementation of the convention.

- *Country-based taxonomic needs assessments and identification of priorities*
- *Regional taxonomic needs assessments and identification of priorities*
- *Global taxonomic needs assessment*
- *Public awareness and education*

2. Provide focus to help build and maintain the human resources, systems and infrastructure needed to obtain, collate and curate the biological specimens that are the basis for taxonomic knowledge.

- *Global and regional capacity building to support access to and generation of taxonomic information*
- *Strengthening of existing networks for regional cooperation in taxonomy*

3. Facilitate an improved and effective infrastructure/system for access to taxonomic information, with priority on ensuring countries of origin gain access to information concerning elements of their biodiversity.

- Develop a coordinated global taxonomy information system

4. Within the major thematic work programmes of the convention include key taxonomic objectives to generate information needed for decision-making in conservation and sustainable use of biological diversity and its components.

- Forest biological diversity
- Marine and coastal biological diversity
- Dry and sub-humid lands biodiversity
- Inland waters biological diversity
- *Agricultural biological diversity (including soil, pollinators and pests and pathogens)*
- Mountain biological diversity

5. Within the work on cross-cutting issues of the convention, include key taxonomic objectives to generate information needed for decision-making in conservation and sustainable use of biological diversity and its components.

- *Access and benefit-sharing*
- *Invasive alien species*
- Support in implementation of Article 8(j) [of the CBD: re. indigenous knowledge]
- Support for ecosystem approach and work under the Convention on Biological Diversity on assessment including impact assessments, monitoring and indicators
- Protected areas

At first sight, GTI and BioNET have a great deal of overlap, but GTI is purely a facilitating mechanism, whereas BioNET is not only a facilitating mechanism but also, especially at the local level, provides an implementing mechanism. Hence, GTI anticipates working through BioNET, and there may be scope for a closer relationship. Given that the CBD has a strong biodiversity focus, it is noteworthy that agricultural biological diversity is identified as a key taxonomic objective. Can this expressed support from the CBD/GTI be converted into funding in support of taxonomy relevant to agriculture? Perhaps not easily; sponsors interested in biodiversity have yet to show significant interest in agricultural biodiversity, whereas sponsors interested in agriculture have more-applied objectives as will be reviewed below.

2.6 BioNET

www.bionet-intl.org/

BioNET – the global network for taxonomy – is an international initiative dedicated to promoting the science and use of taxonomy, especially in the economically poorer countries of the world. To date the network comprises ten government-endorsed regional networks, the Locally Owned and Operated Partnerships (LOOPs), encompassing institutions and 3000 individuals in over 100 countries, and a Secretariat in the UK hosted by CABI.

Working via local and international partnerships, BioNET strives to provide a forum for collaboration that is equally open to all taxonomists and to the other users of taxonomy. Its work contributes to raising awareness of the importance of taxonomy to society, building and sharing of capacity, and meeting taxonomic needs via innovative tools and approaches.

BioNET is uniquely positioned to assist the developing world in responding to their key challenges: food security, poverty reduction, climate change, and the conservation and sustainable use of biodiversity. The network supports the achievement of, for example, the MDGs and the targets of the CBD.

BioNET has established a network structure to support taxonomy in the developing world, and link to the centres of excellence in the developed world. This is what is needed to develop national and regional capacity in taxonomy for agriculture, but the funding at the global level has not followed consistently, apart from sustained support from SDC (Swiss Agency for Development and Cooperation).

Two particular initiatives within BioNET LOOPs illustrate its relevance to agriculture: the ASEAN (Association of Southeast Asian Nations) Regional Diagnostic Network (ARDN) (under BioNET-ASEANET) and the regional identification centre for West Africa (under BioNET-WAFRINET).

ARDN is newly established as a system to provide identifications of organisms of agricultural importance (especially plant pests, diseases and weeds) detected in the South-east Asian region. This diagnostic facility will service production agriculture, market access and quarantine operations. It is available to users in the ASEAN region and draws upon expertise both within and beyond the region. The network will also provide a framework for enhancing national and regional diagnostic capacity, by building diagnostic skills among ASEAN professionals and developing practical, diagnostic tools relevant to the ASEAN region (ARDN, 2009). (Note where ARDN refers to diagnostics, it means identifications in the sense used here.)

Clients forward unknown samples to a Clearing House. Its role is to make an initial identification, record specimens and consign them to experts drawn from a diagnostic expertise register. In due course, sample and identification are returned to the Clearing House and thence to the client. The diagnosis remains confidential until the client elects to publish the record. Expertise gaps will be addressed during the initial years of operation through a programme of training activities. Gaps in scientific knowledge will be addressed by a programme to develop tools and regional resources.

ARDN identifies key advantages to the development of a network structure for regional diagnostics networks:

- It encourages the involvement of taxonomists within national institutions that are somewhat removed from mainstream biodiversity/invasive species/plant health activities.
- It facilitates sharing and maximizes the use of the scarce taxonomic expertise that exists in developing countries, but is currently scattered/dispersed.
- It provides a structured framework for not only South–South but also North–South collaboration in taxonomy, and access to taxonomic services which currently are very much dependent on individual personal contact.

The ARDN initiative has received support or interest from a variety of development agencies. Once it is established and can be evaluated, this pilot may well be suitable for replication elsewhere, based on international donor support. However, areas with less taxonomic expertise in the participating countries will need to rely more on taxonomic support from outside the region – at least to begin with.

The International Plant Diagnostics Network (www.intpdn.org/) under the leadership of the University of Ohio, USA, is developing regional networks in East Africa, West Africa, and Central America and the Caribbean to enhance plant disease diagnostic capability. Another approach to addressing regional needs is the establishment of a regional centre of expertise. This has been the approach taken for insects in West Africa, in an IITA (International Institute of Tropical Agriculture) initiative. IITA has established an insect museum at its Cotonou base in Benin, which acts as a repository and has been nominated as the regional identification centre for BioNET, to support programmes in West Africa and link them to international expertise. Free specimen identification services are provided to WAFRINET members and non-members.

2.7 Pestnet and CariPestNet

There are at least two initiatives set up to use email and Internet to share information and help with identifications: PestNet (www.pestnet.org/) and CariPestNet (www.caripestnetwork.org/). PestNet is an email network set up to help people in the Pacific and South-east Asia[1] obtain rapid advice and information on plant protection, including quarantine. It links the Pacific and South-east Asian regions with plant protection specialists worldwide and is free to members. CariPestNet is a sister network operated by BioNET-CARINET that does the same for the Caribbean. By sending pictures of pests and/or symptoms to an interested group, those who need identifications may get advice on what the pest probably is, or who could identify the pest. Sometimes, network members will refer the picture to one of their contacts, thereby getting a more-authoritative identification. Obviously this is quick and easy, but as the network facilitators point out, it is not reliable or authoritative, and all diagnoses/identifications need to be confirmed by an expert who will need to see suitably preserved material. Furthermore, the quality of the pictures provided is very variable; the time that network participants spend on each enquiry is probably minimal (and would go down with a greater volume of enquiries); there is no quality control; and it can only work to this extent in those groups where identification from a picture is practical. It also relies on the goodwill of members and their

[1] In 2011 it became a global network.

contacts with relevant expertise being willing and able to offer their advice, which may not be what they are employed to do.

2.8 CABI's identification service

The predecessors of CABI were established early last century to provide support to plant protection officers in the British colonies through identifications and information. The latter grew into a range of high quality abstract journals and towards the end of last century into the best database of published agricultural information, now available through the Internet (www.cabdirect.org/). The former grew to three internationally renowned institutes covering entomology, mycology and parasitology, complemented by the herbarium of the Royal Botanic Gardens, Kew (UK), which was able to provide weed identifications. At their peak (from the 1960s to 1980s) the institutes employed around 40 taxonomists to cover all the major groups of agricultural importance, and liaised with other organizations to cover the less-important groups, identifying around 35,000 specimens per year. This work was funded through membership of CABI by its colonial then Commonwealth member countries. In 1993 CABI introduced charges for identifications linked to the member countries reducing their subscriptions. The demand for identification plummeted to around 5000 per year and never recovered. CABI had to cut back on areas of expertise, and as staff were lost its ability to carry out identifications in-house declined, and the number of identifications declined to around 1000 per year, so that now the fungus herbarium and the remaining taxonomic mycologists have been transferred to the Royal Botanic Gardens, Kew, and the remaining capacity left in-house today is molecular-based. The introduction of identification charges is generally considered to be the prime cause of the demise of the greater part of the CABI identification service. The sums involved per identification were not great, but in most developing countries they presented an often insurmountable administrative barrier. It should be recognized that a proportion of the material being sent to CABI was trivial, and should have been dealt with in-country, but nevertheless, a global high-quality service could not maintain itself by charging for identifications. BioNET was established with a view to developing national capacity, while facilitating linkages with expertise internationally, including CABI. There is still a global need for identifications and taxonomic support to agriculture, and BioNET has persisted, but lessons from the past must guide planning for the future. No fee-based identification service for developing countries will be viable.

CABI's microbial identification service is now available free to many CABI member countries, as one of the benefits of membership. The service provides authoritative identification of bacteria and fungi of agricultural importance, including those relating to food security and plant health including quarantine organisms. The free service is available to agricultural research centres including university departments, and government institutions responsible for agriculture and food security.

2.9 Some other identification services

Most developed countries have some form of national identification service for agriculture. Those of Canada seems particularly comprehensive (Rickey *et al*., 2005). Although they have to deal with interceptions, these services are usually orientated towards national agricultural biodiversity. The USA has a National Plant Diagnostic Network (www.npdn.org/), as well as identification services for insects and fungi.

USDA Systematic Entomology Laboratory

www.ars.usda.gov/Main/site_main.htm?modecode=12-75-41-00

Scientists at the US Department of Agriculture (USDA) Systematic Entomology Laboratory (SEL) identify more than 40,000 specimens each year, which provides critical support to research projects in ecology, conservation biology, biological control and IPM. The USDA Animal and Plant Health Inspection Service (APHIS) is the primary user of this service, but the user community is diverse and includes other USDA Agricultural Research Service (ARS) research laboratories, universities and foreign governments. Support to non-American requests is limited and based on the perceived importance of the submission (M.A. Solis, pers. comm., 2010).

Scientists respond to requests for information relating to the taxonomy, biology, ecology and distribution of insect and mite species. Regulatory agencies such as APHIS use this information to develop strategies for protecting the USA from invasive species and agricultural pests. SEL scientists produce databases and interactive identification tools on the SEL website to meet the information needs of the public and scientific community. Much information is gleaned from building, maintaining, and developing digital archives of the Smithsonian Institution's insect and mite collections.

SEL routinely provides specimen identification assistance as a free service to both government and private entities, including federal research and regulatory agencies, state departments of health and agriculture, university researchers and private citizens.

The SEL website lists 24 USDA research entomologists at SEL based at the Smithsonian Institute, but owing to cutbacks only 17 positions are currently filled (M.A. Solis, pers. comm., 2010).

US National Fungus Collections

www.ars.usda.gov/Services/docs.htm?docid=9402

Specimens in the US National Fungus Collections have been assembled from every major area of the world. They are often used for direct comparison with suspected pathogens. Records for a recent, typical year show that services by the staff of the US National Fungus Collections included assistance with fungal nomenclature and synonymy, fungal identification, herbarium specimen data, records of distribution and pathogenicity, information on mould prevention, information on mushroom poisoning and the eradication of mushrooms, and identification of poisonous mushrooms. Services were provided for mycologists, plant pathologists, extension pathologists, and physicians as well as the lay public, and for institutions, including experiment stations, universities, biology publishing firms, research laboratories, government offices, museums and hospitals.

The facilities, programme and staff of the US National Fungus Collections are particularly strong in dealing expertly with mycological problems of foreign origin. The herbarium and major data files have been built up with emphasis on foreign material. Many compendia on foreign pathogens have been produced by using these data. Support is also provided to the plant quarantine programme of USDA-APHIS. As international travel and commodity shipments increase, continuing development of technical information on the mycology of foreign countries is necessary for plant protection in the USA.

The US National Fungus Collections come under the Systematic Mycology and Microbiology Laboratory, whose mission is to increase the knowledge and application of the systematics of fungi essential to solving problems in sustainable and conventional agriculture. Research emphasis is on organisms important as pathogens that threaten the production of a safe and abundant food supply, and biological control agents of insects and diseases in order to reduce the need for chemical inputs in agriculture. Online information about plant-associated fungi is provided to users through Internet access to electronic databases. The US National Fungus Collections and databases about fungi serve as unique reference resources developed for use by customers throughout the world. In spite of this last statement, support to non-USA establishments is not specifically mentioned.

CGIAR centres

Of those CGIAR centres with mandated crops, some or all have developed pest and beneficial species reference collections. Certainly IITA (section 2.6) and IRRI (International Rice Research Institute) (K.L. Heong, pers. comm.) have done so and provide identifications when needed, both to the centre's scientists and to partner national programmes. However, taxonomic capability is limited and shrinking within the CGIAR system, so the sustainability of this support is uncertain.

China

Enquiries were made with regard to identification services in two megadiverse countries known to have significant taxonomic capability.

For China, the following is based on information provided by H. Li (CAAS-CABI China Office, formerly with the Institute if Zoology, Chinese Academy of Sciences - CAS). In China, there is no formal identification service, but there are many taxonomists based with the Institute of Plant Protection (Chinese Academy of Agricultural Science – CAAS), and the Institute of Zoology, Institute of Botany, Institute of Microbiology, etc. (CAS), and at universities (Ministry of Education) who provide identifications.

The Agricultural Technological Extension Service System and Institute of Plant Protection is mostly present at the national, provincial, and county level. Extension staff may help to identify pests, but will refer material to staff at the Institute of Plant Protection, who undertake more research work, for help in making identifications.

Generally, there are two different approaches to sending material for identification. One is by crop association; for example, if farmers find pests or diseases associated with wheat, then material will be sent to a scientist who is working on wheat pests or diseases. Alternatively, material may be sent to a specialist taxonomist with a known family or order expertise. The taxonomists are expected to do such identifications from time to time. Sometimes, the taxonomists have a specific collaboration with local partners, and then identifications are part of their job. Sometimes, identifications are made because of personal contacts but sometimes there has been no previous collaboration. If a lot of material needs to be identified, or material needs to be identified repeatedly, then a charge is made, but usually the taxonomists try to help.

Brazil

Information for Brazil relevant to entomology was provided by Professor Roberto Antonio Zucchi of the Universidade de São Paulo. Brazil has around 100 insect taxonomists spread across universities, institutions and museums. Many of these work on groups that are not usually of agricultural importance, although those that do will make identifications without charge. There is no formal identification service or clearing house, so the process is based on personal contacts or by developing these.

Less-developed countries

China and Brazil have invested in developing taxonomic expertise, but the smaller, less-affluent and less-developed countries have invested correspondingly less. As a result, in the worst cases either identifications cannot be made for most pest groups and all natural enemies, or they are made by untrained personnel with inadequate reference materials, with a corresponding likelihood of error. Without adequate named reference specimens in collections, identifications are likely to be made from books and literature based on what is known about the crop pests and their natural enemies in that country (or worse – in other countries). The most prominent and distinctive species will probably be correctly identified but many will be unidentifiable or incorrectly identified, and new pest problems will not be recognized as such.

2.10 International Barcode of Life

http://ibol.org/ and www.barcoding.si.edu

The following section is taken from (Vernooy *et al*., 2010), much of it unchanged. However, concerns have been raised about over-reliance on DNA barcoding, as discussed in Section 5.2.

DNA barcoding was developed in 2003 to identify species. The technique is based on a simple but powerful observation: that sequence diversity, in short, standardized gene regions (i.e. DNA barcodes), can serve as a tool to identify known species and potentially discover new ones. Moreover, barcoding allows researchers to develop a system for species identification based on digital characters, eventually allowing for automated identifications.

Using barcoding technology, researchers are building a library of short, standardized pieces of DNA from all of the world's species – a massive undertaking that would enable the scientific community to quickly and accurately assess the world's biodiversity and monitor it over time. The promise of this technology has captured the attention of the scientific community, government agencies and the general public. Widespread support has led to nearly US$100 million in grants that have been used to mobilize a large research programme in barcoding and establish the Consortium for the Barcode of Life (CBOL), with 200 member organizations in 50 countries. Protocols for barcode acquisition, gathering barcode records, and developing the informatics platform needed for the curation and analysis of barcode records have led to the creation of BOLD, the Barcode of Life Data Systems (www.boldsystems.org), which now has more than 5000 registered users and holds barcode records for more than 850,000 specimens, representing approximately 100,000 species. Individual organisms are placed in museum collections, and their extracted DNA resides in a secure repository, so that future generations can study them.

To coordinate these global efforts, an alliance of researchers and biodiversity conservation organizations launched the International Barcode of Life Project (iBOL; www.ibolproject.org) in October 2010 during the International Year of Biodiversity. The project will bring together 26 countries to broaden and strengthen barcoding research with potential social, cultural, and economic, implications – direct and indirect – with a special focus on developing countries.

To date, researchers in developed countries have largely performed DNA barcoding, even though most of the world's biodiversity is found in the tropical and subtropical regions. iBOL aims to rectify this situation by collaborating with researchers and local communities in developing countries to retrieve barcodes from five million specimens representing 500,000 species within the first five years of its operations. Work will focus on taxonomic groups targeted for analysis by iBOL because they deliver key ecosystem services (e.g. pollinators), because they are pests (e.g. termites), because they are harvested (e.g. fishes, forest trees), or because they are important targets for conservation programmes (e.g. mammals, reptiles). The opportunity/threat this initiative could present to BioNET is further discussed below in Section 5.2.

2.11 CABI's Plantwise initiative

www.cabi.org/plantwise

CABI is creating a comprehensive global database, bringing together the best worldwide knowledge on crops, pests and diseases to be supplemented by real-time observations from a global network of CABI-trained and accredited plant doctors, delivering primary plant healthcare to the world's most vulnerable farmers. Today, there is no global system of this nature but it builds upon proven technologies and effective techniques already available to CABI.

CABI will provide a unique global pest and disease warning system to guard against future crop losses, improve livelihoods of poor rural farmers and deliver an overall increase in food security by providing extension workers and hence farmers with accessible, authoritative information on combating identified plant pests and diseases, whilst providing researchers with pest distribution forecasts and alerts. The plan is ambitious in scale but built on simple and successful existing initiatives. The new Plantwise Knowledge Bank is underpinned by CABI's existing collection of the world's most extensive and trusted agricultural content – comprising the nine million records in CAB Abstracts, 30,000 pest datasheets from the Crop Protection Compendium, thousands of images, and almost 2000 distribution maps. This will be augmented with research project findings, book content, SPS legislative standards and open access data from authoritative partners, including the FAO (Food and Agriculture Organization of the United Nations), IPPC, and various national plant protection organizations. This will give farmers, extension workers, industrial researchers, risk managers and regulatory personnel access to a consolidated global source for authoritative plant health information and advice.

The database will be informed by inputs from a significant expansion of CABI's plant clinic operation, working at country level with plant science organizations, agricultural ministries, and extension systems to create a sustainable local plant healthcare system. Under this initiative, plant doctors are trained to diagnose and offer practical treatment advice to farmers, free at the point of use, through regular plant health clinics held wherever farmers meet.

Although not specifically mentioned in the Plantwise plans, taxonomic support will be needed at various points, and there is an ongoing discussion between Plantwise and BioNET to assess how BioNET could provide key taxonomic support (e.g. Smith and Mauremootoo, 2010).

Discussion

Although taxonomic inputs are important, sometimes critical, for aspects of agriculture, particularly relating to pest management, there is no international process to ensure that this support is available to those who need it in developing countries. In-country support is variable, and generally correlates with the degree of development or affluence of the country. The only global identification service was that offered by CABI, but this was not sustainable once charging was introduced. Clearly there are many ongoing initiatives that include taxonomic elements relevant to agriculture. Many are still at an early stage of development, but offer great promise for the future. In terms of the requirements for taxonomists, equipment, finances, reference collections, literature and information, the area where there is least progress, and where if anything global capability is in decline, is capacity in trained and experienced taxonomists who are able to reliably identify species and recognize and solve taxonomic issues in their specialist groups. Developed and transition-economy countries invest in taxonomy far more than the less-developed countries, because (one assumes) the former value being able to identify, characterize and understand their biodiversity including agricultural biodiversity – the latter in particular as it has previously been shown to have direct benefits to food production and trade. Hence, mechanisms to develop human taxonomic capacity and to share and network regional taxonomic expertise will be especially important help to address this key bottleneck.

At some point in the future, DNA barcoding could provide a simple, cost-effective alternative to in-country identification capacity; it will be discussed further below (section 5.2).

3. Emerging priorities in ARD and plant health

These are the current major initiatives, what they are doing in relation to taxonomy/collections and, as far as be established, what their perspective is on taxonomic support to agriculture.

3.1 Millennium Development Goals

www.un.org/millenniumgoals/

Of the eight MDGs, #1 'Eradicate extreme poverty and hunger', is the most relevant to agriculture, and will be at the back of most or all agricultural donors' thinking. How does taxonomy help eradicate hunger? It helps if it can help the world to grow more, or lose less (of course the two are inter-related). Growing more relates mostly to more-productive varieties, better matching of crops and varieties to agro-ecosystems, and more-effective production systems. Losing less relates to matching crops and varieties to ecosystems (again), management of field pests (weeds, arthropods, diseases, vertebrates) and storage pests (arthropods, saprophytic agents, vertebrates).

Taxonomy plays a role in the study, evaluation, characterization and identification of varieties and species of crops and crop-related plants, although is not part of the traditional role of the taxonomy community. Taxonomy has a much clearer role in the study, identification, characterization and evaluation of pests and their natural enemies.

Improved nutrition as a function of improved agriculture has a role in MDGs #4 'Reduce child mortality', #5 'Improve maternal health' and #6 'Combat HIV/AIDS, malaria and other diseases' but these MDGs are focussed on other more-direct factors in these areas. There is a role relating to #7 'Ensure environmental sustainability' insofar as more-efficient agriculture reduces the pressure for new land to be brought into cultivation, and makes agriculture more 'biodiversity friendly'. In none of these is there a direct, obvious role for taxonomy comparable with that in supporting pest management to reduce extreme hunger. BioNET's work is, however, related to #8 'Develop a global partnership for development', although the targets identified under this MDG do not directly relate to BioNET's scope.

3.2 CGIAR change programme

The CGIAR system is the major global agricultural research initiative. It is in the process of reinventing itself as a coordinated, cooperating group of centres, delivering results-orientated research based on Mega Programs supported by a shared fund. As at July 2010, the following Mega Programs had been identified (CGIAR, 2010):

- GRiSP: global rice science partnership (fast-track)
- MAIZE: global alliance for improving food security and the livelihoods of the resource poor in the developing world (fast track)
- WHEAT: global alliance for improving food security and the livelihoods of the resource poor in the developing world (fast track)
- Climate change, agriculture and food security (fast track)
- Integrated agricultural production systems for dry areas
- Integrated systems for the humid tropics
- Harnessing the development potential of aquatic agricultural systems for the poor and vulnerable
- Policies, institutions, and markets to strengthen assets and agricultural incomes for the poor
- Roots, tubers and bananas for food security and income
- Grain legumes: enhanced food and feed security, nutritional balance, economic growth and soil health for smallholder farmers
- Dryland cereals: food security and growth for the world's most vulnerable poor
- Sustainable staple food productivity increase for global food security: livestock and fish
- Agriculture for improved nutrition and health

- Durable solutions for water scarcity and land degradation
- Forests and trees

None of these identify taxonomy explicitly, or indeed pest management, perhaps the major user of taxonomy in agriculture. Some elements may include pests implicitly or explicitly (although this is likely to be addressed by a plant breeding approach rather than the sort of ecological approaches which need support from taxonomy):

- Foster more-sustainable rice-based production systems that use natural resources more efficiently, are adapted to climate change and are ecologically resilient, and have reduced environmental externalities;
- Develop [maize] crop management advice;
- Reduce wheat vulnerability to globally important diseases and pests;
- Develop smallholder farmer- and eco-friendly, sustainable integrated crop, soil fertility and pest management options [for grain legumes].

It seems safe to conclude that taxonomy is not above the horizon in the Mega Programs planned by the CGIAR system at present, but there will be a variable demand for taxonomic support across several Mega Programs. It may be anticipated that Mega Programs will allocate support to taxonomy as and when needed to achieve their objectives. This may be done partially in-house, but will almost certainly require partners, albeit partners at the forefront of their taxonomic group, most probably in a developed country. There appears to be a niche to provide taxonomic support to the CGIAR system, but how to develop this is not clear, except by investing in developing links with each relevant Mega Program and/or CGIAR centre. If BioNET were to include this in its strategy, it should be in the context that CABI also has aspirations to work more-closely with the CGIAR system, and this would need coordination.

3.3 Taxonomy of crops and crop-related plants

Bioversity International (Bioversity), formerly IPGRI (International Plant Genetic Resources Institute), is a CGIAR research institute and involved in the change programme described above. It has a mandate to advance the conservation and use of genetic diversity to improve people's lives. In collaboration with partners around the world, Bioversity seeks sustainable solutions to meet three important challenges:

- Malnutrition and hidden hunger of missing micronutrients;
- Sustainability and resilience in food supplies and farming systems;
- Conservation and use, ensuring that agricultural biodiversity remains accessible to all.

Note that here agricultural biodiversity means crops and related species, and not the biodiversity associated with agricultural systems.

Bioversity has received core support from developed countries, World Bank, UNEP (United Nations Environment Programme), etc., although in the future, funding can be expected to be channelled more through the CGIAR funding system rather than directly.

Identification of varieties and cultivars of food crop plants and their relatives are being addressed, including the application of molecular methods (see e.g. TAG (2010) for *Musa* spp.). The orphan crops (i.e. those not covered by the CGIAR system), such as some commodity crops, are mostly being addressed crop by crop, by concerned government and industry interests. For example, cocoa is covered by groups such as USDA, CIRAD (Centre de Coopération internationale en Recherche agronomique pour le Développement, France), CATIE (Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica), the University of Reading, UK, and the cocoa industry major players, as well as NARS.

The Bioversity International Species Compendium is a searchable database providing information at taxon level about seed survival during storage, germination requirements and dormancy, reproductive biology, pests and diseases (Thormann *et al*., 2004). The Germplasm Resources Information Network (GRIN) taxonomy (Section 3.4) was adopted as the standard reference for nomenclature and species synonymy as it is the most extensive, current and accurate plant database existing, and in addition also free available on the Internet.

Thus, the focus of Bioversity is on crops and crop-related plants, rather than agricultural biodiversity as a whole. BioNET has no significant activities relating to crop plant taxonomy and there does not seem to be a niche for them to undertake any. At the moment, BioNET and Bioversity are working in parallel in similar fields, but with little overlap, so there may be scope for sharing experiences (e.g. collections issues, access and benefit sharing issues, identification methods and training), which could lead to collaboration.

3.4 GRIN taxonomy for plants

www.ars-grin.gov/cgi-bin/npgs/html/index.pl

The USDA-ARS National Plant Germplasm System maintains a computer database, the Germplasm Resources Information Network – GRIN, for the management of and as a source of information on its 536,657 germplasm accessions. The taxonomic portion of GRIN (GRIN TAXONOMY) provides the classification and nomenclature for these genetic resources and many other economic plants on a worldwide basis. Included in GRIN TAXONOMY are scientific names for 26,622 genera (14,110 accepted) and 93,295 species or infraspecies (55,656 accepted) with common names, geographical distributions, literature references and economic impacts. The scientific names are verified, in accordance with the international rules of botanical nomenclature, by taxonomists of the National Germplasm Resources Laboratory using available taxonomic literature and consultations with taxonomic specialists. Included in GRIN TAXONOMY are federal- and state-regulated noxious weeds and federally and internationally listed threatened and endangered plants. Since 1994 GRIN taxonomic data have been searchable on the Internet.

3.5 Global Forum for Agricultural Research

Agrobiodiversity is a key theme for the Global Forum for Agricultural Research (GFAR) and it is trying to build coherent actions among diverse partners so that the sum is much greater than the parts (M. Holderness, pers. comm.). It seems that BioNet would fit in well for addressing non-plant aspects. GFAR has already built connections with Bioversity, ITPGR (International Treaty for Plant Genetic Resources), Crops for Future, Global Hort (Global Horticultural Initiative), INBAR (International Network for Bamboo and Rattan) and PlantNET (Plant Information Network System of the Botanic Gardens, Australia), and there is room for BioNET. At the moment, this seems to be a case of linking up existing initiatives, and the scope for new funding is not clear.

3.6 FAO

FAO's Plant Production and Protection Division, AGP, (FAO, 2010) promotes sustainable intensification of crop production. This approach requires the integration and harmonization of all appropriate crop production policies and practices aimed at increasing crop productivity in a sustainable manner, thereby meeting key MDGs aimed at reducing hunger and preserving the natural resources and environment for future use. The focus of AGP's activities is to develop and strengthen:

- Effective and strategic decisions that increase crop production using an ecosystem approach;
- National capacities to monitor and to respond effectively to trans-boundary and other important outbreak pests;
- Policies and technologies appropriate to the needs of a country and/or region to reduce negative impact of pesticides;
- Conservation and sustainable use of plant genetic resources with strong linkages between conservation, plant breeding and seed sector development.

The second of these in particular requires taxonomic support, although this is not specifically formulated. It includes core activities on IPM and farmer field schools, pollination services, IPM, migratory pests, wheat rust disease (Ug99), crop and crop-associated biodiversity, weeds, etc. However, of these only pollination services identifies taxonomy as relevant. FAO's Global Action on Pollination Services for Sustainable Agriculture addresses a range of issues including working with other institutions to overcome the taxonomic impediment to pollinator conservation and use, and has been working with BioNET, particularly in Africa.

There is no indication that FAO is in a position to support taxonomy for agriculture, although in the past it has been ready to pay for identifications of new and emerging pests of concern.

3.7 International Plant Protection Convention

www.ippc.int/

IPPC - the International Plant Protection Convention - is an international agreement on plant health with 173 current signatories. Its aim is to protect cultivated and wild plants by preventing the introduction and spread of pests. The Secretariat of the IPPC is provided by FAO. The Commission on Phytosanitary Measures is the governing body of the IPPC. Its implementation involves collaboration by national plant protection organizations (NPPOs) — the official services established by governments to discharge the functions specified by the IPPC — and the nine regional plant protection organizations (RPPOs), which act as coordinating bodies at a regional level to achieve the objectives of the IPPC.

International travel and trade are greater than ever before – and as people and commodities move around the world, organisms that present risks to plants travel with them. The IPPC allows countries to analyse risks to their national plant resources and to use science-based measures to safeguard their cultivated and wild plants while minimizing interference with the international movement of goods and people.

Amongst other things, contracting parties to the IPPC have agreed, to the best of their ability, to:

- Establish and update lists of regulated pests, using scientific names, and make such lists available;
- Conduct surveillance for pests and develop and maintain adequate information on pest status in order to support categorization of pests, and for the development of appropriate phytosanitary measures.

These actions can only be undertaken if a country's pests, including newly introduced ones, can be identified.

The IPPC provides an international framework for plant protection that includes developing International Standards for Phytosanitary Measures (ISPMs) for safeguarding plant resources.

ISPMs developed as of 31 July 2009 include standards for:

- Procedures and references;
- Pest surveillance, survey and monitoring;
- Diagnostic protocols for regulated pests;
- Import regulations and pest risk analysis;
- Compliance procedures and phytosanitary inspection methodologies;
- Pest management;
- Post-entry quarantine;
- Exotic pest emergency response, control and eradication;
- Export certification.

Most of these will require taxonomic support to implement at the national and regional level (IPPC has confidential data on national capacity).

The IPPC strategic plan for capacity building includes, under pest information:

- Gap analysis to determine requirements for surveillance, diagnostics, reference collections, information systems, etc.;
- Enhancement of surveillance skills through training – especially practical application;
- Enhancement of diagnostic capabilities through on-job training, etc.;
- Enhancement of diagnostic capability through development of laboratory infrastructure, tools and networking;
- Enhancement of reference collections – physical facilities, protocols;
- Creation of information systems at local and national levels;
- Creation of mechanisms to provide pest information to NPPOs;

- Training in compilation of pest information and management of information systems for national actors, including NPPOs.

There is a substantial overlap with BioNET here, and the two are obvious partners. In developing its strategy, BioNET should look at ways to work with IPPC. However, there is also a dialogue between IPPC and CABI, so that BioNET would need to be coordinated or integrated with this as appropriate.

Summary

Taxonomy is relevant to work on crop species and related taxa, but this area is already well covered, so there seems little scope for BioNET to become substantially involved. New initiatives are mostly taking taxonomy for granted. This may mean that resources will be allocated as and when needed, or it may mean there is a planning and/or capacity gap. BioNET should explore the scope for integration of its activities for agriculture with the CGIAR Mega Programs, IPPC capacity building and GFAR.

4. Funders and the scope for their support

A review was made of the approaches of different agricultural funding sources, including bilateral and multilateral development agencies, corporates and foundations. Representative organizations were selected on the basis of their known support in this area, based on CABI's experience and the advice of SDC (Carmen Thönnissen, pers. comm.).

Bilateral donors and development agencies included:

Australian Centre for International Agricultural Research (ACIAR; www.aciar.gov.au/)

- AusAid (www.ausaid.gov.au/
Department for International Development (DFID, UK; www.dfid.gov.uk)
- Swiss Agency for Development and Cooperation (SDC; www.sdc.admin.ch/)

Multilateral donors and development agencies included the European Commission and the World Bank (Agriculture and Rural Development programme).

It would be appropriate for multilateral and bilateral donors concerned with agriculture to support the BioNET programme and/or GTPF. However, these donors are focussing their attention on the MDGs and opportunities to have direct and measurable impact on them. Taxonomy simply does not fit this approach. Advice received indicates that taxonomy can be incorporated into large, focussed proposals where there is a specific need, or commissioned as needed in large initiatives such as the CGIAR Mega Programs, but substantial interest in a separate global support mechanism for taxonomy (or even just identifications) is unlikely. It might be argued that donors support many things that do not have direct, measurable impact on the MDGs, so why not the GTPF or BioNET? Donors have been very explicit about supporting the MDGs, and existing activities that are not demonstrating measurable impact may continue to be supported, but are likely to be increasingly challenged to demonstrate their impact to justify further funding. Seeking substantial and sustainable new funding from donors for an activity that is challenged to show direct impact is unlikely to be rewarding.

Corporate sponsorship would normally be in one of two forms – either by direct corporate giving to an area relevant to the business of the company, or through a company philanthropic foundation which may or may not focus in areas directly relevant to the company's business. To assess the scope for corporate support to taxonomy in support of agriculture, I examined the current position of the corporate members of the CABI Crop Protection Compendium (CPC) development consortium, going back over about 20 years, and the recent sponsors of the new insect collection facility at the Natural History Museum, London, UK. The corporate members of the CPC development consortium comprised several major producers of agrochemicals and seeds and one farming machinery producer. As the CPC is an important tool for pest management and SPS issues, the beneficiaries overlap substantially with those of BioNET. The corporate and foundation sponsors of the NHM insect collection facility were much more diverse, while the beneficiaries were a similar group to BioNET, but with a strong biodiversity focus.

Corporates in the field of agriculture will support global initiatives that are relevant to agriculture – not only will they want to be seen to be part of such initiatives, but they may also find the activities directly useful to them and they are likely to follow each other's lead in supporting something widely useful. If the GTPF can be presented as a global initiative that will help agricultural production, e.g. through improved crop protection, then corporate support from the large agricultural companies is certainly possible, although it will take investment, time and contacts to exploit this. Corporates directly involved in commodity crops are already supporting government and industry-based approaches to the taxonomy, characterization and recognition of their crop plants and related taxa (Section 3.3). Corporate sponsors working through their philanthropic foundations are unlikely to find support to taxonomy or identifications charismatic enough to feel that they will gain the profile they want by supporting such activities.

The other foundations considered included:

- The Bill & Melinda Gates Foundation (www.gatesfoundation.org/)
- The Rockefeller Foundation (www.rockefellerfoundation.org/)
- The John D. and Catherine T. MacArthur Foundation (www.macfound.org/)
- The Total Foundation (http://foundation.total.com/)
- The Syngenta Foundation for Sustainable Agriculture (www.syngentafoundation.org/)
- The Ford Foundation (www.fordfound.org)

The comments about philanthropic foundations of corporate sponsors are generally true of other foundations. Certainly some foundations will support taxonomy in the context of biodiversity, but none have yet been identified that would support taxonomy and identifications in agriculture. This is not to say there are none, but to find such a foundation amongst thousands would require a substantial effort that no one is in a position to support at present.

Conclusions

1. In the context of agriculture, it is very difficult to justify funding for taxonomy in isolation for the developing world.
2. To meet the recognized needs, taxonomy needs to be seen to be directly supporting activities which will achieve direct impact, e.g. in terms of the MDGs.
3. This means that in the majority of cases, taxonomy will be in support of specific pest and SPS issues.
4. In order to be supported by the agricultural sector, GTPF or BioNET will need to be seen to be clearly supporting a global initiative that will have relevant impact. Two possible examples are the CGIAR programme and CABI's Plantwise initiative.
5. The CGIAR programme is moving towards focussed Mega Programs, so although they should be encouraged to participate in the GTPF and BioNET, there is unlikely to be general support from this system.
6. Therefore, with regard to activities in agriculture, it is recommended that BioNET further explore how it and the GTPF can support CABI's Plantwise initiative.

5. Strategic opportunities for taxonomy and BioNET in food security

In the following discussion, it will rapidly become clear that the perceived demand for taxonomic inputs to agriculture do not lead to direct impact, but need to be mediated through pest management, e.g. improved advice made available to farmers on pest management, early detection of new pests leading to appropriate action to minimize impact and spread, and SPS support.

Thus taxonomy is a means to an end in agriculture. It is an essential support to pest management, which in turn is the key to losing less production to pests, and increasing food production and food security. Taxonomy is also needed to facilitate trade in agricultural goods, particularly by supporting SPS mechanisms in international trade.

5.1 National diagnostic/identification centres and regional diagnostic/identification networks

There is a case to develop in-country (and regional) identification centres for agricultural pests and their natural enemies, which at least can deal with most of the common species – if only to reduce pressure on external sources. But national investment is required to make this sustainable, and many countries are not able to afford this yet.

As already discussed, the most clearly recognized need from agriculture is for identifications, and products based on identifications, such as field guides, information summaries, etc. This sits well within BioNET's perceived role. National diagnostic/identification centres will need to be supported where established, and established where not present. If the Asian Regional Diagnostic Network – ARDN – is effective, this model should be tested in other regions. The regional networks will need to be able to link to centres of excellence anywhere in the world, but to be sustainable, national or at least regional capacity is needed.

Regional diagnostic networks can also be used to support:

- Pollinator conservation and management
- Soil organism and fertility management
- Pest and stored product lists and identification guides
- SPS training and tools

5.2 Barcoding for identification of agricultural pests and natural enemies

If the iBOL initiative (Section 2.11) can achieve a significant proportion of all it is setting out to, it appears that much of the demand for identifications for agriculture can soon be met by automated DNA barcoding and Internet identification against a library of the DNA of the world's species. One could imagine a future, not so far away, where every country has at least one diagnostic laboratory equipped to extract DNA barcodes, which could be uploaded to an Internet library site, matched to a species barcode, and an identification provided in seconds. More ambitiously, a portable device that could be used in the field has been suggested, but for now this is probably far in the future.

The enormous investment in barcoding, often coupled with a perception that it is seen as an alternative to traditional taxonomy, have led to concerns being raised as to its effectiveness, universality and appropriateness. Barcoding is not an alternative to other approaches to taxonomy, and needs to be developed together with the best taxonomic expertise available for each group. Combinations of taxonomic approaches including barcoding are currently generating some most interesting and useful research, which also validate the use of barcoding for identification. One example based on the Lepidoptera of part of Costa Rica is summarized below. This was selected because it is already familiar to the author and involves taxonomic groups with which he is familiar and he thus feels competent to confirm the validity of the results from his own knowledge.

Once barcodes have been recorded for several reliably identified specimens from the range of a species, the future identification of this species can be carried out with minimal input of taxonomic expertise. In a way, each species now only needs to be identified once, and thereafter it can be identified by its barcode. However, it would not be wise to see barcoding as a panacea. A universal barcode is not realistic, and it is accepted that several sequences will be needed to be able to identify different taxonomic groups, e.g. the fungal nuclear ribosomal internal transcribed spacer (ITS) sequence is likely to be used for fungi (Seifert, 2009). There are also indications that the same barcodes could appear in different species perhaps as a result of hybridization events (Schmidt and Sperling, 2008; Trewick, 2008). However, a barcoding approach is already matching or exceeding the accuracy of a morphological approach in those groups where it has been most developed, as described in the following example.

The detailed studies based on Janzen and co-workers' massive Lepidoptera rearing programme in Costa Rica (Janzen *et al*. 2009, and references therein; Janzen and Hallwachs, 2010) shows what can be done. For the species-rich families of Hesperiidae, Sphingidae and Saturniidae, 4260 individuals of 521 species were examined. Of these, 98% (510 species) could be identified from their barcode, once it was realized that there were five previously unrecognized groups of cryptic species. Those few species whose barcodes overlap are closely related and not confused with other species. Of the 11 species (four species pairs and a triplet) that could not be separated, six could be separated when longer barcode sequences were used, and the remaining five have yet to be clarified. This is a better level of resolution than was possible with morphological taxonomy before the barcoding work began. By 2009, based on more families of Lepidoptera and their natural enemies, recognition of taxonomic species had reached 99.5%. This pilot shows that identifications based on barcodes will work at the country level.

Studies are still needed to see how barcoding works for widely dispersed species – can they be identified by their barcode throughout their range, or are there geographical differences? If the latter, what is their significance – clinal differences or cryptic species? Once the answers to these questions are better known, it should be entirely possible to identify the known species and recognize new species of the families studied from their barcode alone.

A significant issue with the barcoding approach, particularly for microbes where the taxonomy is improving most rapidly, is that the existing data may be compromised (Bidartondo *et al*., 2008; P. Bridge, pers. comm.). It has been estimated that around 20% of the systematically useful sequences for fungi in Genbank are either incorrectly named or compromised in other ways. A major problem here is that data deposited in Genbank can only be annotated or edited by the original depositor, and so rarely reflects any subsequent changes or corrections. A not uncommon example is where the sequence from a strain is deposited as 'sp.', and is then found to be a new species and is subsequently described. As only the original depositor can change the name on the sequence, what commonly happens is a second version of the sequence is deposited with a different name from the first, or the record is left as it is. There are a number of species where the reference sequence for the type or ex-type is only held in Genbank as 'sp.' This causes considerable confusion and means that almost any attempt to identify microbes purely from sequences routinely requires an involved taxonomic exercise to determine the validity of the reference sequences. This issue will need to be resolved before widespread use of barcoding to identify plant diseases is taken up.

Identification of natural enemies, especially parasitoids, will also not be so easy, as current taxonomic knowledge is far less comprehensive than for many insect pest groups. Furthermore, studies on the material reared in Costa Rica using molecular tools have revealed a large amount of cryptic biodiversity amongst morphological species of parasitoids. When large numbers of reared specimens of Tachinidae and parasitic Hymenoptera with known diverse hosts were examined using barcodes, many new, narrowly host-specific parasitoid species were recognized which had previously been grouped together as a single morphological, oligophagous or polyphagous, species.

It is clear that barcoding is generating many taxonomic questions which need the attention of taxonomists to resolve and publish on (Miller, 2007) – already the anomalies found in current taxonomic treatment of even the well-known groups outstrip the capacity of the taxonomic community to address them.

Barcode identifications have the additional advantage that they can be used to match all stages of the life cycle – and to identify damaging life cycle stages that are not normally used for taxonomic recognition of species. This will be especially useful for agricultural pests and their natural enemies. For example, damage to crops is caused by caterpillars, rarely by adult moths and butterflies. For reliable morphological identification, most caterpillars have to be reared to adult and the adult identified, but with barcoding, any stage can be identified.

The above discussion indicates that the technology is already available for a barcoding approach that could be established to identify animal pests of crops and animal natural enemies. The indications are that barcoding, albeit based on different genetic material, will work for plants (Kress *et al*., 2005), and it seems reasonable to anticipate that the approach can be used on pathogens (Seifert, 2009). A challenge with pathogens developing inside plants or animals will be how to separate the genetic material from the host, either physically before extraction (e.g. by culturing the pathogen) or mathematically after analysis. The present rate of progress suggests that this problem will be solved.

So should developing countries prioritize training to develop their own specialized taxonomists, or would they do better to develop generalist taxonomists (e.g. entomologists, pathologists) to work with a global project that attempts to inventory the barcodes of biodiversity associated with crops globally? It will not be easy, but the iBOL partners have already barcoded more than 100,000 species. In comparison, the CABI Crop Protection Compendium contains nearly 4000 full data sheets, and nearly 40,000 basic datasheets – covering crops, pests (including weeds and diseases) and natural enemies. To be able to identify the 4000 species prioritized with full datasheets by barcoding would be a significant step towards a global identification capacity, but once the 40,000 species with basic datasheets are completed, most identifications of biodiversity associated with agriculture could be automated.

BioNET has already worked with the barcoding initiative (Rassmann and Smith, 2009), but should further consider the implications of the barcoding initiative and how BioNET's network structure could pilot and streamline the task of making barcoding available to facilitate identifications of pests and natural enemies in developing countries. It could then be optional whether developing countries develop their own taxonomic expertise to resolve the questions thrown up about pest species by barcoding or encourage sponsors to fund this at centres of excellence anywhere in the world.

It might be concluded that developing countries will not need their own identification capacity, just the ability to extract a DNA barcode, and on one level this would be true. However, for the foreseeable future, the improved quality of identifications and the recognition of previously unrecognized species will continue to generate demands for taxonomic input in support of agriculture in developing countries, and the BioNET network will be needed, for example, to facilitate access to experts worldwide or facilitate local capacity building and cooperation.

5.3 Rapid response to identify (suspected) new pests

In a way, this should not be a justification for BioNET, inasmuch as a way will be found to identify new pests if they are serious. Nevertheless, the combination of Plantwise and BioNET should ensure that new pests are picked up as early as possible and identifications made at the appropriate level. Early identification of new/spreading pests is seen as a key benefit of Plantwise. The BioNET network can ensure that early detection leads to early identification.

Rapid identification of SPS interceptions are another issue. Here, if a port of entry inspector has to decide what to do about an interception that is contaminated by an unidentified organism, then rapid identification is essential. This is critical for internationally traded food, but not so critical from a food security perspective, except when the contaminated consignment is food aid. Such consignments have been implicated in the introduction of invasive alien species, which have had a huge negative impact on local agriculture (Murphy and Cheesman, 2006) and need to be checked rigorously but rapidly to minimize such introductions.

5.4 Underpinning IPM

It is widely recognized that in most situations IPM should be based on what is already present/necessary – agronomic practice, seed selection and indigenous natural enemies. Interventions need to planned on an at-need basis, so as to minimize the effect on the beneficial impact of existing practice and natural enemies. A great deal can be managed on the basis of natural enemy diagnosis, and farmers will not go beyond this. However, to do this, research or reliable information from the literature needs to have established what the groups of natural enemies are, what their feeding niche is, what their impact is, etc. At some stage identifications, and often taxonomic research, is needed to establish these and report them in such a way that the information is available and usable for others; this requires names.

For example, it is not useful to encourage a group of natural enemies that feed exclusively on aphids if your key pest problem is a stem borer. The roles of the different groups of beneficials need to be understood to give appropriate advice to farmers. This hinges on putting names to what is in the farmer's fields, whether at the family, genus or species level.

However, these are not ends in their own right, rather support to pest management partners. Therefore, BioNET needs to partner with a global pest management initiative that can be shown to have direct impact on the MDGs.

Conclusions

1. Taxonomic support to agriculture needs to focus on meeting the key demands for identifications and products based on identifications. This will involve partnering initiatives addressing pest management which will target aspects of the MDGs.
2. The scope to address agriculture's needs through regional diagnostic networks and new technology such as DNA barcoding needs to be assessed for developing countries.

Acknowledgements

My thanks to those whom I have consulted in preparing the report on which this CABI Working Paper is based, who have shared information or given me the benefit of their advice: Phil Abrahams (CABI Plantwise), Denis Blight (Australia), Eric Boa (CABI Plantwise), Paul Bridge (CABI Bioservices), Fernando Consoli (Universidade de São Paulo, Brazil), Julie Flood (CABI E-UK), Heong K.L. (IRRI), Mark Holderness (GFAR), Paul Kirk (CABI/Kew Herbarium), Li Hongmei (CABI East and Southeast Asia – China), K.Y. Lum (CABI South-East Asia and BioNET-ASEANET), Peter G. Mason (Agriculture & Agrifood Canada), Sean Murphy (CABI E-UK), Patricia Neenan (CABI – North America), M. Alma Solis (USDA-SEL), Carmen Thöenissen (SDC), Janny Vos (CABI - Europe), Jeff Waage (London International Development Centre, UK), and Roberto Antonio Zucchi (Universidade de São Paulo, Brazil) – naturally, the use to which I have put this information is my responsibility. I thank Dan Janzen (University of Pennsylvania, USA) and John Burns (Smithsonian Institute) who have kept me informed regarding their inventory and barcoding work for many years.

I particularly thank Richard Smith, Director BioNET Secretariat, who gave me the benefit of his advice and knowledge of BioNET, which significantly improved aspects of the original report.

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Acronyms

ACIAR	Australian Centre for International Agricultural Research
AGORA	Access to Global Online Research in Agriculture
AGP	FAO's Plant Production and Protection Division
APHIS	Animal and Plant Health Inspection Service of USDA
ARD	agricultural research and development
ARDN	ASEAN Regional Diagnostic Network
ARS	Agricultural Research Service of USDA
ASEAN	Association of Southeast Asian Nations
ASEANET	South-east Asian LOOP of BioNET
BioNET	BioNET INTERNATIONAL
BOLD	Barcode of Life Data Systems
CAAS	Chinese Academy of Agricultural Sciences
CABI E-UK	CABI Europe – UK
CABI	CAB International
CARINET	Caribbean LOOP of BioNET
CAS	Chinese Academy of Sciences
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Costa Rica)
CBD	Convention on Biological Diversity
CBOL	Consortium for the Barcode of Life
CGIAR	Consultative Group for International Agricultural Research
CIRAD	Centre de Coopération internationale en Recherche agronomique pour le Développement (France)
CPC	Crop Protection Compendium (CABI)
DFID	Department for International Development (UK)
FAO	Food and Agriculture Organization of the United Nations
FSC	Forest Stewardship Council
GBIF	Global Biodiversity Information Forum
GFAR	Global Forum for Agricultural Research
Global Hort	Global Horticulture Initiative
GRIN	Germplasm Resources Information Network
GRiSP	global rice science partnership (CGIAR)
GTI	Global Taxonomy Initiative
GTPF	Global Taxonomy Partnership Fund
iBOL	International Barcode of Life
IITA	International Institute of Tropical Agriculture
INBAR	International Network for Bamboo and Rattan

IPGRI	International Plant Genetic Resources Institute (now Bioversity International)
IPM	integrated pest management
IPPC	International Plant Protection Convention
IRRI	International Rice Research Institute
ISPM(s)	International Standards for Phytosanitary Measures
ITPGR	International Treaty for Plant Genetic Resources
ITS	internal transcribed spacer (DNA sequence)
LOOP(s)	Locally Owned and Operated Partnership(s) of BioNET
MDG(s)	Millennium Development Goal(s)
NARS	national agricultural research systems
NPPO(s)	national plant protection organizations
PlantNET	Plant Information Network System of the Botanic Gardens (Australia)
RPPO(s)	regional plant protection organization(s)
SAN	Sustainable Agriculture Network
SDC	Swiss Agency for Development Cooperation
SEL	Systematic Entomology Laboratory of USDA
SPS	sanitary and phytosanitary
USDA	United States Department of Agriculture
WAFRINET	West African LOOP of BioNET

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