GISP

The Global Invasive Species Programme

Invasive species management –

what taxonomic support is needed?

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GISP an international partnership dedicated to tackling the global threat of invasive species.

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GISP's mission is to conserve biodiversity and sustain human livelihoods by minimising the spread and impact of invasive alien species.

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Acronyms and abbreviations

BioNET-ASEANET	The Southeast Asian taxonomy partnership
CABI	CAB International
CBD	Convention on Biological Diversity
COP	Conference of the Parties (of the CBD)
GBIF	Global Biodiversity Information Facility
GISD	Global Invasive Species Database
GISIN	Global Invasive Species Information Network
GISP	Global Invasive Species Programme
GRIS	Global Register of Invasive Species (of GISD)
GTI	Global Taxonomy Initiative
I3N	Invasives Information Network of IABIN
IABIN	Inter-American Biodiversity Information Network
IPPC	International Plant Protection Convention
ISPM	International Standard For Phytosanitary Measures
ITIS	Integrated Taxonomic Information System
IUCN	International Union for Conservation of Nature
LOOP	Locally Owned and Operated Partnerships (of BIONET)
SPS	Sanitary and Phytosanitary measures of the WTO
WTO	World Trade Organization

Contents

Summary

This is the first global level assessment of the taxonomic support needed to manage invasive alien species.

The results of this assessment confirm and help explain why taxonomy is a critical tool for combating the threats from invasives. Results and recommendations are based on analyses of selected documentary and expert sources. They provide a reference and framework for action for agencies and authorities responsible for invasives management; for taxonomic institutions; and for networks, funders, coordinating and policy bodies.

Three broad types of need were identified:

I end-users: taxonomic outputs and service's needed by non-taxonomists for invasives management

II within institutions: taxonomic capacity, information resources and prioritisation within institutions in order to deliver those services

III across institutions: activities and prioritisation of needs at a level above individual institutions, to enable them to implement the changes required.

The main needs are:

- lists of names of invasives, including taxonomic names, synonyms and vernacular names, to be created, maintained and made available
- pathway and distribution mapping and modelling, and threat assessment, to be facilitated by specimen- and observation-based data on invasives captured and made available through a global system
- modelling tools to be developed and made available
- sustainable identification services for invasives at appropriate geographical levels facilitated and supported
- identification tools in appropriate format and language, including high numbers of images, created and their availability improved
- reference collections established and maintained at appropriate institutions nationally or regionally
- improvement of understanding of taxonomic needs associated with management of invasives by all parties
- access to taxonomic information to be considered at the planning stage of management and control programmes and measures to ensure this built into plans.

Innovation in delivering taxonomy to end-users is essential to respond to the threat posed by invasives with necessary urgency, making best use of available capacities. Much can be achieved by promoting, mobilising and packaging existing information according to user needs.

But such actions are only a part of the solution. There is a near absence of taxonomic capacity to support invasives management in most (especially developing) countries and a critical decline of expertise even in Europe. Training of the taxonomic experts needed to create products for end-users is of great importance. Institutions and funders need to recognise that invasives are a priority and that generating products and information needed to confront invasives are important outputs of taxonomic institutions.

Recommendations to enable these needs to be met are directed to:

- phytosanitary and biosecurity authorities, conservation agencies, etc. that use or would directly benefit from taxonomic support in their invasives management work
- national museums
- biological collections in universities and research and extension facilities, etc. that are the sources of existing and potential taxonomic support
- information and technical cooperation networks and initiatives
- policy instruments concerned with invasives as pests, threats to biodiversity or disease introductions
- funders of invasives management programmes and taxonomy
- ministries responsible for environmental protection and biosecurity.

All have roles in creating an enabling environment for the delivery of taxonomic support. End-users can accelerate the provision of taxonomic support through best practice in use of names, management of data and specimens, commissioning of identification aids and species distribution modelling, etc.

Taxonomic institutions need to increase their support for invasive management by, for example, creating a verified list of invasives names, the extension of their invasives reference collections, taxonomic and parataxonomic training, digitisation and sharing online of data from relevant collections and the adoption of new molecular and digital technologies for invasives identification.

Supra-institutional, coordinated and strategic actions will create the necessary financial and technical environment for taxonomic institutions to increase their supply of taxonomic products and services significantly. For example: international adoption of protocols for invasives identifications will raise the standard of taxonomic support and increase the success rates of invasives management.

Addressing the needs identified in this assessment is achievable and affordable. Much relevant work is underway and could be greatly accelerated through coordinated actions leading to a fruitful environment which empowers taxonomists to produce the required tools and resources.

Recommendations

Taxonomic need	Recommendations to:	Recommendations	
I. Taxonomic outputs and services needed by non-taxonomists (end-users) to improve the prediction, detection, monitoring and control of invasives.	National and regional sanitary and phytosanitary regulatory agencies; biosecurity agencies; conservation management agencies; quarantine services; national park management authorities…	**1.1**	Assess in detail and publicise taxonomic needs, blocks and barriers in taxonomic information and expertise.
		1.2	Ensure proposals and applications for funding include required taxonomic support.
		1.3	Deposit voucher specimens from intercepts and other invasives management activities in taxonomic institutions, to provide a check on original identifications and facilitate future identifications.
		1.4	Commission and use identification services able to provide rapid, quality-assured responses on demand.
		1.5	Commission and make freely available identification aids in appropriate formats (online, computer-based and hard copy).
		1.6	Ensure data from specimens from intercepts and other invasives management are captured digitally and made openly available.
		1.7	Speed up the creation of occurrence maps for invasives by linking data on new observations to mapping tools.
		1.8	Commission/use baseline information on native species distributions conserved with specimens and observations as a basis for identifying non-native components and predicting invasive threats.
		1.9	Commission/use mapping and predictive tools, and encourage necessary extensions to their functionality. These tools use observational and specimen-based data as a basis for targeting invasives management effort, risk assessment and planning.
		1.10	Ensure relevant staff receive training in appropriate level of taxonomic expertise and knowledge.
		1.11	Ensure reliable and timely inter-regional and inter-institutional communication through use of up-to-date species names, sharing synonyms and vernacular names where possible.

Taxonomic need	Recommendations to:	Recommendations
II. Taxonomic capacity, information resources and within-institution prioritisation required if the taxonomic sector is to deliver the required outputs and services.	National museums; biological collections in universities and research and extension facilities …	**2.1** Participate in needs and capacity assessments for taxonomy in the context of invasives.
		2.2 Recognise the importance of providing identifications, research outputs and other information on invasives, and seek ways of increasing this output.
		2.3 Establish and maintain reference collections, including voucher material, to support identification services.
		2.4 Seek means of delivering identifications in a time- and cost-effective manner, minimising the cost to inquirers.
		2.5 Ensure sufficient staff time/posts are available to address invasives issues, including both inquiries and research.
		2.6 Investigate means of accelerating and improving the identification process by experts and non-experts, including by: • delivering identification aids in response to user-defined issues, in appropriate formats (high image content; accessible terminology; accessible via the internet and to those with no or poor internet access; accessible in relevant languages; include native species that might be confused with invasives) • agreeing standardisation of global-level descriptors, and investigating their use to compile globally valid identification aids with a focus on invasive species and their relatives • making available, via a global information system, digital images of specimens at all life stages and, where appropriate, of habitat impact or damage to other organisms • developing new methodologies, for example DNA barcoding.
		2.7 Increase the rate of digitisation of data from specimens of invasives.
		2.8 Further develop models to analyse occurrence data and incorporate analytical tools into relevant data portals.
		2.9 Create and maintain, in partnership, a managed list of names of invasives, bearing in mind the different status of species in different areas of their distribution, and the geographical scale of the invasiveness problem. Include alternative taxonomic views, synonyms and vernacular names.
		2.10 Support and deliver training to non-taxonomists and others on taxonomy of, and in the context of, invasives.
		2.11 Strengthen efforts to inform and educate other biologists about the significance of synonymies, alternative classifications and name changes.

Taxonomic need	Recommendations to:	Recommendations
III. Supra-institutional activities necessary to promote prioritisation and application of taxonomy to tackle invasives.	International networks and initiatives; international and national policy instruments concerned with invasives as pests, threats to biodiversity or disease introductions; funders of invasives management programmes and taxonomy; ministries responsible for environmental protection and biosecurity...	**3.1** Ensure national and regional taxonomic needs and capacity assessments are undertaken comprehensively to provide the necessary basis for action and prioritising of resources. Capacity assessments need to define what capacity exists to meet defined needs; what new capacity in expertise, collections and information systems is required; and how it can best be developed and sustained.
		3.2 Develop a strategy for delivering, funding and sustaining the national, regional and global levels of taxonomic support needed for invasives management, including staffing, collections and infrastructure.
		3.3 Funding bodies supporting invasives management should ensure that proposals include: • reasonable plans, with supporting evidence, to ensure the availability of required taxonomic information and support • resources for taxonomic work and capacity-building where necessary for the immediate and ongoing success of invasives management interventions.
		3.4 Make accessible training and capacity-building systems needed to sustain identification services to all countries.
		3.5 Clarify and assign responsibilities for delivering quality-assured identification services nationally, regionally and globally, with guarantees of response times included, and develop an economic model to ensure sustainability.
		3.6 Develop protocols (including precision and rapidity) for identifications of invasives, perhaps building on relevant IPPC standards already in place and being developed.
		3.7 Taxonomic institutions and their funders should recognise the publication of identification aids, name information, etc. as being of high value, and develop institutional and individual performance indicators to facilitate this.
		3.8 Support development of identification tools through facilitating capture of expert taxonomic knowledge in digital systems and development of appropriate informatics tools.
		3.9 Compile and illustrate glossaries of terms used in identification tools.
		3.10 Support development of novel methods of identification of invasives.
		3.11 Develop and maintain a freely available database of identification tools.
		3.12 Develop standard protocols for specimen digitisation, and agree priorities across institutions.
		3.13 Regulatory and management authorities should make data, including intercept data, openly available.
		3.14 Agree a target date for digitising all new and existing vouchered invasives specimens, and facilitate meeting this target.
		3.15 Form an international group to correlate and manage updated taxonomic nomenclature for all invasive species, following the call in the GISP Global Strategy on Invasive Alien Species.
		3.16 Establish standards for databases of names and allied information, taking into account the needs of invasives management, IPPC, WTO–SPS and quarantine officials, building on current work.
		3.17 Support enhancement of communication and awareness-building efforts so that: • more taxonomists understand how they can contribute to invasives management • invasives managers and policy-makers understand better how taxonomic support can assist them. This might involve multi-sector forums, stakeholder meetings, literature and other means.

1 Introduction

Invasive alien species are non-native species that threaten, or have the potential to threaten, the environment, health or economic production. They are widely regarded as the second-greatest threat to biodiversity globally (second only to habitat loss).
(Definition adapted from CABI and GISP Phase II implementation plan.)

Invasive alien species (invasives) threaten our well-being and the natural world in a multitude of ways. The challenges of managing invasives are urgent, and are growing in scale with globalisation and climate change. The Millennium Ecosystem Assessment classified invasives along with climate change as the two drivers damaging ecosystem function and human well-being that are the most difficult to reverse (Hassan *et al.*, 2005: 96). Their impacts extend from biodiversity conservation and sustainable use to agricultural productivity, crop storage, fisheries, forestry, trade, health, biosafety and beyond. The annual cost to the USA of invasive species has been estimated at $137 billion (Pimentel *et al.*, 2000), a figure considered to be conservative by the Millennium Ecosystem Assessment (Carpenter *et al.*, 2005: 401). The problem is global, and managing it requires international as well as local action.

Unless greater *management steps* are taken to prevent harmful introductions that accompany increased *trade*, invasive species will cause increased *ecological changes* and losses of ecosystem services in all scenarios.
(Millennium Ecosystem Assessment: Carpenter *et al.*, 2005: 378.)

Many aspects of invasives management depend on, or benefit significantly from, taxonomic support – the expertise and information needed reliably to recognise, name and identify species. To quote from the Comprehensive review of activities for the prevention, early detection, eradication and control of invasive alien species (CBD, 2001a): 'Basic biological knowledge (e.g. taxonomy) must be combined with evolving technologies and tools for [invasives] prevention and management. These measures rely heavily on the existence of reliable and taxonomically comprehensive data.' But despite acknowledgement of the importance of taxonomy by many policies, strategies and papers concerned with combating invasives, there is little clarity concerning the scope and application of the taxonomic knowledge required. Because the taxonomic needs of invasives management have not been defined, the nature of the required taxonomic support, and where it is critical to invasives management, have not been investigated.

How can greater taxonomic support for invasives management be delivered? Taxonomy is a highly specialised discipline with expertise widely dispersed worldwide. Information and specialists are dispersed not only geographically, but also across institutions from a number of sectors, including agriculture, natural history, health, biosecurity and education.

A major challenge is mobilising a prioritised, coordinated, international response from taxonomists and their institutions, and ensuring the necessary information and tools reach those individuals and institutions engaged in invasives management. Before meeting this challenge, greater clarity is needed as to the nature of the taxonomic needs for invasives management.

The ubiquity of invasives across human activity has led to analogous work in different fields. The issues involved in biosecurity, plant pests and pathogens, weed control, and the spread of diseases and disease vectors across the planet are, in many respects, the same as those of invasives. But these different areas have spawned distinct terminologies and regulatory frameworks. Part of today's challenge is achieving effective regulatory and technical cooperation across these different areas, taking into account their individual needs and constraints. For taxonomy, this may mean greater cooperation with other disciplines, such as ecology and biocontrol. It also means improved cooperation with the user communities, responding to their needs whether they originate from agriculture, biodiversity conservation, health, trade or biosecurity authorities.

Purpose of the assessment

This is the first global assessment of taxonomic needs relating to invasives management. It uses selected documentary and expert sources to characterise the types of taxonomic information and support that are generally unavailable.

The purpose of this assessment is to identify the deliverables needed by invasives managers, and the institutional and supra-institutional actions and changes that are necessary to ensure these are created and continue to be delivered to meet threats posed by invasives as they emerge. It is anticipated that with this assessment, the taxonomic sector will be better positioned to contribute to the prediction, detection, monitoring, prevention and control of invasives.

To date, the identification of needs for taxonomic institutions in order to support invasives management has been surprisingly weak and fragmentary. The only attempt at an overview of taxonomy and invasives, the Davis Declaration (Anon., 2001), has had limited circulation. Moreover, the Davis Declaration focused on 'information hubs' as a proposed solution to delivering taxonomic expertise and support, rather than detailing what that support would comprise, and what needs were to be met. The 2007 needs assessment

by the Global Invasive Species Information Network (GISIN) provides some information on taxonomic needs, but focuses on an information system rather than on the complete spectrum of activities related to invasives. Many statements concerning requirements for taxonomic support to combat invasives in the various documents consulted are unspecific, for example speaking of 'capacity-building' without clarifying what deliverables are expected from that capacity. They are also widely scattered in publications that lack impact in the scientific community, are geographically specific, are directed towards informatics rather than taxonomic information issues, or consider problems of a single sector such as agriculture. In contrast, this assessment presents taxonomic institutions and international initiatives with a basis for a more coordinated, prioritised international taxonomic response across the various sectors engaged in managing invasives.

Needs assessments at national, regional and global levels have been called for by the Convention on Biological Diversity (CBD) as the first step in implementing its Global Taxonomy Initiative (GTI). 'Needs' in this context are for benefits arising from taxonomy – outputs such as keys, identifications, distributional data and species diagnoses, the absence of which is proving an impediment to implementing the CBD. Needs assessments are distinct from capacity assessments, which refer to the capacity to undertake taxonomic work, typically without linking this to particular deliverables. This assessment will be a source for strategy and policy development under the CBD.

The beneficiaries, target organisations and wider stakeholders in the assessment are as follows.

- Beneficiaries: principally agencies and authorities, such as quarantine, parks managers and plant protection organisations, charged with detecting and controlling threats posed by invasives. Such authorities frequently note the inadequacy of taxonomic support for their work.
- Target organisations: the authors anticipate that the assessment will:
  - be a resource for priority-setting by national museums, collections, other taxonomic institutions interested in delivering policy-relevant research, species information, identification tools and other outputs for (and in many cases with) the beneficiaries listed above
  - be a resource for priority-setting by national catalyse and prioritise relevant taxonomic research, training, product development and capacity-building
  - be a resource for priority-setting by national be used to further and direct technical cooperation by international initiatives as a counter to the weakening and increasingly fragmented taxonomic capacity.
- Stakeholders: international and national policy instruments and decision-makers, and conventions concerned with invasives as pests, threats to biodiversity or disease introductions, in particular the CBD, the International Plant Protection Convention (IPPC), Sanitary and Phytosanitary Agreement of the World Trade Organization (WTO–SPS)and the Ballast Water Convention.

Figure 1 The relationship between beneficiaries, target organisations and wider stakeholders

Management of invasives requires action by a wide range of stakeholders, at all levels and across professional and other boundaries. Generally, each type of management action, whether raising awareness among farmers of beneficial insects that control invasive pests, establishing legal and regulatory authorities, or setting international strategy draws on some taxonomic information or support, even if this is not immediately obvious. It is anticipated that this assessment will help sensitise invasives programmes to the benefits of integrating taxonomic activities into their objectives where this is not yet the case.

Global context

Global importance

The Millennium Ecosystem Assessment, probably the most significant stock-take of the health of the planet, identified invasives as one of the five main drivers directly affecting ecosystem processes and human well-being. The impact of

invasives on most ecosystems was found to be increasing, often rapidly, with growing trade a major factor (Millennium Ecosystem Assessment, 2005a: 16, Fig. 13). The impact on marine ecosystems, species and water quality of invasives associated with shipping is a particular concern.

Habitat change

One factor leading to greater impacts of invasives is habitat fragmentation or disturbance. Disturbed ecosystems are thought to be less resistant to the spread of invasive human pathogens (Millennium Ecosystem Assessment, 2005b: 28). Climate change and other causes of ecosystem disturbance also create well documented opportunities for other types of invasives, such as weeds. For example, Hurricane Katrina in 2005 has been followed by the establishment of *Triadica sebifera*, the Chinese tallow tree, over wide areas of affected coastal areas in southern USA (Sheikh, 2005).

> The general impact of *climate change* is that weedy species (those that are highly mobile and can establish quickly) and *invasive species* will have advantage over others
> (Millennium Ecosystem Assessment: Carpenter *et al.*, 2005: 202.)

Invasive alien species and islands

The dramatic impact of invasives on islands is often highlighted. There is good reason: extinction rates are higher on islands than in continental areas, and invasives are the cause of most extinctions and population declines (Millennium Ecosystem Assessment, 2005b: 33). But our knowledge of the occurrence and impact of invasives on islands is surprisingly limited. A recent review of invasives in British Overseas Territories (Varnham, 2006), most of which are islands, found information on species occurrence to be highly variable and very dependent on the date of the most recent survey.

Biosecurity

Biosecurity is an increasingly prominent aspect of the global context. Biosecurity at the national level is concerned with species that pose a risk to human or animal health, but which are not necessarily alien. In cases where invasives are considered a threat to national-level biosecurity, there will be a need for taxonomic information to support measures to combat them.

Biosecurity at the international level seeks both to prevent the transmission of diseases and pathogens that may be harmful to humans and animals across international boundaries, and to prevent the deliberate theft or diversion of deadly pathogens and toxins for criminal purposes.

Responsibility for the identification of such pathogens or toxins is shared between agricultural research centres, specialist laboratories linked to national and international security services, and taxonomic research institutes.

However, the World Summit on Sustainable Development's plan of implementation makes no reference to biosecurity, and in the context of this assessment biosecurity has not been dealt with as a separate issue.

Policy context

There are over 40 international policy instruments, some binding, that address various problems related to invasives (McNeely *et al.*, 2001). Of these, the CBD is the most comprehensive in scope. The IPPC and the WTO–SPS have more limited scope, but as trade instruments they have great economic and political significance. The Cartagena Protocol focuses on biosafety. The overlapping mandates of these organisations are depicted in Figure 2 (page 8). The Ballast Water Convention has recently agreed to address a major vector of marine invasives: international shipping.

Convention on Biological Diversity

For the 189 countries that are Parties to the CBD, invasives were recognised as a major threat to biodiversity from the outset. Article 8(h) of the Convention calls for its Parties to 'prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species'. The importance placed on this Article is evident from the status of invasives as a 'cross-cutting issue': one that, like taxonomy, must be considered when implementing each aspect of the CBD.

At present, the most important objective of the CBD is the '2010 target': to achieve by 2010 a significant reduction in the current rate of biodiversity loss at global, regional and national levels, as a contribution to poverty alleviation and to the benefit of all life on Earth. 'Threats to biodiversity' has been selected as a focal area for indicator development, with Goal 6 setting two challenging targets for invasives, both of which demand taxonomic inputs (CBD, 2004d, 2006c).

Convention on Biological Diversity 2010, Goal 6: Control threats from invasive alien species

Target 6.1: Pathways for major potential alien invasive species controlled.

Target 6.2: Management plans in place for major alien species that threaten ecosystems, habitats or species.

At its sixth meeting, the Conference of Parties (COP) to the CBD agreed 15 guiding principles for the prevention, introduction and mitigation of impacts of invasives (contested

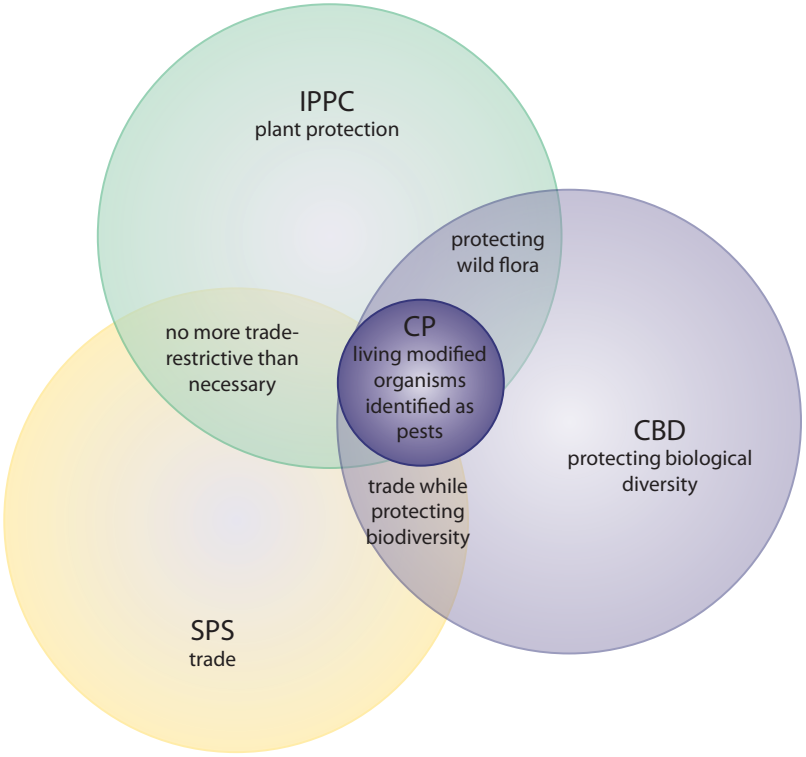

Figure 2 Overlapping mandates of the IPPC, WTO–SPS, CBD and Cartagena Protocol (CP) (source: Breithaupt & Nowell, 2006: slide 11)

by Australia; CBD, 2002b, Annex). The importance of taxonomy to a number of principles is evident, for example Principle 5 on Research and monitoring.

Convention on Biological Diversity, Guiding principles for the prevention, introduction and mitigation of invasives alien species (CBD, 2002, Annex)

Principle 5: Research and monitoring

In order to develop an adequate knowledge base to address the problem, it is important that States undertake research on and monitoring of invasive alien species, as appropriate. These efforts should attempt to include a baseline taxonomic study of biodiversity. In addition to these data, monitoring is most important to early detection of new invasive alien species. Monitoring should include both targeted and general surveys, and benefit from the involvement of other sectors, including local communities. Research on an invasive alien species should include a thorough identification of the invasive species and should document: (a) the history and ecology of invasion (origin, pathways and time-period); (b) the biological characteristics of the invasive alien species; and (c) the associated impacts at the ecosystem, species and genetic level and also social and economic impacts, and how they change over time.

At the eighth COP in 2006, a planned activity for invasives was agreed for the GTI, including a set of outputs and timelines (Table 1).

Following CBD COP Decisions VI/23, VII/13 and VIII/27, joint work plans are under development by the Global Invasive Species Programme (GISP) in an effort to avoid duplication of effort and foster cooperation between international agencies engaged in invasives management. Workshops convened to help design the work plan identified taxonomy as one of the priority areas.

International Plant Protection Convention (IPPC)

In existence since 1950, the IPPC is implemented by its contracting parties via national and regional plant protection organisations. The objective of the Convention is to prevent the introduction and spread of pests and pathogens affecting both agricultural and wild plants. There is a significant overlap of objectives with the CBD (Figure 2) and the synergies between the conventions are recognised, in part, through a joint work plan. Recently, at the eighth COP of the CBD, a decision was taken to include taxonomy in this joint work plan (CBD, 2006b).

World Trade Organization Sanitary and Phytosanitary Agreement (WTO–SPS)

The SPS Agreement deals with specific issues concerning human, animal and plant health, and lays out rules for

Table 1 Taxonomic outputs for invasives management agreed in Convention on Biological Diversity Conference of the Parties Decision VIII/3, 2006	
Outputs	Target date
Databases of invasives and occurrences of invasions developed and/or expanded, and made widely available	2008
Working identification keys for known invasives associated with main invasion pathways produced and disseminated	2009
Working lists of organisms in areas that are exposed or susceptible to main invasion pathways produced and utilised by local monitoring authorities	2009

coordinating policies. Sanitary and phytosanitary measures can take many forms, including requiring products to come from a disease-free area, inspection of products, or specific treatment of products. To improve the efficiency of the SPS Agreement, international standards are used in its operation: those of the IPPC for plants, and of the World Organisation for Animal Health for animals. Taxonomic support is needed to implement a number of standards, so exporting countries need access to taxonomic expertise if they are to be able to trade in agricultural and other biological commodities. In addition, importing countries need to draw on taxonomic information to predict potential pest distributions as part of import risk analyses.

Ballast Water Convention

The International Convention for the Control and Management of Ships' Ballast Water and Sediments states (Article 2, General Obligations):

> 'Parties undertake to give full and complete effect to the provisions of the Convention and the Annex in order to prevent, minimize and ultimately eliminate the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments.'

> 'Parties are given the right to take, individually or jointly with other Parties, more stringent measures with respect to the prevention, reduction or elimination of the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments, consistent with international law. Parties should ensure that ballast water management practices do not cause greater harm than they prevent to their environment, human health, property or resources, or those of other States.'

With support from the United Nations Development Programme and the Global Environment Facility, the Convention set up the GloBallast Programme to assist developing countries in implementing effective measures to control the introduction of foreign marine species.

Taxonomy and invasive species

The nature of taxonomy

Taxonomy is the science of naming and classifying organisms. With approximately 1.78 million different species so far distinguished and named, and estimates of at least 15 million species in total, the taxonomic task is considerable. Invasive species are by no means all known and named, and identification aids are not available for many of them.

The most fundamental output of taxonomy is the names themselves, both for previously known species and for species new to science. Lists of names of that are accurate, up-to-date, widely understood and internationally applied are perhaps the most far-reaching contribution of taxonomy to invasives management. With a name comes the ability to share information relating to invasive or potentially invasive species. Sharing information is of fundamental importance because invasives management is an international and intersectoral endeavour, relying on access to relevant information from different disciplines, and often from different countries. Because names applied to species can and do change (for example at a rate of 1% per year in Fishbase, one of the most developed species databases available), it is important to ensure names used are those in current scientific use, and can be linked to other names that have been applied in the past (see 'The nature of names', page 11). Further problems can arise when there are differences in the naming of species between one country or region and another. This can lead to species being misidentified, and to preventive or management action being misdirected or delayed (see 'Resolving the Southeast Asian Termite Paradox' page 23). Similarly, inconsistent nomenclature in the legislation of different countries can lead to confusion, to action not being taken, or to action being taken unnecessarily against unthreatening species (Anon., 2005). Provision of names is basic to almost all taxonomic products, and explicit in some (for example, lists of species or descriptions of new species) (Figure 3).

Taxonomists use a wide variety of tools to create the names for organisms. Pre-eminent among these are vast collections of specimens and major libraries. The specimens – which in total amount to several billion, held in collections globally – are all associated with data on when and where they were collected.

Taxonomists, depending on their institutional mandate, may orient their work towards research outputs; services and products needed by end-users outside taxonomy; or a combination of both. As a result, the outputs of taxonomy can be tailored to specific scientific, technical and regulatory needs (Figure 3). The 'default' audience for much taxonomic work is taxonomists themselves, so the level of information, language and presentation used in taxonomic publications is typically not appropriate for non-specialists or those not undertaking taxonomic research. This is an issue in invasives management, as many of the users of taxonomic information in this context are non-taxonomists.

Taxonomy in the context of invasives management

It may be helpful to consider how the results of this assessment relate to the central stages in invasives management as identified in the *GISP Toolkit* (Figure 4, page 28). Discussion of the results and scope for taxonomic support in each of the stages of management can be found in section 5 (page 33).

**Spiralling whitefly – *Aleurodicus dispersus*
1% of species names change each year. Enforcement of legal regulations governing invasives requires certainty about the specimen in hand.**
Photo: G Goergen, IITA ©

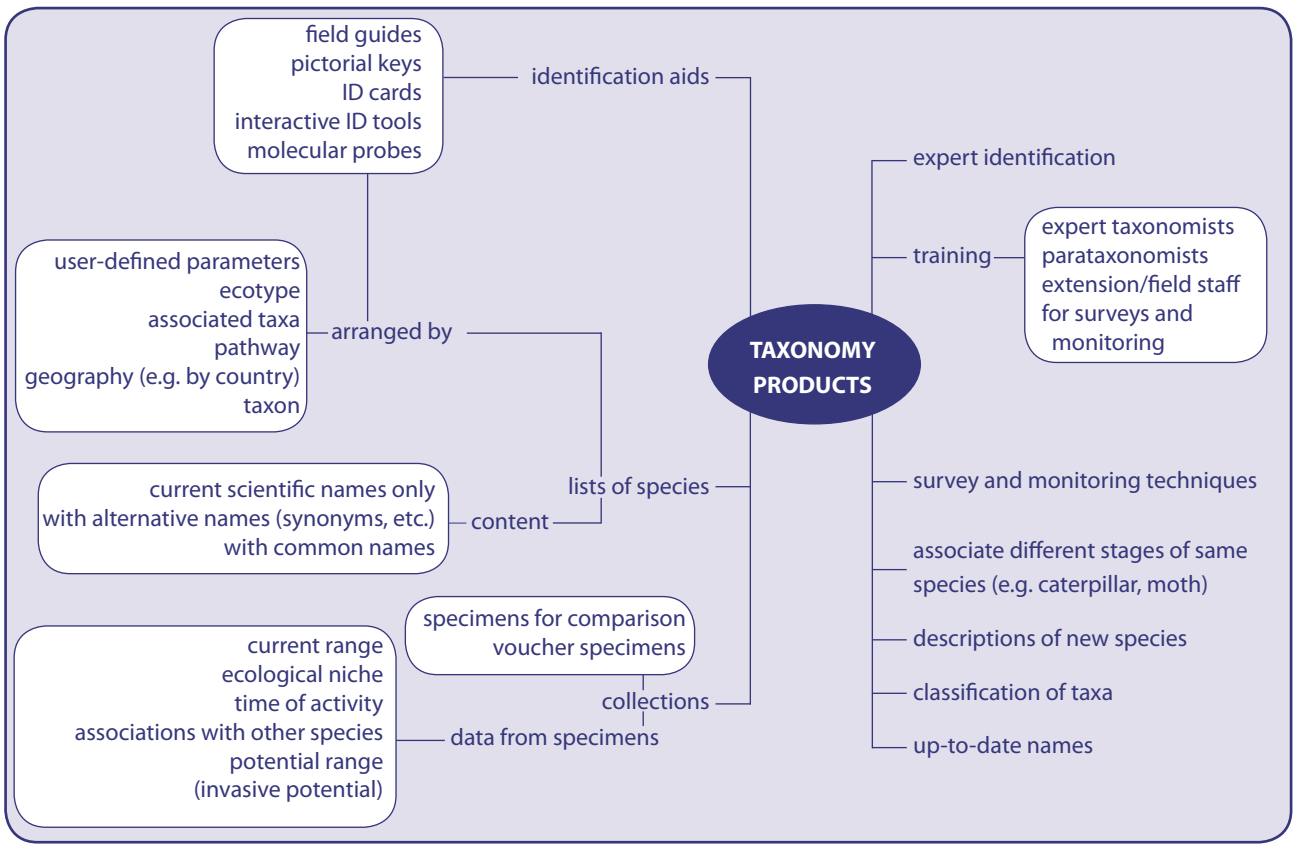

Figure 3 Products of taxonomy

The nature of names

Species of animals, plants and microorganisms all are given names by taxonomists. Each one will have a name in two parts: a genus and a species name in combination. Ideally, every species will have only one combination. However, as more is understood about relationships of species to each other, species are moved between genera and the combinations change. For example, the Mexican cutworm moth now known as *Scoleocampa mochisa* was originally known as *Saccharophagos mochisa*. Both combinations refer to the same species. Sometimes taxonomists working independently inadvertently describe a species more than once, so that it has two names. When this is discovered, the two names are 'synonymised', and the species name published first is used. For example, garlic mustard, invasive in parts of the USA, has the scientific name *Alliaria petiolata*, but was also independently described as *Alliaria officinalis*; the latter is a synonym of the former. Although a modern taxonomic product would provide the current name of these, there can be major delays in such information reaching all parts of the world and in publications being updated, so some institutions will continue to use a name that elsewhere is treated as a synonym or no longer used. Such differences are often at national level, as each country will take note of advice from its own experts.

In addition to being synonymised, species are sometimes split, when it is recognised that a so-called 'species' actually includes more than one biological species. In such a case, it may not be clear which published and other records refer to which of the newly distinguished species. Also, species may be misidentified and observations linked to the wrong name. In such cases, it is important to know which concept of the species was being used.

Another problem is that common names are often used. One might hope that there is a one-to-one relationship between common names and scientific names, but this is often not the case – a common name may apply to more than one species, or there may be more than one common name for a single species.

All this means that a 'name', when used in invasives management, needs to be up-to-date and recorded with all previous name combinations, all synonyms and common names, with an indication of the place of origin of each common name and its language.

2 Approach and methodology

The nature of a needs assessment

The distinction between needs assessment and capacity assessment is discussed above (page 6). A number of taxonomic assessments have been carried out around the world, but many are weighted towards capacity assessment, with suggestions made regarding the potential uses of the taxonomic information produced. The greater the proportion of users involved, as distinct from taxonomists, the more the assessment will be a true reflection of user needs, and thus a call for delivery of appropriate products. This is not to say that capacity statements are not required; without such assessments it can be impossible to identify the true resource requirements.

The methodology of the current assessment is based on the recent UK Taxonomic Needs Assessment (Taylor, 2006), which focuses on the needs of conservation. Other examples where the users are the primary focus of consultation include the Southern African survey of needs of the users of botanical information (Steenkamp & Smith, 2002), and the taxonomic needs assessment for plant pathogenic organisms in Southeast Asia (Evans *et al.*, 2002).

The current assessment is fundamentally a consultation within the invasives policy and management sectors to identify the taxonomic deliverables needed. The institutional and supra-institutional actions and changes necessary to ensure these deliverables are created are discussed.

The assessment

Scope

For this assessment, taxonomic needs are articulated by personnel in the invasives sector, ranging from individual quarantine officers and control staff to international organisations and UN conventions. The assessment focuses on documents and initiatives that operate at a global or regional level, which offer syntheses of information and experience gained from stakeholder engagement. Although valuable, these sources may lack important details (for example, calls for increased taxonomic capacity that are not associated with clear identification of the uses of that capacity).

The main sources of information were high-level documents at the global and regional levels, with a preference for the former; and interviews with representatives of global and regional organisations and initiatives, to provide a background to the documentation and an overview of the opinions currently held within such institutions.

Documentary sources

We reviewed more than 50 documents and reports published between 1999 and 2006 (see Bibliography). We focused on documents created by policy-making organisations such as the CBD because of their scope and the high level of international scrutiny and acceptance of their content. We also sought documentation arising from international stakeholder consultations, and from international organisations such as GISP, including both formal publications and unpublished reports in the public domain.

Most of these sources discuss invasives at a general level. A few discuss marine invasives and one aquatic invasives, and one is restricted to terrestrial vertebrate invasives. Documents were identified through the knowledge of the research team, advice of invasives professionals (particularly those interviewed) and cross-referencing between documents.

Only a few documents deal extensively with the taxonomic needs of invasive species management; many more make a few salient references to taxonomic needs; and others refer to management activities predicated on taxonomic support.

While some taxonomic needs were expressed in useful detail (e.g. 'access to experts to identify quarantine intercepts'), in many cases the need was expressed, but with no indication of how it should be met (e.g. 'intercepts need to be identified'). A need frequently expressed in documents is the very broad requirement for training and other capacity-building (e.g. CBD, 1998, 2000b, 2002b, 2004a). Clearly, capacity-building will potentially be a route to meeting a number of needs, yet in many cases these needs are not stated, or are implied rather than explicitly articulated. For example, a requirement for surveys (as identified in the *GISP Toolkit*; Wittenberg & Cock, 2001) rests on the taxonomic capacity to identify the organisms collected or seen, although this is not explicitly stated. Reports of interceptions in China, where weed seeds of 547 species were intercepted in 12 ports (Xie *et al.*, 2000), indicate the scale of the need for taxonomic identifications and thus for capacity. In the discussion below we indicate situations where there are such implied needs and, drawing on the interviews in particular, we seek to clarify their significance.

Expert consultations

Twenty-one experts (Annex 3), selected for their experience within organisations central to international activities in support of invasives management, were consulted via interviews and/or questionnaire. Consultations were necessary to establish the context and detail of some statements found in documents, as well as to establish both a wider and up-to-date view of the taxonomy needed for invasives management. Where documentary sources were

found to contain recommended solutions, description and analysis of root problems was sometimes lacking. Interviews and questionnaires were used to explore the problems faced in greater depth.

Individuals from strategy and policy levels were chosen to inform on the different aspects of invasive species; they came from governmental, non-governmental and inter-governmental organisations prominent in the field of invasives, and had extensive experience in issues related to invasives. They were identified through personal contacts, references from interviewees, or staff listings. Interviews were undertaken in person, by email or by phone. A questionnaire was used as a framework for interviews, although additional questions were asked to elucidate points of importance. Interviewees' responses were expressed as personal opinions, and do not necessarily represent the views of their organisations. Where respondents requested anonymity, their statements have not been attributed. Some interviewees found it easier to respond as an individual rather than as a representative of their organisation.

Limitations of the methodology

An assessment at the global scale, using high-level documentations and staff, cannot provide all the detail necessary for precise targeting of actions to meet needs. In order to gather such detail, and understand and evaluate the methods already being employed to meet needs at national and regional levels, we will need to work with invasives managers and appropriate documentation. We plan to undertake this in a future project, in which we will undertake consultations at country and institution levels for selected comparable and contrasting countries, examining the match between solutions and needs.

3 Taxonomic needs

The taxonomic needs identified from the documents and interviews are of three broad types.

- **I** End-users: taxonomic outputs and services needed by non-taxonomist invasives managers to improve the prediction, detection, monitoring and eradication of invasives.
- **II** Within institutions: taxonomic capacity, information resources and institutional prioritisation required for the taxonomic sector to deliver those outputs and services.
- **III** Across institutions: supra-institutional activities necessary to promote prioritisation and application of taxonomy to tackle invasives.

I End-users

This section identifies the taxonomic outputs and services most important to practitioners and regulatory and environmental management authorities from various sectors engaged directly in invasives management (Table A1, page 39).

Lists of species

Although species lists were not the most-cited need, they underpin other needs in this section. An indication of this is that in the GISIN (2007) survey, although lists of names were not cited as a need, more than 90% of respondents (n = 134) used genus + species name to search for other information, and 81% noted that they would be interested in data on synonyms and colloquial names, in the context of profiles and species pages.

Lists of species, particularly of known invasives, were stated as a need in half of the documents (Genovesi, 2000; Shine *et al.*, 2000; Reaser *et al.*, 2002; Council of Europe, 2003; Macdonald *et al.*, 2003; CBD, 2006b; Murphy & Cheesman, 2006), and in over half the interviews. In the context of prevention, prohibition is generally carried out based on lists of species, rather than country of origin or other categories (CBD, 2001a). Many of the interviewees emphasised the need for multiple lists, in particular lists defined geographically (e.g. by country or region), by pathway or by biome.

Interviewees made the point that a species that is invasive in one location is actually native elsewhere, and that species lists should therefore be accompanied by an indication of both native and non-native ranges. It follows that to ensure a species can be classified appropriately as alien in a particular location (non-native to a country, district or region), the biota of the location must be known. Consequently, the need for baseline data – inventories of native and other species already present – was noted in several documents (Anon., 2001; McNeely *et al.*, 2001; CBD, 2006b).

Lists of species are only as valuable as the accuracy of the names they contain. However, names change with new research (see 'The nature of names', page 11). These changes may result in inconsistencies if they are recorded differently in different national and other lists. For example, a survey within Australia in 2003 discovered that managers were trying to reconcile 12 different census lists for vascular flora, all of which overlapped and differed in taxonomic concepts, and were being updated only randomly (Orchard, 2005). In addition, some species are better known by vernacular names than by scientific names. There is consequently a need for taxonomic scrutiny when building lists, ensuring a common classification is used and all alternative names (synonyms,

Lists of known invasive alien species

Lists of various types are used by invasives managers. Some are incorporated in international policies and regulations. Frequently employed at country or regional level are 'black lists', which comprise high-priority species that are not permitted to be introduced (Genovesi, 2000; Wittenberg & Cock, 2001; Murphy & Cheesman, 2006).

Also used are 'pied lists', which contain known pest species with strict regulations and measures to ensure pest-free imports, and 'white lists', which include species cleared for introduction – organisms declared as safe (Wittenberg & Cock, 2001). Most, if not all, countries have their own national lists of prohibited organisms.

These and other lists of invasives are crucial to decision-making at points of entry, and to deciding whether action should be taken against a species. However, lists may differ in the names applied to the same species, limiting the efficiency of interception services. Lists also need regular updating to ensure consistency with the latest taxonomic concepts, as for example under the IPPC, which recognises 'change in taxonomy' as one of the most common reasons why lists of regulated pests need updating (IPPC, 2005: Requirement 5, Maintenance of lists of regulated pests).

Asian tiger mosquito – *Aedes albopictus*
Will this be carrying diseases in your country tomorrow?
It is now possible to use data from biological collections to predict biological invasions
Photo: Susan Ellis, Bugwood.org

vernacular names, etc.) are included (CBD, 1998; Lyons & Miller, 2000; Anon., 2001; Naumann & Mamat, 2002). GISP, in *A Global Strategy on Invasive Alien Species* (McNeely *et al.*, 2001), called for an international committee to correlate and manage updated taxonomic nomenclature for all invasive species.

The importance of linking lists and databases to a single portal to avoid duplication was noted by interviewees. This brings up the possibilities inherent in modern web-enabled databases, of linking very disparate information types and producing user-defined outputs. The names of species, and the data on which distributions can be assessed and potential invasiveness predicted, are currently being unified in interoperable distributed databases and made accessible globally (particularly though GBIF). GISIN plans to capitalise on this to provide appropriate information.

Although databases accessible on the web are developing rapidly, they are still relatively data-poor in comparison with the data potentially available. Hence their value to invasives management remains limited. Moreover, the limited accessibility of online information in developing countries, referred to below in the context of identification aids (page 17), applies equally to online databases. Nonetheless, resources exist, such as the Global Compendium of Weeds, which contains at least some of the synonyms and common names as well as other information.

The results highlight that species lists, whether lists of pests and pathogens whose introduction is prohibited by law, or checklists for surveys, are a central tool. Lists are used in a variety of contexts to uphold international regulations, such as the phytosanitary obligations of exporters and importers of agricultural and other products, and use by border-control agencies to enforce regulations governing the movement of species known to be, or with the potential to be, invasive. A pest list is required for each contracting party under the IPPC as a tool to support surveillance and reporting of plant pests. Article IV/2 (b) of the IPPC states that the responsibilities of an official national plant protection organisation shall include the following: 'the surveillance of growing plants, including both areas under cultivation and wild flora, particularly with the object of reporting the occurrence of pests.' Article VIII/2 (b) states that the contracting parties 'shall cooperate with one another to the fullest practicable extent in achieving the aims of this Convention, and shall in particular: cooperate in the exchange of information on plant pests, particularly the reporting of the occurrence, outbreak or spread of pests that may be of immediate or potential danger, in accordance with such procedures as may be established by the Commission.'

A pest list database is also required under WTO–SPS obligations by Article 5 (Assessment of risk and determination of the appropriate level of sanitary or phytosanitary protection) and Article 6 (Adaptation to regional conditions, including pest- or disease-free areas and areas of low pest or disease prevalence).[1]

1. Article 6/3 states: 'Exporting Members claiming that areas within their territories are pest- or disease-free areas or areas of low pest or disease prevalence shall provide the necessary evidence thereof in order to objectively demonstrate to the importing Member that such areas are, and are likely to remain, pest- or disease-free areas or areas of low pest or disease prevalence, respectively. For this purpose, reasonable access shall be given, upon request, to the importing Member for inspection, testing and other relevant procedures.'

Modelling distributions of invasive alien species from biodiversity data

Specimen data from specimens in museum, herbarium and culture collections, and observational data on species occurrences can, if georeferenced, be used to model overall species distribution, both currently and under different models of climate change. Systems such as ecological niche modelling link these georeferenced point data to a range of environmental, topographic and other broad-scale characteristics to produce a predicted ecological niche, including geographical distribution. This prediction is based on the home range of the species, and can be tested by further collection or observation. It can also be used to predict the potential range of a species if it is introduced into a place outside its natural distribution. Some uses of the method have included associated species (e.g. vectors) and their own modelled niche, in order to refine the prediction for the target species. The system relies on having point (georeference) data, ideally of breeding populations; a single port interception provides relatively poor data in this regard, as it conveys no certainty that the species could survive once in the local environment. However, interception data do identify possible invasion pathways, and are valuable for that reason.

For phytosanitary purposes under the IPPC, lists need to include the scientific name with its author (where appropriate), as well as the common name for the taxonomic group and any synonyms, for quarantine pests and regulated non-quarantine pests (see 'Lists of known invasive alien species'). One response to these requirements is the Pacific Islands Pest List Database, although this list does not include all synonyms, nor does it provide alternative taxonomic views, even though these exist for some species covered.

'Black lists', 'pied lists' and 'white lists' are also used by invasives managers (see 'Lists of known invasive alien species' below). Other examples of lists of invasive species are those that are geographically defined (e.g. '[invasives] known to occur below 1000 m asl in South America'); pathway lists (e.g. 'Pests associated with fruit imports from Southeast Asia'); and lists of common names, synonyms and species or commodities associated with regulated organisms.

Distribution information and pathway maps

The ability to prevent a biological invasion is greatly enhanced if the arrival of potentially invasive species can be predicted. Import risk analysis involves making such predictions, and is a requirement for importing countries under the IPPC (IPPC, 2004). It is possible to predict the likely invasiveness of a particular species, or species likely to be associated with it, using species occurrence data. These data may be derived from taxonomic collections housed in museums and herbaria, or from the literature (for example, lists of species occurring in different countries and regions, primary taxonomic literature or records of interception). In every case, the scientific names attached to the observed locality of origin of a specimen or record must be checked by an expert with taxonomic competence to ensure the appropriate one is being used; such checks are undertaken on CABI *Distribution Maps of Plant Pests*, for example. Prediction also requires an understanding of the ecological limits that constrain where a species can occur, its likely reproductive success if introduced, and its other potential interactions with native species and ecosystems.

The need for distribution data for invasive species was stressed more by interviewees than in the documents reviewed, although the constraints on prevention strategies 'introduced by the considerable knowledge gaps in marine native and introduced distributions' were highlighted by GISP in its best practices for management on introduced marine pests, as was the need to share distribution data for invasives (Macdonald *et al.*, 2003). The focus was mostly on distribution data with maps, but two responses recommended distribution in text form, on the grounds that this is easier to access and download via the internet. There were also suggestions to have distribution data available via databases such as Australia's Virtual Herbarium or to share it via the GISD and/or GBIF or other portals via which data can be accessed in map form as well as text. The IUCN has suggested that statistical information and models to develop and strengthen predictive capacity should be part of a knowledge base to inform legal management of invasives (Shine *et al.*, 2000).

Identification of pathways[2], production of pathway maps and studies of pathway changes, are identified as important both in documentary sources (CBD, 2000a, 2002b, 2005b; CGIAR, 2001; SCBD 2001a, 2001b; Wittenberg & Cock, 2001; Reaser *et al.*, 2002; Macdonald *et al.*, 2003; Hilliard, 2005; GISIN, 2007) and by respondents. Such information is important for risk analysis and prediction of possible invasions. It is also of

2. 'Pathways' in invasives management are the channels by which species are transported, accidentally or intentionally, from one location to another. For more information see the USDA National Invasive Species Information Center, Manager's Tool Kit.

value in risk analysis within countries, so that the risk involved in moving specimens of an invasive within a country can be assessed and legal restrictions put in place if required (Shine *et al.*, 2000). Although the identification of pathways involves a number of data sources, information from taxonomic sources is important to enable modelling of environmental tolerances of species in the context of pathway conditions. Such data may include digitised data from specimens held in the collection, which may also include data on associated species (host plants, food species, etc.) that can assist in identifying places where the species might be able to live. Another source of information in plotting pathways is specimens collected along the potential route, for example in ships' ballast water; such specimens will need to be identified and vouchers stored.[3] In assessing possible changes to pathways, and the establishment of new pathways, modelling software may help to identify possible vulnerable areas and pathways that a species could tolerate.

Predictions may be equally valuable when determining the risk from invasive species posed by a new tourist route or other communication route. In each case, a new potential pathway for invasive species is created. Other needs mentioned were tools to evaluate invasiveness (CBD 2001b; CGIAR, 2001). Taxonomic expertise and, critically, the biological information conserved with specimens and observations are vital to provide the baseline data for such evaluations (Shine *et al.*, 2000).

The sensitivity of authorities to sharing information on observations of invasives in some circumstances may account, in part, for the lack of discussion about distribution information in the documents examined. Early warning and mapping distributions are important in the context of invasives. But when the species concerned are pests that may be on black lists in other countries, a decision to publicise the presence of the species may lead to significant economic penalties in lost trade opportunities if an importing country is not satisfied that shipments from the country reporting the occurrence are free of the suspect species. In another scenario, a country may notify the country of origin of an intercepted pest, but there is a risk that if it published the interception more widely, the record would appear on distribution maps without explanation, and consequently other countries may place restrictions on export. In this context, there might be disagreements between exporting countries and list/distribution compilers about the presence or absence of a pest, and the fear of legal reprisals may hinder participation.

Identification support

The core of any management of an invasive species or pest is its successful identification. This is true of every stage – interception, assessment, surveys, monitoring. This requires a system to ensure delivery of identifications when and where needed, with the appropriate level of precision.

While the deliberate movement of an organism is typically accompanied by information providing its name and a declaration that the shipment is free of controlled pests and pathogens, potentially invasive organisms are routinely discovered within shipments, and need to be identified to determine whether they pose a threat. Even specimens named on manifests may need to be formally identified in case of doubt. Consequently, regulations mandating export and import inspections are the norm worldwide. Their implementation poses a particular challenge – identification of species encountered must be rapid to minimise costs from unwarranted delays, yet sufficiently robust to stand legal scrutiny should the occurrence of prohibited species be challenged.

> As a minimum, *legal frameworks* should support identification and monitoring of alien species, as part of a broader requirement for *identifying* and *monitoring* components of biological diversity.' (Shine *et al.*, 2000).

There are attempts to provide clear quality controls and protocols under the IPPC, summarised in *ISPM 27: Diagnostic protocols for regulated pests* (IPPC, 2006a).

Quarantine and border-control staff have frontline responsibility for carrying out examinations and determining actions to deal with such accidental introductions. Making reliable identifications is particularly challenging for many insects, fungi and other organisms that are difficult to identify; where an invasive species resembles a native species; or where the invasive species is related to other, non-native species that coexist with it but are not invasive, and therefore do not pose a threat to native biodiversity.

Taxonomic identifications may be provided via several routes. Where they are available, local non-specialist staff may use field guides or other identification aids (themselves outputs of taxonomy). The range of identification tools is increasing, with a variety of molecular, digital, digital image-matching, acoustic and other technologies available to supplement more common pictorial or biochemical approaches. Where identifications are problematic, in-country taxonomic experts may be needed. Where appropriate taxonomic expertise does not exist locally, or tools such as voucher specimens are not available, regional or global identification services may be able to assist if resources permit. In some contexts, it is critical that the

3. A voucher specimen is an example of a species or strain that has been authoritatively identified and is retained to provide a comparison for future identifications.

identification is performed by an expert, as for Parties to the IPPC, where ISPM 27 (IPPC, 2006a) states 'Each protocol contains the methods and guidance necessary for the regulated pest(s) to be detected and positively identified by an expert (i.e. an entomologist, mycologist, virologist, bacteriologist, nematologist, weed-scientist, molecular biologist) or competent staff that are specifically trained.'

Support for the identification of specimens was the most commonly recognised need in this assessment, with 104 references to the need for improved 'identification support' or 'identification tools and guides' from both documents and interview responses.

Identifications may be provided locally for a regulatory agency by a specialist; by an appropriate expert overseas; or, as is commonly the case, by non-expert users of identification tools and guides (CBD, 2000a, 2001b, 2006b; Wittenberg & Cock, 2001; Hilliard, 2005). Specialist support may be provided informally or, if available, via an organised, professional identification service with guaranteed response times and quality standards.

The need for access to specialists was raised repeatedly both in documents (CBD, 1998; Wilson *et al.*, 2003) and interviews. Several web-based databases of taxonomic expertise have been set up, including one specifically tailored to invasive species in Europe (Delivering Alien Invasive Species Inventories for Europe, DAISIE). The identification of 'online access to taxonomists' and 'remote diagnostics' as priorities further indicates that while specialist support is important, it is generally not available locally. Greater support for species identification at ports of entry was highlighted as a particular priority.

Whether identifications are performed by specialist taxonomists or by non-specialists will depend on a variety of factors, including application of IPPC international standards (IPPC, 2006b), or requirements for confirmation of a permitted species that might be confused with, or is closely related to, a potential invasive species (CBD, 2001a). In some circumstances, a named specialist is required as part of a protocol, for example for the IPPC draft standard on 'Establishment of areas of low pest prevalence for fruit flies (Tephritidae)' (IPPC, 2006b).

Consulting a specialist may take longer than performing the identification locally, as such experts are often in regions or countries other than the site of capture, and because it is often not possible for institutions to prioritise providing identifications of samples of invasive species if no payment is available for the service. Charging for specialist identifications was raised by interviewees as a problem, and one possible strategy identified is prioritising expenditure on specialists for confirmation of apparent new interceptions. The alternative of training and employing non-specialists is not cost-free. In addition, specialists are more likely than non-specialists to produce accurate identifications to the desired level (species, strain). Other potentially complementary solutions – capacity-building and online access to specialists – are discussed below.

The difficulty in obtaining authoritative and/or urgent identifications is evident in the prioritisation of 'identification services' as a need. Respondents informed us that identifications are sometimes required urgently, especially when authoritative identifications are needed, as with the certification of agricultural produce for export or when prompt decisions are required for financial or management reasons.

Identification tools and guides

The need for identification keys was highlighted both in documents and overwhelmingly by interviewees, including those who use keys in their professional identification work. Both specialist taxonomists and non-taxonomists use various types of identification aids. The current paucity of these resources was noted as a barrier both in documents (Lyons & Miller, 2000; Anon., 2001; Naumann & Mamat, 2002; Council of Europe, 2003; CBD, 2006b) and by respondents, including those who use keys in their professional work. The users of such tools are often non-taxonomists, such as ecologists, parataxonomists[4], amateur naturalists and plant health officers working in-country. Another set of users are quarantine officers at point of entry, who need easy-to-use keys and guides to be able to recognise and intercept a new introduction or to prevent repeated entry of an existing alien species. Responses highlighted the need for identification guides that are easy to use, picture-based keys and field guides.

Various priorities for new keys were suggested, in particular 'priority taxonomic groups', 'known [invasives] associated with major pathways of introduction' and 'keys in local languages'. The importance of the latter is demonstrated by the World Bank's support for the production of at least 70 local-language field guides to a variety of taxa, although it is not known if any have been produced to support invasives management. Those wanting to produce electronic keys in a variety of languages can use the Lucid software developed by the Centre for Biological Information Technology (University of Queensland): this supports any language and has been used to produce over 90 keys directly relevant to invasives management. The geographical range of keys and other identification aids was also commented on by respondents. Many current keys are valid only for a single country or region, whereas invasives, by their nature, are found outside the places where they have been keyed as part of the local fauna and flora. The production of global keys was noted as an approach that would be particularly appropriate for invasives management and that would reduce duplication

4. Parataxonomists are non-specialists who have received training in such skills as collecting, specimen preservation and preparation, digital imaging and databases, but not in formal taxonomy. They do not necessarily work in a museum or herbarium, but they do produce quality material for study. Their role is fundamentally more active than a research assistant, but less authoritative than a professional taxonomist.

African honey bee – *Apis mellifera scutellata*

Only expert identifi cation can uphold legislation protecting this major crop pollinator from invaders in South Africa

Photo: Scott Bauer, USDA Agriculture Research Services, Bugwood.org

of effort in producing keys. Development of standard descriptors of key characters for organisms, where this is possible, will facilitate the generation of keys. It was also noted that keys need to be linked to species profile data, such as distribution, pathway and ecological information (CBD, 2006b). More precise determination of what keys would provide greatest support to invasives management will require further examination, although keys for pathways were noted as being particularly important (CBD, 2006b). Most keys describe organisms in a specific context, such as adult insects as opposed to larval insects or insect eggs. However, these contexts do not necessarily coincide with those used by personnel concerned with invasives management.

A number of respondents, including some engaged in providing identifications professionally, noted the need for accurately identified specimen images. These would help with identification, as scientific drawings and taxonomic descriptions can often be difficult for non-taxonomists to interpret.

Web-based identification aids were regarded as a desirable resource by some respondents. Efforts are being made by various institutions to create of online identification tools. There is some concern that facilities to use web-based tools are not sufficiently available to those engaged in frontline invasives management in the developing world, and that this would therefore not be a complete solution. Some interviewees suggested that collaboration and creating common lists of descriptors for key-making would make it possible to create globally valid identification resources, as discussed above. Such identification tools might be constructed using a software application. One interviewee identified the need for a database of existing electronic taxonomic keys, both to help with identification and to identify gaps in knowledge and in the availability of keys. The possibility of remote diagnostics was also mentioned as a possible solution, involving a mix of technological solutions and a centralised human resource.

Novel methods of identification are being developed, particularly molecular techniques such as genetic screening and 'DNA barcoding', which may be valuable (CBD, 2002a, 2004c). Molecular tools can also be used to determine the place of origin of specimens, as has been done with fruit fly incursions in the USA, for example (CBD, 2001a). Respondents called for the further development and deployment of such tools, noting that they would assist in screening of invasives at ports of entry/export, particularly for species that are difficult to identify. Following discussions among invasives specialists and taxonomists developing molecular markers, an International Network for Barcoding Invasive and Pest Species has been formed under the auspices of the Consortium for the Barcode of Life.

To improve detection rates at ports of entry, better facilities are needed in terms of both traditional identification approaches using printed guides and microscopes, and facilities for using modern digital and molecular technologies.

Surveys and monitoring

Surveys and monitoring are widely recognised as vital for dealing with invasive species (CBD, 1998, 2000a, 2002b, 2005a, 2005b, 2006b; Genovesi, 2000; Lyons & Miller, 2000; Shine *et al.*, 2000; McNeely *et al.*, 2001; SCBD, 2001b;

Wittenberg & Cock, 2001; Meyerson & Reaser, 2002; Naumann & Mamat, 2002; Reaser *et al.*, 2002; Council of Europe, 2003; Mauremootoo, 2003; Macdonald *et al.*, 2003; BNPP, 2004). Some respondents highlighted surveys and monitoring as a priority, but did not consider these to be outputs of taxonomy in particular. Likewise, documentary sources that prioritise the need for surveys and monitoring do not always mention taxonomic input.

Under the IPPC, elements of surveillance systems as part of national frameworks should include identification of pests already in a country, and identification and surveillance of areas that are pest-free, or from which a pest has been eradicated (IPPC, 2006a, 2006b). However, few national plant protection organisations currently carry out regular surveillance because of the costs involved (Hedley, 1999, reported in SCBD, 2001b). Taxonomic input is critical for assessment and monitoring in a number of ways (Figure 7, page 30). Article 7 of the CBD, which deals with identification and monitoring, was the basis for developing the GTI.

Both documentary evidence and individual responses stated that surveys and monitoring are central to early detection, particularly at high-risk locations such as ports of entry and watersheds (SCBD, 2001b; Reaser *et al.*, 2002). Surveys and monitoring allow detection of invasive spread, assessment of impact on indigenous species, and assessment of biotic recovery after the use of chemical, biological or other invasives control measures. Baseline surveys are needed, as well as targeted surveys (either at species or ecosystem level) and general surveys. Surveys may be conducted at any level, from local to regional, and apply to aquatic ecosystems as much as terrestrial. As mentioned by an interviewee, baseline surveys and distribution maps of native biodiversity are fundamental to classifying a new species observation as an invasive or a native species extending its range. Documentary evidence suggests that national monitoring and early warning systems are often weak (SCBD, 2001b: 13), and that a common constraint is inadequacy of baseline data.

Black Locust – *Robinia pseudoacicia*
Seeds of 547 weed species were recently intercepted in 12 Chinese ports. Identification aids help border inspectors prevent biological invasions
Photo: Ohio State Weed Lab Archive, Ohio State University, Bugwood.org

Access to information

The critical need for improved access to information is a theme evident across the responses and documentary evidence. Priorities include access to taxonomic information, taxonomic literature, invasives management guidelines, specimen images and guides. Although the need for greater electronic and, where possible, online access to information is undoubtedly an important observation, account should be taken of developing countries' lack of, or limited access to, the internet. Limited download capacities and limitations on appropriate file sizes must be taken into account when developing and executing such tools. End-users of taxonomic products in many countries are known to prefer, or can only readily use, hard-copy publications.

II Within institutions

The needs cited in the previous section are all 'primary' needs – they reflect what the personnel working with invasives (end-users) need from taxonomy as deliverables. The assessment also revealed another set of needs – the capacities and information resources the taxonomic sector needs in order to address the primary end-user needs. These are considered in this section, and include taxonomic capacity-building, the use of that capacity, and the scientific and technical work to make available information resources in support of timely responses to invasives management needs. Underlying each need is the question of how taxonomic institutions should prioritise their operations in order to deliver the products and support needed by end-users (Table A2, page 40).

One general point made by a number of interviewees concerns the need to bring taxonomy, its outputs and practices into closer alignment with the requirements of non-taxonomic end-users. Respondents commented on the outmoded style of many taxonomic outputs, and the need to make them easier to understand and more accessible. Another suggestion was to increase the frequency of outputs by publishing during the course of a study, perhaps on the web.

Taxonomic capacity-building: personnel

'Capacity', 'taxonomists' and 'parataxonomists' all scored highly in the assessment, especially in a high proportion of the documentary sources. Some of these sources also recognise taxonomic capacity-building to be a central component of any national strategy for prevention and management of invasives (CBD, 1996, 1998, 2000b, 2002c, 2005b, 2006b; Anon., 2001; Macdonald *et al.*, 2003; Murphy & Cheesman, 2006; Ramsar COP Resolution VII/14). The IUCN Guidelines for the prevention of biodiversity loss due to biological invasion recommend that 'staff for quarantine, border control, or other

relevant facilities … [receive] practical training for aspects like identification and regulation' (Shine *et al.*, 2000: 118). This is important in recognising that appropriate training must be provided for those who have to make recommendations or take decisions, or who provide identifications using tools produced elsewhere.

The training and infrastructure needed to address collection and curation needs is a further important aspect of capacity-building, as is the literature needed by practising taxonomists/parataxomists. Interviewees emphasised these needs. Capacity-building for taxonomy is explored in the *Guide to the GTI* (SCBD, 2007).

The fundamental need for more taxonomists could be addressed by a variety of strategies. One approach suggested is for fellowships that allow institutions to 'borrow' specialists from other parts of world (Naumann & Mamat, 2002). Such a redirection of existing expertise may be feasible in certain cases but, noting the widely recognised decline in the number of taxonomists in most countries, developing and developed, and that their numbers are insufficient to meet needs (including invasives management) under the CBD, this is unlikely to be a sufficient solution on its own (Herrera, 2001; Klopper *et al.*, 2001; Wilson *et al.*, 2003; Taylor, 2006). It is not, in any case, a sustainable solution as many of the potential benefits of short-term placements are, by definition, temporary. New taxonomic posts to support invasives management (as called for by participants at GISP workshops in Africa and Europe and in the *GISP Toolkit*: Lyons & Miller, 2000; Wittenberg & Cock, 2001; Macdonald *et al.*, 2003; Reaser *et al.*, 2005) are likely to be essential to meet invasives management needs in many countries and regions. A call has been made for national and regional taxonomic capacity assessments in the light of user needs (CBD, 2000b). A few such assessments are already available, and some are cited here.

Young people need to be encouraged to train as taxonomists, and in order for taxonomy to appeal to up-and-coming scientist, employment opportunities are needed (CBD, 1998; Reaser *et al.*, 2002). One interviewee mentioned the 'brain drain' from taxonomy, where students who train as taxonomists end up working in other fields due to a lack of encouragement to stay in the field and scarce employment opportunities. This is on top of the brain drain familiar across scientific and technical disciplines, where developing countries are unable to retain trained personnel in-country due to the prospect of better employment opportunities overseas. Interviewees also commented that there are not many taxonomists around, and many of those who are working are close to retirement. This demographic trend is also pointed out by the Asian GTI needs assessment (Wilson *et al.*, 2003) and the UK Taxonomic needs assessment (Taylor, 2006).

The need for training was noted in many documents and interviews. Training is required at a number of different levels: to develop new taxonomists (Anon., 2001; Wittenberg & Cock, 2001; CBD, 2005b) and to train parataxonomists (Anon., 2001; Naumann & Mamat, 2002). The need to train staff for whom taxonomic work is only part of their duties has also been raised. Such staff, who would perhaps be working at point of entry, or in a support role, or as extension workers, should be trained in basic taxonomic knowledge and to carry out straightforward identifications, particularly of alien species on a black list and of native species (Wittenberg & Cock, 2001), and in use of identification tools such as diagnostic software (Naumann & Mamat, 2002). These suggestions, in addition to the priority given to keys and guides for non-taxonomists in the previous section, indicates an awareness that non-taxonomists are a useful resource for identification that needs to be mobilised by creating the right tools and support. Training has also been mentioned for specimen preparation and curation (Council of Europe, 2003), and for field techniques for surveys (European Union strategy on invasive alien species).

Taxonomic capacity-building: collections and facilities

Improved facilities are needed for biological collections [CBD, 1998; Council of Europe, 2003; GTI workshops in Asia (Shimura, 2003), Africa (Klopper *et al.*, 2001) and Central America (Herrera, 2001)]. Interviewees worried that collections are being abandoned and are not being used to their full potential. Specimen data from collections, and improved access to collections and collection data, were mentioned as valuable sources of information (see page 22). An increased number of curators are needed to maintain collections, and groups that are difficult to collect and preserve (often underrepresented in collections) need improved focus. The point was made that specialists use in-country collections where they exist, and that the availability of these reduces the need to contact specialists in major collection-holding institutions in the North. It was also seen as important that the contents of collections around the world should be made known to countries of origin: this will help them understand their own biota and improve their ability to identify invasives.

Increased laboratory facilities were called for (Council of Europe, 2003); these will be required particularly if molecular identification techniques become used more widely. The capacity assessment carried out as part of the first Asian GTI workshop (Shimura, 2003) identified laboratory capacity and facilities as less than adequate in around half of responding organisations, including culture collections and other users of technical equipment such as electron microscopes.

Access to expertise and identification services

Increasing the number of expert staff is not the whole answer, and it appears from the assessment that accessibility needs to be improved. One suggested method was a register of taxonomic experts along with directories of institutions that carry out identifications, as well as those holding

collections or dealing with detection, monitoring and control of invasives. Other types of information could simply be shared, perhaps through the Clearing-House Mechanism of the CBD.

Online access to taxonomists was also raised as a possible solution by a number of interviewees. The online network PestNet allows those with pest problems (generally invertebrates or pathogens) to discuss them with specialists on a charge-free voluntary basis, and this might act as a model.

For identification services, a barrier identified several times was the cost of identifications, and the need for rapid and authoritative identification at a cost manageable by poorer nations. Clearly, cost is an issue: the need of many major institutions to charge for their services has doubtless cut the number of specimens being identified. In turn, this will affect the ability of non-taxonomic organisations and smaller collections to build up authoritatively identified reference collections. A suggestion was made that invasives should be exempt from charging, although an economic model to support this was not described. The other element, speed of response, is also important as invasives management demands timely and often rapid identifications.

Another idea addressing access was to develop a system of voucher specimens that can be sent out at a short notice (CBD, 2005b). By having specimens sent for comparison with a suspected invasive species, it was supposed that identification could be made more quickly and more reliably than by relying solely on keys in the absence of a specialist.

A relevant point made in interviews is that there are standard diagnostic protocols available for regulated pests, such as that used by the European and Mediterranean Plant Protection Organisation (EPPO, 2002) and, adopted more recently, the IPPC standard *ISPM 27: Diagnostic protocols for regulated pests* (IPPC, 2006a). These cover a number of elements, including requirements for identification services.

Nomenclature and classification

Interviewees mentioned a need for more access to, and information on, updated taxonomic classification, synonymy and coexisting taxonomic classification. They identified difficulties in accessing the latest nomenclatural information, and confusion regarding synonymies and other nomenclatural changes. Suggested solutions included a 'taxonomic clearing-house mechanism' (CBD, 2005b) to help with enquiries, a 'name-resolving service' for synonymies, and an updated catalogue of names. All these functions are currently undertaken for species names in general by initiatives such as GBIF, ITIS and Species 2000, but the use of these informatics services by personnel involved in invasives management appears to be limited. The development of the GISD's Global Register of Invasive Species (GRIS) promises to alleviate the problem (see page 27), although integration with GBIF will be necessary. There is clearly a need for the content of information sources to match known invasive species. Recognising this, the Davis Declaration called on 'the Integrated Taxonomic Information System (ITIS), the Global Biodiversity Information Facility (GBIF), BioNET-International, and the GTI to make invasives a priority, establish global standards for [invasives] taxonomic classification, and improve the availability of accurate taxonomic information' (Anon., 2001).

Among interviewees, the opinion was expressed that 90% of biologists do not understand synonymies and alternative classifications, along with a corresponding belief that steps should be taken to build increased understanding of taxonomic nomenclature among biologists.

Common names were also considered important, as information on species often comes in from non-scientists, such as farmers or the public. In recording common names, it is important to maintain links between the name and its locality, as names for the same organism tend to differ between areas. In many cases there is not a 1:1 relationship between common names and scientific names, and clarity about the origin and language of a common name needs to be available to avoid confusion.

Digitisation of data and data standards

The CBD (2002b) called for the creation of a Global Invasive Species Information Network (GISIN), urging Parties to the CBD and others to make information available, and calling for 'development of databases and facilitated access to such information for all countries…'. The Decision also states that 'States should assist in the development of an inventory and synthesis of relevant databases, including taxonomic and specimen databases, and the development of information systems and an interoperable distributed network of databases for compilation and dissemination of information on alien species for use in the context of any prevention, introduction, monitoring and mitigation activities. This information should include incident lists, potential threats to neighbouring countries, information on taxonomy, ecology and genetics of invasives and on control methods, whenever available.' The need for interoperability of databases was echoed by a number of interviewees, and is a part of the GISIN methodology to ensure easy exchange of data and information. To enable interoperability to be developed, data standards were noted as important by a number of interviewees, as they are critical for the sharing and interpreting of data. The standards will also include the validation of data and protocols for dealing with errors.

The potential value to invasives management of integrated data from taxonomic collections is noted on page 16. The mobilisation of these data, and the prioritisation of specimen and observational data on invasive species, is vital to realise the potential of these techniques. This was underlined in

Resolving the Southeast Asian termite paradox

A few species of the termite genus *Coptotermes* are notorious as pests of timber internationally, responsible for enormous losses in buildings throughout the tropics and subtropics. The ability of these termites to nest in pieces of moist timber and form new nests from fragments of the colony enables them to survive as stowaways on board ships that spread them to new geographical areas. Large amounts of money are spent annually to control these pests and in developing control measures.

For many decades, and until recently, there has been a paradox in the pest status of these termite species. *Coptotermes havilandi*, a serious alien pest in parts of South and North America, is thought to have been introduced from Southeast Asia, yet in countries in its supposed area of origin it has never been accorded much importance as a pest. Instead, the pest species known to the region were said to be primarily *C. gestroi* and *C. travians*.

This paradox prompted the Forest Research Institute Malaysia to undertake a study on the taxonomy of these species. They showed that *C. havilandi* and *C. gestroi* were in fact the same species. Thus the alien species introduced to the Americas should be known as *C. gestroi* rather than *C. havilandi*. It was also shown that the true *C. travians* was not a pest that enters buildings, but rather a forest species, and that what was wrongly called *C. travians* in Malaysia and neighbouring countries was in fact *C. gestroi*.

In Southeast Asia there is, in fact, a single pest species, *C. gestroi*, that was introduced to various parts of the world, including the Americas and islands in the Caribbean, Pacific and Indian oceans. In view of the status of *C. gestroi* as a pest species of international concern, it was given a common name, the Asian subterranean termite. Numerous studies have been conducted in different parts of the world on the biology and management of the various termite pest species that were thought to be different. The recognition of a single species is enabling scientific information from different countries to be pooled, facilitating the development of improved pest management strategies.

(Source: Kirton, 2005.)

the recent GISIN survey (GISIN, 2007), in which respondents noted their interest in information from herbarium specimens, including metadata on how records had been verified. The continued development of interoperability between, for example, databases focusing on names of species, those dedicated to specimen-level information, and those carrying black list data provides the possibility of flagging mismatches in the application of names. This can take place only with a coordinated approach by the holders of data and mobilisers such as GISIN and GBIF. An important consideration is that databases need to be maintained, which entails a cost in both time and effort.

Access to taxonomic literature

There are a number of statements calling for more information to be made available at country, regional and global levels, and pointing out the difficulties in combating invasives in the absence of information that, while in the public domain, is not readily available (CBD, 1998; SCBD, 2001b; Evans *et al.*, 2002; Naumann & Mamat, 2002; Council of Europe, 2003; BNPP, 2004; Murphy & Cheesman, 2006). This information – a central component of which is taxonomic – should be made more easily available, including through digital and other means. Comments from interviewees included the difficulty in finding taxonomic references, which are often not published in widely available journals; and that taxonomic papers are often esoteric in their content and terminology, and do not include basic biological information on organisms.

Resolving this probably requires a two-pronged action. The legacy literature from 250 years of taxonomic research is necessary for taxonomists worldwide to undertake their research, including the naming and description of invasives. Very few institutions can afford to maintain a large library containing all the literature their staff need, not only from the past, but new literature as it is published. Solving this will need a combination of sharing hard copy; digitising past literature and making it available in forms that are easy to access; addressing copyright issues to make literature freely available; and moving some taxonomic work to the World Wide Web. The Biodiversity Heritage Library project is an

important initiative in this area. It will be possible to extract and package literature relevant to invasives made available under this project according to, for example, particular user or regional needs. Initiatives are also under way to extract relevant components of the taxonomic literature according to user-defined queries (for example, Integrated Open Taxonomic Access, INOTAXA).

The second aspect is improving the relevance and quantity of literature focusing on taxonomic aspects of invasives management, including identification aids for particular pathways. Here, also, the access issue remains, but the question of production is important: taxonomists themselves, in concert with others, need to produce the type of taxonomic literature that meets the needs of users in invasives management. Such needs will often be different from those of scientists studying particular groups of organisms. Publications designed around pathways of invasive alien species need to focus on taxa according to their potential or status as invasives and their geographical distribution. They need to use the life stages most often encountered by practitioners in the field (insect larvae, seeds) rather than those most easily identified (adult insects, flowers). This will require greater communication between users and producers than is perhaps currently the case.

A review of existing literature concerning issues regarding invasives in both taxonomy and research is also needed to avoid duplication. Other requests were the inclusion of biological information in taxonomic literature, and a statement that more publications on invasive species are needed.

III Across institutions

The needs covered in the two preceding sections are the primary needs and the responses necessary at institutional level to meet them. This assessment brought out a third level of need, concerned with the framework in which institutions operate and how they set their priorities, as well as supra-institutional activities (Table A3, page 42). Many of the CBD COP Decisions apply at this level. Often there is no clear mechanism for responding to such needs, in part because many types of organisation are involved. An example is education: it is widely stated that more taxonomists need to be trained but, while individual taxonomic institutions can take this on as an activity, there is also a need for universities globally to ensure taxonomy is on the curriculum.

Some sources examined in this assessment, while acknowledging the need for more capacity, go further, emphasising the need for innovation. A telling statement was made in the report of a workshop held by GISP in Southern Africa (Pallewatta *et al.*, 2003): 'For agricultural and horticultural quarantine services, a taxonomist can only be expected to identify a small proportion of the potentially harmful species that may move through any port of importation or exportation. Therefore, using current methods for organism identification, a cadre of taxonomists is needed for effective identification services, and each requires considerable training and years of experience. Building taxonomic capacity that depends on human expertise is, therefore, a long-term, costly exercise. The need, however, is vital, urgent, and massive. It is unrealistic to expect that a sufficient number of competent taxonomists will be trained within the foreseeable future, so new, cost- and time-effective mechanisms for providing identification services must be implemented.' This indicates clearly that novel solutions need to be found – carrying on current activities alone is not sufficient.

Taxonomic needs assessments and prioritisation

Taxonomic needs assessments are required to identify the particular needs of invasives management, and have been called for by the CBD in particular (CBD 1996, 1998, 2000b, 2002c, 2006b) and in the *GISP Toolkit* (Wittenberg & Cock, 2001). Taxonomic assessments, coupled with capacity assessments, are necessary at national, regional and global levels. The authors are not aware of many such assessments in the public domain. Although Parties to the IPPC have access to the Phytosanitary Capacity Evaluation Tool, which includes taxonomy, the results are typically confidential. One regional assessment focusing on invasives is the BioNET–ASEANET assessment of taxonomy of arthropod pests (Naumann & Mamat, 2002). In highlighting the taxonomic needs of invasives management, such assessments, should enable decision-makers and funders at all levels to take appropriate action to ensure needs are met appropriately. In Table A3, the number of interviewees citing the requirement for needs assessment is not given, as all interviewees, once asked, cited such taxonomic needs, together with appeals for these need to be met; the requirement for the assessment seemed self-evident.

The need for priority-setting for taxonomic work came solely from documents (CBD, 1998, 2000a, 2000b, 2002b; Naumann & Mamat, 2002; Council of Europe, 2003), and five out of the seven instances came from the CBD COP Decisions. Only one interviewee mentioned priority-setting, which he said needed to be sector-based (e.g. agriculture, forestry). However, both documents and interviewees identified gaps in knowledge that need to be prioritised (see 'Gaps in taxonomic knowledge and resources identified in the assessment'). The tone of all documents and interviews suggested that taxonomic work to address issues regarding invasives needs to be prioritised, even if this was not stated explicitly.

Prioritisation can also be seen in national strategies and legislation. Some national biodiversity strategies specifically include the need for inventories of alien species; for example, the IUCN reports that in Poland funds were allocated for this and specific scientific institutions and botanical gardens tasked to produce inventories (Shine *et al.*, 2000). Similarly, Argentina's draft biodiversity strategy included the creation

of a database of native and alien species (Shine *et al.*, 2000). Australia has a legal requirement for identifying and monitoring biodiversity, including processes or activities that are likely to have a significant impact on conservation and sustainable use, a category that includes alien species (Commonwealth Environment Protection and Biodiversity Conservation Act No 91, 1999; cited by Shine *et al.*, 2000). New Zealand's (1993) Biosecurity Act has a legal basis for gathering, recording and disseminating information on invasive species present on its national territory.

The current document provides the first global-level needs assessment, although more detail will be required to help define specific national and institutional needs.

Collaboration and strategies

An activity such as invasives management, which involves different sectors, different countries, and different regulatory and information-sharing systems, must develop methods of collaboration in order to succeed. This is noted in a number of documents as identification of needs for developing overarching strategies, information-sharing and coordinating activities (Anon., 2001; McNeely *et al.*, 2001; SCBD, 2001b; Wittenberg & Cock, 2001; Naumann & Mamat, 2002; Reaser *et al.*, 2002; Council of Europe, 2003; Macdonald *et al.*, 2003; BNPP, 2004).

The South Pacific Regional Environment Programme's Regional Invasive Species Strategy includes the requirement for a regional system of information collection and exchange, and contributing states will collaborate in compiling black lists (Shine *et al.*, 2000). The need for collaboration applies at all levels, within as well as across sectors, so that networking between experts is needed as well as an increase in information sharing.

Other needs for collaboration, which are somewhat glossed over in some documents, are between workers in invasives management and taxonomists; between taxonomists and informatics specialists; between informatics specialists and data modellers; and between all and policy-makers. Often, existing taxonomic capacity relevant to invasives management will be found outside regulatory and other authorities with invasives management responsibilities. It may be necessary to consider how national, regional and wider networks and incentives for taxonomists may be strengthened to provide taxonomic support. In collaborative work, as elsewhere, prioritisation of activity needs to be informed by policy and user requirements to maximise the delivery of products that can and will be used.

There are numerous examples of established collaborative networks fulfilling distinct roles. For taxonomic institutions, BioNET is a good example with its Locally Owned and Operated Partnerships (LOOPs) endorsed by over 100 countries and territories and a Secretariat. Some of these are engaged with invasive species issues, such as BioNET–CARINET, BioNET–SAFRINET and BioNET–ASEANET, which has carried out subregional needs assessments of pests and pathogens, and is working with the GISIN to set up a Southeast Asia regional node. BioNET itself has a Memorandum of Understanding with GISP, and is mentioned in the GISP Phase II working group on National and Regional Facilitation and Cooperation: 'Development of national and regional frameworks, the development of pertinent toolkits, taxonomic capacity (in collaboration with BioNET), the establishment of regional centres and pilot projects.' GISIN is working with the Taxonomic Database Working Group [now known as Biodiversity Information Standards (TDWG)] (comprising informaticians, modellers and biologists from many different countries) and IUCN's Invasive Species Specialist Group to develop data standards, and with the GBIF, and individual scientists are working with GBIF-mediated data to address questions regarding invasives (Higgins *et al.*, 1999; Peterson, 2003; Peterson *et al.*, 2003). All these organisations interact with the CBD, to both keep in touch with and inform policy at international level.

In addition to collaboration, strategies at global, regional and national levels are needed to maximise the application of work to deal with invasives management (CBD, 2000a, 2002b; Anon., 2001; Wittenberg & Cock, 2001; Reaser *et al.*, 2002; Macdonald *et al.*, 2003; Mauremootoo, 2003). Such strategies should involve means of meeting taxonomic needs in order to avoid problems; coordinated efforts at national and global levels will be an important mechanism in the management of invasives (CBD 2006b).

Research

More taxonomic research is needed, both for increased taxonomic knowledge and for the generation of baseline species data (CBD, 2000a, 2002b, 2006b; Anon., 2001; Wittenberg & Cock, 2001). Research on the impacts of invasives, and a review of existing research into invasives, both taxonomic and for the creation of baseline data, were identified as useful. Other needs included research into matching molecules to morphology with molecular identification in mind; making known problems and solutions accessible; and conducting research into known invasives to predict future invasions and susceptible habitats.

It is clear that even basic research on species identity is of tremendous importance, even when an invasive or pest species is apparently well known (see 'Resolving the Southeast Asian termite paradox')

In addition to these types of research needs, some interviewees and documents identified gaps in taxonomic knowledge necessary for the study and identification of invasives (Annex 2, page 43). This is not intended as a comprehensive list of groups that need urgent taxonomic attention, but is produced as a by-product of discussing taxonomic needs with stakeholders from different backgrounds, and is included to illustrate the work needed

in this area. One interviewee cited 'poorly-known groups' as a priority for taxonomic research, specifically referring to forest pests of Siberia, an ecological/geographical unit linked to an increasingly important pathway. This type of information is highly informative as it could be used by taxonomists to undertake research of immediate relevance to a particular problem.

Education and training

Training is required at different levels and is best provided according to identified needs. Overall, there are needs for *ad hoc* training and short courses focused on identification tools, or suites of species, or collecting and monitoring techniques; there is also a wider need to ensure that a core cadre of taxonomists is maintained and developed. Training of taxonomists, parataxonomists and others has been mentioned as something institutions should do in response to the needs identified for invasives management. However, taxonomy generally has significant and widely reported problems in recruiting students.

To redress this situation, a number of actions are needed. Clearly, taxonomists cannot be trained if there are no courses in educational establishments. Equally, universities cannot be expected to run courses on taxonomy if there is limited interest among potential students in taking such courses. The problems come back to the perceived value of taxonomy, and its highlighting in the context of identified benefits such as the management of invasives. If the value of taxonomy to managing major threats to biodiversity such as invasives is appreciated more widely, there might well be greater interest in studying taxonomy.

Training programmes are a cross-cutting need throughout this assessment. Regional and global training courses in identification of invasives were the most common training need, but training is also required in collection and curation of specimens, in database use and in other relevant IT skills. An online education programme on invasives management has been suggested.

Training may be delivered by consortia of institutions or by individuals. It may be delivered in-country, or in taxonomic institutions. As there is no single list of invasive species relevant to all regions, training needs will vary according to which organisms are invasive in a particular location. There may be value in training materials being produced in a consistent format so they can be shared between training institutions, forming the basis of an identification toolkit.

Awareness-raising

There are often significant limitations in taxonomists' understanding of how they might help address issues concerning invasives; and among invasives managers and policy-makers regarding the actual and potential roles of taxonomy in the management of invasives. Both limitations are obstacles to more effective invasives management. This can be a particular problem in the course of developing funded programmes if incorrect assumptions are made about the availability of taxonomic expertise or information, or the extent of knowledge about particular species. In addition, there appear to be gaps in communication that may be leading to duplication of work.

Awareness needs to be raised in several different communities. Practitioners working with invasives can usefully be made more aware not only of how knowledge gaps can be filled and the likely level of work that may be required, but also of the potential to provide information of a type that would benefit invasives management but currently is rarely available to practitioners, such as that provided by ecological niche modelling. Decision-makers and funding bodies need to be similarly informed; suitable representation on grant advisory panels or among project referees may help respond to unrecognised taxonomic needs in a timely manner.

The work outlined above will require funding, and funding bodies need to be aware of the taxonomic implications of projects. The CBD COP, in numerous Decisions, has raised the issue of appropriate funding for taxonomy to assist in implementing the Convention, most recently in Decision VIII/3 (CBD, 2006b). Taxonomists also need to be made more aware of the specific needs of invasives management, and to tailor their outputs appropriately.

Funding

The sources examined made only 14 direct references to funding, although the funding implications of the needs identified might be considered significant, and many are long-term. That said, some short-term needs, particularly for identification aids, could be met for modest investments in expert time and publication materials. Considering the more fundamental needs of building and maintaining capacity in the long term, this is likely to involve public funds – taxonomy is a classic 'public good' – but also perhaps greater private sector support than at present, especially where the benefits of invasives management are clearly linked to trade and financial benefits.

The direct impacts of invasives on human well-being and livelihoods merit support for activities related to invasives from overseas development funding sources. In each case, success in building taxonomic information, expertise and tools will require close integration with end-users and with the various broader initiatives supporting invasives management internationally.

4 The role of taxonomy in invasives management

This section examines the implications of the assessment, in particular where taxonomic effort needs to be directed to contribute most to decision-making and risk management for invasives. A framework for invasives management is described in the Options flowchart of the GISP Invasive Species Toolkit (Wittenberg & Cock, 2001). In Figure 4 (page 28), this flowchart is modified to indicate the processes where taxonomic products and support are, or could be, applied. Among central contributions of taxonomy to invasives management are scientific and common names, expertise and tools for the identification of suspect specimens, survey techniques and biological control research.

Prevention

Prevention is the most cost-effective approach to invasives management (Wittenberg & Cock, 2001), whether introductions are deliberate or accidental[5]. Much of the need for taxonomic involvement is in the prevention phase; all the management options identified in the GISP flowchart at this level require a degree of taxonomic input.

The issue of name changes, and of different names being used for the same species in different lists, has been discussed above (page 14). To minimise risk, taxonomic inputs should be sought when compiling lists, and after a list has been compiled it should be subject to regular taxonomic scrutiny to ensure further changes are accommodated. An example of an international collaboration to produce an agreed international list of names for regulatory purposes is *Fauna Europaea*.

A model for a possible process of providing and checking names and their synonyms is indicated in Figure 5 (page 29) for names included in international regulations (cf. Figure 3, page 10), and in Figure 6 (page 29) in the context of other lists used for quarantine. The extent to which this model is applied at national levels is not known, but it is likely that in practice

5. Deliberate introductions result from the purposeful transport of organisms, for example horticultural plants or seeds. Accidental introductions are those where alien species are transported accidentally via, for example, packaging materials, cargo containers, ship hulls or tourists.

Table 2 Tools to prevent invasions

Tools	Contributions from taxonomy [added to original]
Public information	Posters, websites, leaflets etc. featuring illustrations of species of concern use illustrations and name information from taxonomy
'Early warning', the capability to predict potential new invasion sites for an invasive species, and/or predict potential new invasive species for a region or site	Species occurrence data from taxonomic institutions are critical for predicting the potential of a species to be invasive in a new location
Risk assessments and environmental impact assessments	Prediction of invasiveness, rapid biodiversity assessments and identification guides are outputs from taxonomy
National and international regulations on prevention measures and their enforcement with inspections and fees	Consistent, internationally accepted species names, including mapping of local taxonomies and common names to scientific names, are necessary to enable communication and prompt action
Treatment of imported commodities, including through fumigation, immersion, spraying, heat and cold treatment, and pressure	A risk when treating commodities is the persistence of potential invasives in immature forms or reproductive units such as pupae or spores. Species expertise and/or identification guides are needed for inspections
As a last resort, trade restriction or prohibition consistent with the WTO Sanitary and Phytosanitary Agreement	Confidence in species identification is critical when using legal instruments that limit trade
(Source: Annotation of McNeely *et al.*, 2001: 25, Box 9.)	

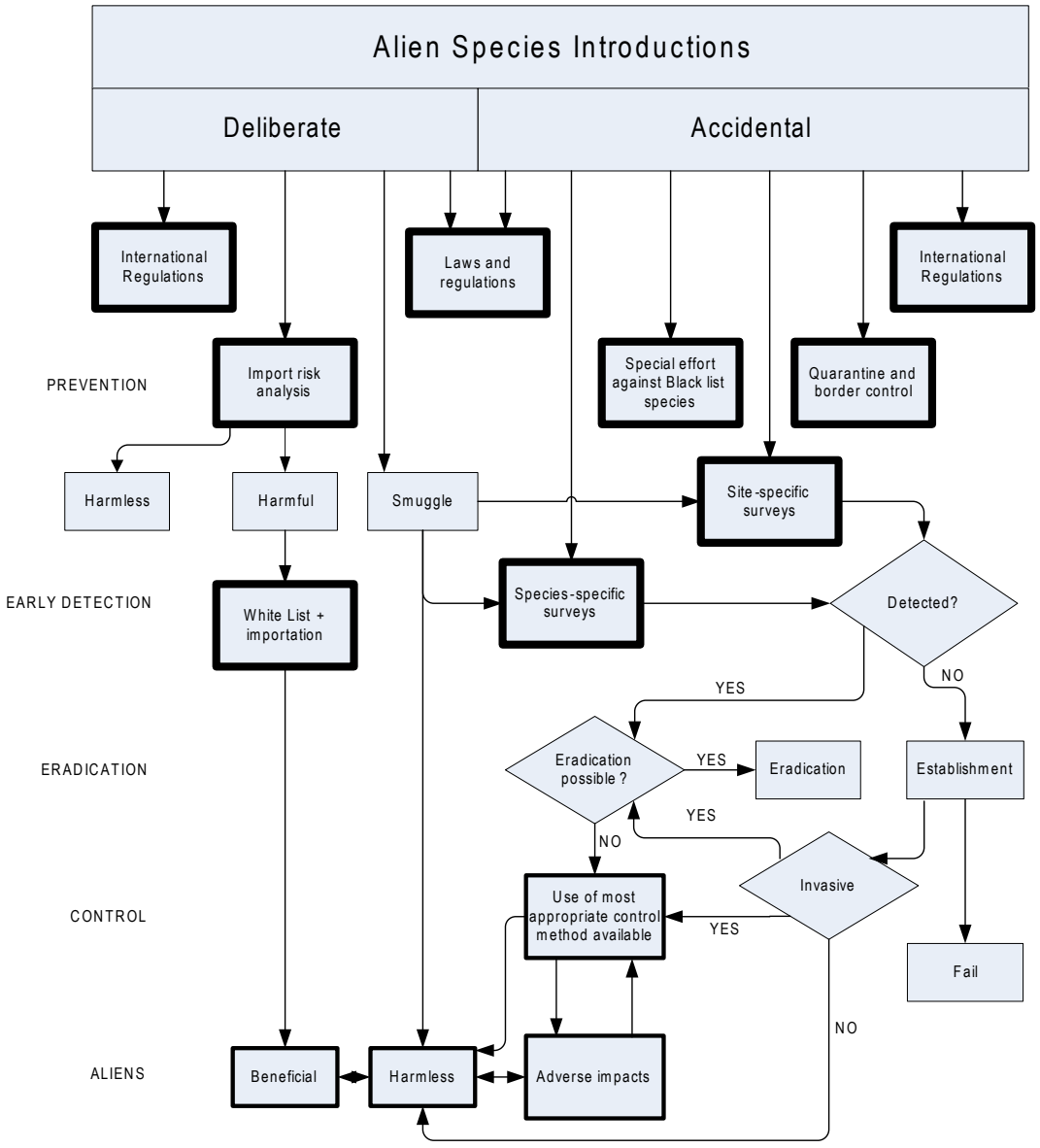

Figure 4. Taxonomic interventions in invasives management. Boxes with bold outlines indicate where taxonomic resources are relevant (e.g. identification aids or services, advice, monitoring). (Source: adapted from a flowchart in the *GISP Toolkit*: Wittenberg & Cock, 2001: 2, Figure 1.)

there are several routes through which names are added to lists of invasives for regulatory and other purposes. The main requirements are that:

- all names are accessible to the user
- different lists are kept synchronised to give a consistent taxonomic view
- taxonomic scrutiny is applied regularly.

Several relevant initiatives are involved in building components of such a system, including GISIN, GISD, GRIS and GBIF. An important corollary is that names (especially vernacular names) are an imperfect match to concepts, and taxonomic concepts change over time. It is therefore important that the ultimate model includes a check on taxon concepts to ensure the information pertaining to an invasive species follows the concept, not the name, in the event of change. The inclusion of GBIF as a source of names and specimen data will assist in this process, and interoperability of the systems used by these and other initiatives should streamline the model.

The taxonomic components around interception of invasives are provided in Figure 6. A central component of prevention is the ability to identify potential invasives at ports of entry. However, meeting the identification needs arising from interceptions and other invasives management continues to be a difficulty. Currently there are insufficient taxonomists available to carry out this work, and the difficulty in obtaining a timely response causes costly problems. Free online systems exist (notably PestNet), but these are based on voluntary contributions and, although useful to an extent, they have no mechanism for quality control other than participant scrutiny, they are not capable of dealing with the potential volume of identifications, nor do they deliver quality-assured identifications within a guaranteed time frame, as would be expected from an identification service. Also, such systems are not sustainable, and arguably prevent adequate

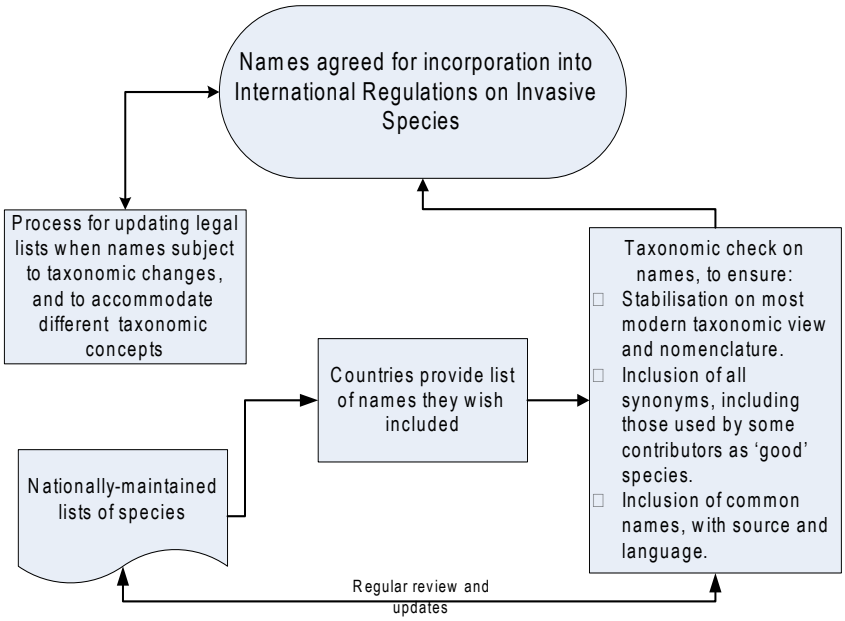

Figure 5. A process for checking and reviewing names for use both nationally and for international regulatory instruments

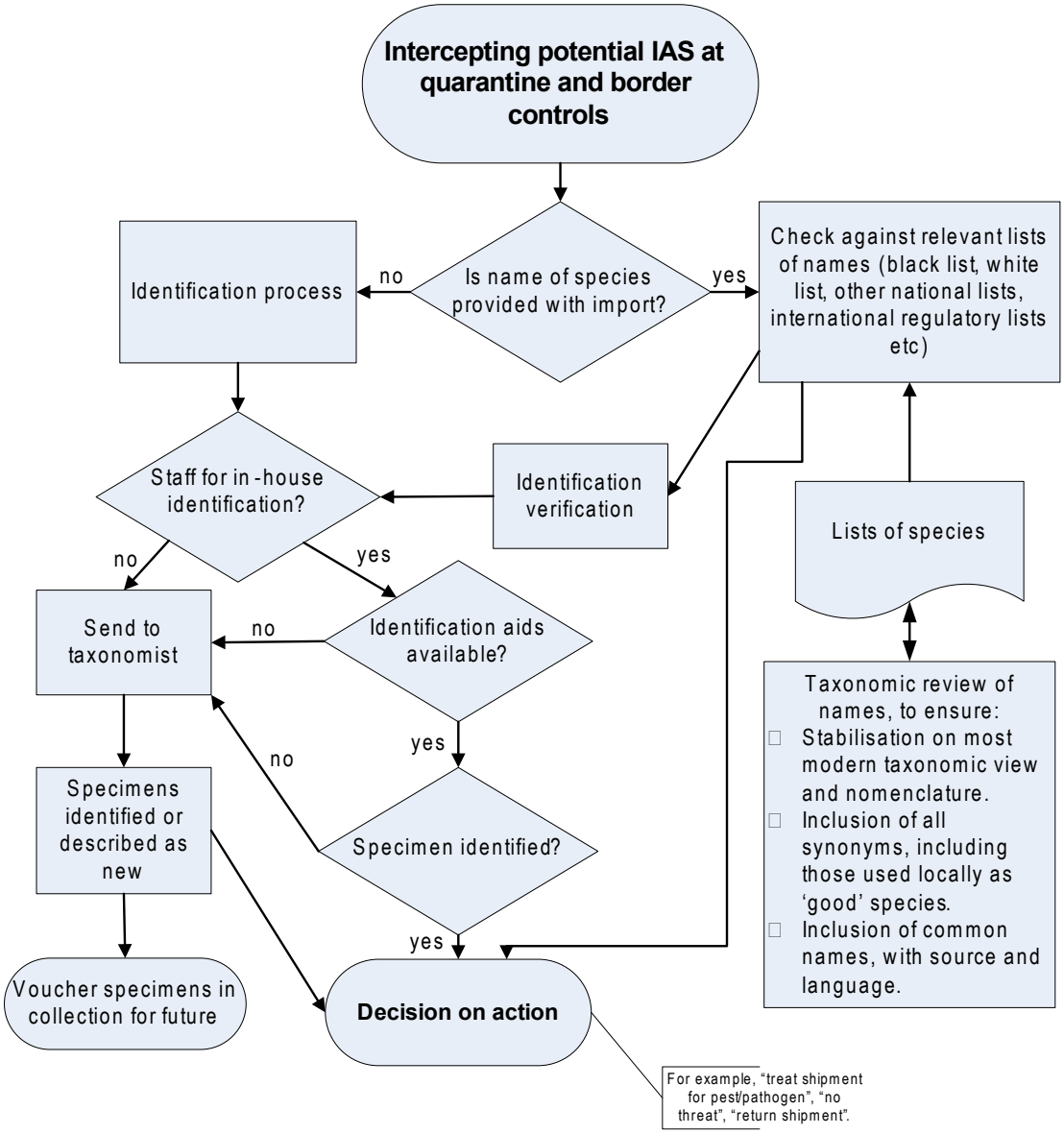

Figure 6. A process for including taxonomic requirements in the interception process

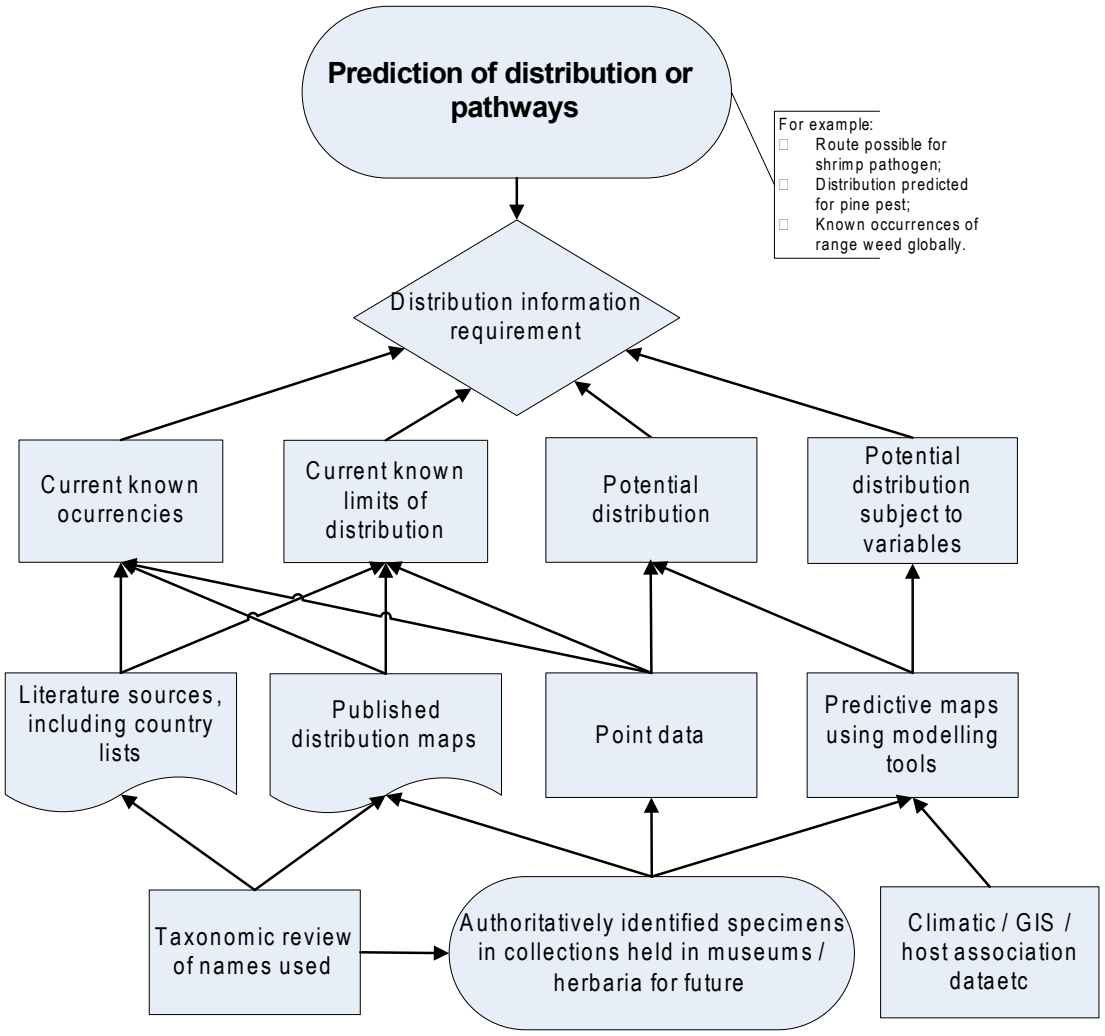

Figure 7. A process for including taxonomic requirements in predicting and modelling distributions and pathways

funding being raised to keep the required taxonomists in employment.

Novel molecular techniques are being developed that might speed up identification (see page 18), but as yet there is a paucity of molecular probes, so the majority of invasives are not categorised. More fundamentally, the genetic variability within and between species has not been established for many species, although the situation is changing rapidly.

A further mechanism is using an understanding of the distribution, and potential distribution, of problematic species. Here again, there are several possible inputs from taxonomy (Figure 7). Distributions may be provided only as 'point data' – each record of a species being plotted on a map. Alternatively, a map amalgamating these into a range can be produced, reflecting where a species is known to occur. With the addition of data on climate, soils, day-length or other relevant information, a map can be produced showing the places where a species *could* occur. Such predictions can greatly assist countries in identifying potential risks of invasion from various pathways and targeting measures to prevent the introduction of invasives. An extension of this would be to factor in potential distributions of disease vectors. This is not the place to discuss in detail to potential of these analytical techniques, but more to note that their success depends on digitised data from collections and observations, interoperability of the systems used, and taxonomic scrutiny of identifications and the names employed. The IUCN has identified the need for this type of predictive capacity as part of the suggested content and use of a knowledge base in the context of legal frameworks to deal with invasives (Shine *et al.*, 2000).

Early detection

Early detection is always likely to be a critical intervention point in invasives management because prevention measures can only ever minimise, not eliminate, the risk of introductions. Should an introduction have occurred, the earlier it can be detected, the better the prospects for containing the invasive's dispersion and minimising the cost of control. Robust surveys, either species- or site-specific (e.g. ports, particular ecosystems), are central to the detection and monitoring of introduced species.

Surveys may not involve taxonomists in their execution, but

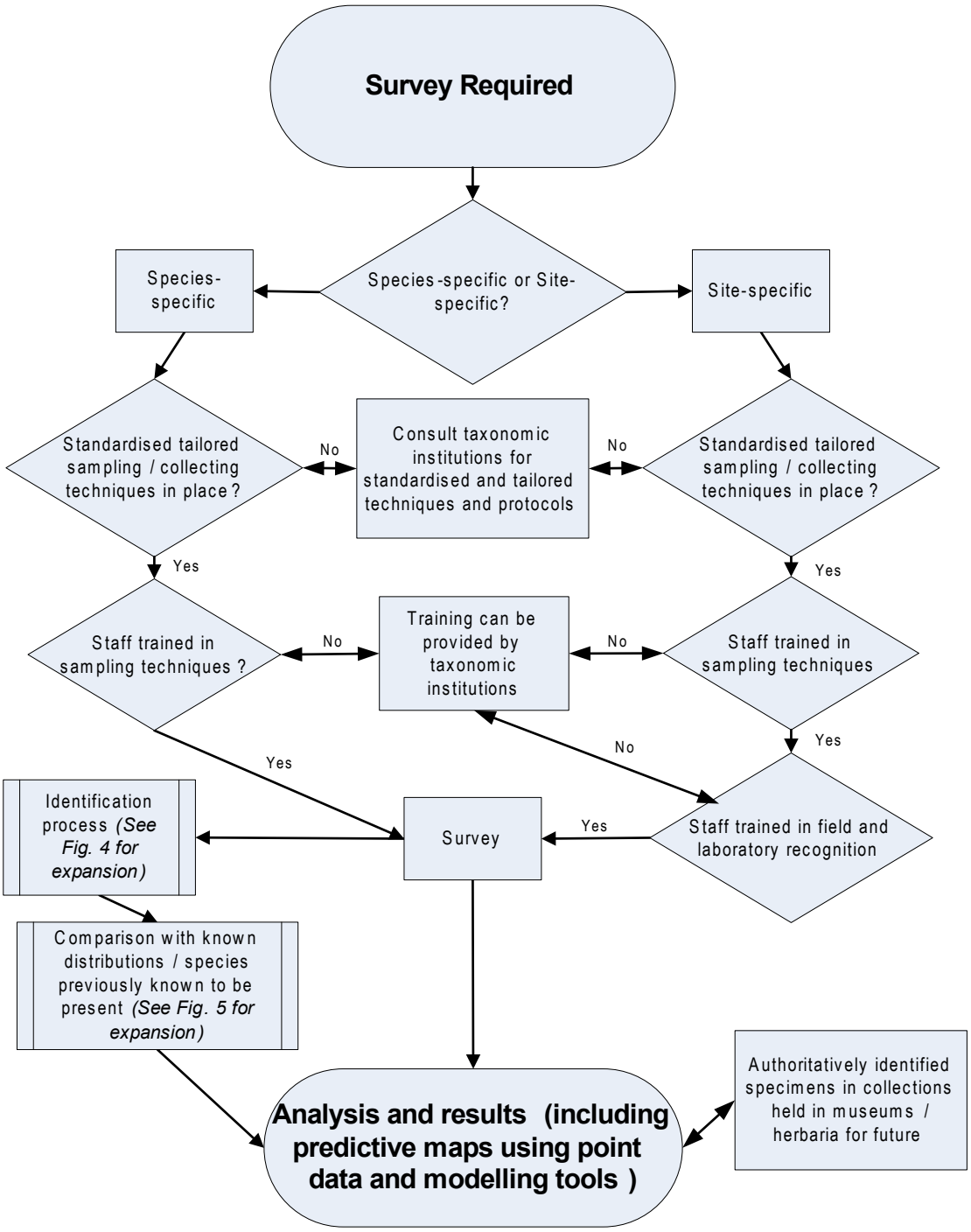

Figure 8. A process for including taxonomic requirements in carrying out surveys of invasives, and their impacts

they often benefit from the use of sampling protocols that have been developed by taxonomists for many different species groups, and from the training that may be required to use them (Figure 8). Standardised trapping techniques may be identified within protocols for assessment and monitoring particular pests under IPPC guidelines (e.g. for fruit flies; IPPC, 2006b). Taxonomists can also contribute a good understanding of the natural history and ecology of the target species. The specimens collected in a survey will require identification, either by non-taxonomists using identification aids produced by taxonomists and/or by taxonomic experts themselves. Although some surveys identify specimens only to 'recognisable taxonomic units', and do not give them formal identifications, this practice limits the potential for comparing survey results between sites or between times, and precludes the employment of sophisticated modelling techniques. Incorporation of data on distributions or, more effectively, point data for authoritatively identified specimens, both from the survey and from other collections, may assist in developing trend maps or predictive maps. Finally, although there is no standardised system, it is good practice for observations, including surveys and inventories, to be vouchered with examples of the specimens concerned (see page 17), so

that specimens collected in different places or at different times can be compared. A document on adoption of international standards, presented to the Commission on Phytosanitary Measures at its meeting in Rome in March 2007 (IPPC, 2006b), noted with respect to organisms new to science, or for which only incomplete identification was possible, that 'It is recommended that specimens are deposited in an accessible reference collection for future further examination.' To be useful in the longer term, and to more countries, vouchers need to be stored in well managed collections, either locally or in a regional or international repository.

As with many other elements of invasives management, identification is of central importance, and the more tools and skills can be made directly available at the point of capture and observation, the more likely it is that early detection can be achieved and action targeted appropriately. An example of provision of this type of information is provided by a UK Darwin Initiative-funded project on Sri Lankan land snails (Naggs, 2006). A national survey of terrestrial molluscs allowed the establishment of specimen reference collections and a database on distributions. The survey established that, particularly in the Central Highlands, the most damaging species of exotic pest gastropods were firmly established at very high densities. However, as a result of the work, the Sri Lankan managers developed a good knowledge of what pest species were present, and the project produced identification guides to the native fauna that will allow a speedy response to the arrival of new exotic slugs and snails, making it possible to prevent further damage to both agriculture and biodiversity.

Eradication and control

When prevention fails and invasives become established, an assessment of their impact is required, with eradication or control measures applied where appropriate. Surveys linking habitat preferences with species occurrence may help with decisions about whether action is required. For example, surveys of introduced geckos on the Galapagos showed that introduced and native species had different habitat requirements, and that action to control the alien species was not required on those grounds. Taxonomic expertise was intrinsic to this exercise (Cruz, 2005).

If eradication or control is required, these may involve physical removal, chemical treatment or biological control. Whichever method of control is chosen, only when a suspected invasive alien species is correctly identified can effective control or mitigation measures be implemented, drawing where possible on best practice learnt from tackling the invasive species elsewhere. Biological control has proven to be a highly successful, environmentally benign, economic yet effective method of control in many cases. It depends on research by taxonomists, or those with taxonomic competence, to identify natural enemies that are found with, and limit the population of, the problem species in its native area. There are examples of successful use of biocontrol agents against invasives, such as the weevil *Cyrtobagous salviniae* against the waterweed *Salvinia*, where taxonomic input was crucial to identifying the species of *Salvinia* and distinguishing the active weevil from very similar relatives (Lyal, 2005).

Control measures generally involve some risk to native biota. Taxonomy contributes to environmental impact assessments, through surveys, identifications and species checklists.

5. Conclusions

The results of this assessment confirm and help explain why taxonomy is a critical tool for combating the threats from invasives. Taxonomic expertise, biological collections, species information and services can contribute to each stage of invasives management identified in the *GISP Toolkit for Best Prevention and Management Practices* (Wittenberg & Cock, 2001):

- prevention
- early detection
- eradication
- control.

Even where there is no direct link with taxonomists, action throughout the management system is predicated on taxonomic information – basic information on the identity, name and occurrence of both alien and native species. These points were made repeatedly by professionals working with invasives throughout the assessment.

The most commonly asked-for taxonomic products to assist in combating invasives are very practical and, in principle, straightforward to deliver. Keys, guides, images, species lists and voucher specimens, to name a few, can all be produced provided experts have the time, resources and recognition for this fundamental provision. Advancing technologies continue to increase the potential value of taxonomic support to invasives management. Real-world examples already demonstrate how data from digitised biological collections can be used to predict which species are likely to be a threat from different introduction pathways. For some species, molecular markers are already used by identification services to increase their responsiveness and output.

There is a lack of awareness of resources that are already available among end-users of taxonomic support for invasives management. Lists, registers of experts and online resources often do not seem to reach potential beneficiaries. A review of existing information and an accessible global information system, such as the one being developed by the GISIN initiative, will help enormously in getting the information to the end-user.

Promoting, mobilising and packaging existing information according to user needs is only part of the solution. Sustaining (and where necessary establishing) reference collections and associated taxonomic expertise remain of central importance for developing taxonomic products, now and in the future. For example, countries can gain permission for an agricultural export rapidly only if an accurate pest record supported by physical specimens held in a collection exists in the region (Evans *et al.*, 2002). Yet the picture is bleak: there is a near-absence of taxonomic capacity to support invasives management in most (especially developing) countries, and even in Europe the taxonomic expertise relevant for plant protection 'will irreversibly disappear' unless urgent action is taken (EPPO, 2004).

Training of the experts needed to create products for end-users is therefore of great importance. Institutions and funders need to recognise that invasives are a priority, and that generating products and information needed to confront invasives are important outputs of taxonomic institutions. The fact that biodiversity is often poorly known – especially in developing countries, where capacity is typically very limited but where diversity of organisms is greatest – is a major obstacle to be overcome.

Innovation in delivering taxonomy to end-users is essential to respond to the threat posed by invasives with necessary urgency, making the best use of the capacity available. Taxonomic experts should share their knowledge between sectors and countries, and should assist in creating an army of parataxonomists and extension workers able to identify new and existing invasive alien species. Developing and employing a single set of morphological descriptors will make it possible to repurpose keys according to local needs and emerging threats.

Also needed are national and regional networks to mobilise taxonomists and provide training, identifying responsible institutions and partnerships for the development of taxonomic services and information, and to an extent these are under way. There is also a need to build research networks that incorporate risk assessment and risk management.

Addressing the needs reported in this study adequately is achievable and affordable. Much relevant work is under way, and could be greatly accelerated through coordinated actions leading to a fruitful environment that empowers taxonomists to produce the tools and resources needed for successful invasives management. When better engaged in invasives management programmes, many more taxonomists will be able to respond with information on names, species distribution data, identification aids and expertise appropriate to local contexts. Ensuring this happens is a responsibility to be shared by:

- invasives managers, the end-users and ultimate beneficiaries of taxonomic support
- institutions that provide taxonomic support
- policy, funding and technical coordinating bodies that provide incentives, set priorities and create an enabling environment for taxonomic institutions committed to helping prevent and manage invasives.

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Text in red links directly from the pdf version of this document to the relevant website.

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7. About the organisations

The Global Invasive Species Programme (GISP) is an international partnership dedicated to tackling the global threat of invasive species. Established in response to the first international meeting on invasive alien species held in Trondheim, Norway (1996), GISP's mission is to conserve biodiversity and sustain livelihoods by minimising the spread and impact of invasive species. GISP provides support to the implementation of Article 8(h) of the Convention on Biological Diversity, and has contributed extensively to the knowledge and awareness of invasive species through a range pf products and publications. Working primarily at international and regional levels, GISP aims to build partnerships, provide guidance, develop a supportive environment and build capacity for national approaches towards the prevention and management of invasive species.

BioNET is an international, not-for-profit initiative dedicated to promoting taxonomy, especially in the biodiversity-rich but economically poorer countries of the world. Working via locally owned and operated partnerships (LOOPs), BioNET strives to provide a forum for collaboration that is equally open to all taxonomists and to all users of taxonomy. Working with partners locally and internationally, our work contributes to raising awareness of the importance of taxonomy to society, building and sharing capacity, and meeting taxonomic needs via innovative tools and approaches.

The Natural History Museum [formerly known as the British Museum (Natural History)] is one of the largest natural history museums in the world, and holds internationally important collections and libraries. Its 300 scientific staff study species of plants, animals and microorganisms from all over the world, and form one of the largest groups of taxonomists anywhere. For many years the Museum has strongly supported outreach and training, and is continually seeking ways in which taxonomic knowledge and information can be made more widely available.

The International Sustainable Development Fund is a fund managed by the Department for Environment, Food and Rural Affairs (UK). The objective of the fund is to accelerate implementation of commitments made at the World Summit for Sustainable Development through high-level sustainable development dialogues with rapidly developing countries (India, China, Brazil, South Africa, Mexico) and through multi-stakeholder partnerships.

Annex 1 Detailed results of the assessment

Table A1 Number of references to end-user needs for taxonomic outputs

	Number of references in:		
Need	**Documents**	**Interviews**	**Total**
Identification support Information on where and how to get specimens identified Improvement of detection facilities at ports of entry Taxonomic support to identify newly arriving species Online access to taxonomists Remote diagnostics	9	37	46
Identification aids Identification keys and guides for known invasives with main invasion pathways Online identification keys Keys and guides for species which have applied value Global keys with common descriptors Translation of keys into local languages Molecular screening of specimens New information tools for priority taxonomic groups	7	52	59
Lists of species Lists of invasives Accessible lists with taxonomic information on invasives 'Black lists' of species known to be harmful to biodiversity (speed decision-making) Lists and databases available from a single portal	15	15	30
Surveys and monitoring Survey and monitoring programmes Measures of effectiveness for management and control programmes Scientific advice on survey methodologies Invasives prevention and control projects	32	11	43
Distribution information Distribution data Distribution in text form Distribution via databases	1	22	23
Pathway maps Pathway maps Predictive tools to evaluate invasiveness List of procedures for pathway analysis	12	11	23

Table A2 Number of references to taxonomic sector needs relevant to institutions' ability to produce outputs for invasives management			
	Number of references in:		
Need	**Documents**	**Interviews**	**Total**
Capacity (expertise and facilities) Increased taxonomic capacity Employment of scientists (e.g. taxonomists) to address invasives Development of a corps of experts/trainers	20	13	33
Taxonomists To address lack of taxonomists Training programmes for taxonomists Access to a network of marine taxonomists to identify specimens Assessment of national and regional taxonomic capacity Parties to report on measures to strengthen taxonomy Taxonomists need to be encouraged to stay in taxonomy	21	9	30
Parataxonomists Training for parataxonomists More personnel, including parataxonomists More people working at ports	12	2	14
Collections and curation Facilities for collections Reference collections and voucher specimens available Laboratory facilities Maintenance of collections Improved access to collections Collections needed More curators needed	4	20	24
Nomenclature and classification Name-resolving service for synonymies Global standards for taxonomic classification of invasives Taxonomic classification Cross-reference species names/synonymy/coexisting taxonomies Common names 90% of biologists do not understand synonymies and alternative taxonomy Updated catalogue of names	3	25	28
Digitisation of data Coordinated databases with information on invasives Specimen data Improved availability of accurate taxonomic information Digitisation of data Maintenance and management of databases Digitisation of literature on collections Interoperability of databases	10	21	31

Table A2 continued			
	Number of references in:		
Need	**Documents**	**Interviews**	**Total**
Identification services	9	15	24
Literature Better access to literature Increase in publications on invasives Reviews of the literature and sources of literature Taxonomic literature Taxonomic literature is often esoteric Taxonomists need to be encouraged to publish as they go, perhaps on the web	6	18	24
Data standards Validation of data (protocols) How to deal with errors	0	11	11

Table A3 Number of references to supra-institutional activities and prioritisation of needs			
	Number of references in:		
Need	**Documents**	**Interviews**	**Total**
Prioritisation Priority-setting for taxonomic work Priorities to be sector-based	11	–	11
Collaboration Networking on all levels Networking between experts Sharing of information, communication links Coordinated mitigation measures and reporting systems Linking developing countries to developed countries Networking between point of entry and invasives experts	20	25	45
Strategies Global, regional, national (early detection, prevention, reporting, risk analysis, control) Creation of a risk assessment centre (coordination)	21	11	32
Research Taxonomic research Taxonomy for generation of baseline species data Research and development Research on impacts of invasives Review research needs regarding invasives Matching molecular to morphological data is critical Predicting which ecosystems are at greatest risk of invasion by determining the distribution of taxa closely related to known invasives	22	12	34
Education and training Training programmes for new scientific/technological approaches to taxonomy Training in collection and curation techniques Training in database use Regional and global training courses Online education programme on invasive species management Invasive alien species on school and university curricula Training through internships, scholarships, exchanging staff Best practice and training modules	18	11	29
Awareness-raising Raise awareness among decision-makers of issues concerned with invasives and taxonomy Promote the GTI Produce and distribute audiovisual materials Global initiatives to promote issues concerned with invasives	6	5	11
Funding Funding for taxonomic capacity-building to support prevention, monitoring and mitigation of invasives Funding for taxonomic and academic work	7	7	14

Annex 2 Gaps in taxonomic knowledge and resources identified in the assessment

- Knowledge of marine species.
- Basic global-scale taxonomic studies in mariculture (cultivation of marine organisms for food and other products).
- Catalogues and identification in marine, coastal, montane and alpine habitats in Kenya.
- Training and guides to identify poorly known groups, coral species and other island species.
- Taxonomic studies or revisions of important island taxa, including marine, freshwater and terrestrial species.
- Taxonomic expertise to make inventories of island species and to assess their conservation status and threat criteria.
- Taxonomy of inland water systems.
- Taxonomic coverage for alien freshwater aquatic species.
- Taxonomy of inland water biodiversity of economic as well as ecological importance.
- Identification of hotspots of mountain biodiversity.
- Working lists of organisms for montane areas.
- Working identification keys for montane areas.
- Supporting work on taxonomic issues in forest ecosystems.
- Taxonomic information on pollinators.
- Continuity of taxonomic and reference collections of bees and pollinators.
- Assessment of taxonomic knowledge on pollinators.
- Taxonomic capacity to carry out inventories of pollinator diversity and distribution.
- Taxonomists and parataxonomists of bees and other pollinators.
- Keys for bee genera.
- Taxonomic coverage is weaker for lower taxonomic categories.
- Marine taxonomy, life-cycle biology, and native and introduced range distributions.
- Species of commercial importance, threatened species and species used in aquaculture.
- Information on poorly understood and cryptogenic species (species of unknown origin).
- Monograph studies of exotic and invasive taxa.
- Taxonomic work for biocontrol.
- Experts on aphids and thrips.
- Taxonomic expertise in Porifera.
- Taxonomic expertise in Ectoprocta.
- Taxonomic expertise in Annelida.
- Taxonomic expertise in Urochordates.
- Taxonomic expertise on pathogens.
- Taxonomic expertise on nematodes.
- Taxonomic expertise on bacteria.
- Taxonomic expertise on weeds.
- Taxonomic expertise on insects.
- Taxonomic expertise on fungi.
- Taxonomic expertise on sponges.
- Taxonomic expertise on polychaetes.
- Taxonomic expertise on acidians.
- Taxonomic expertise on bryozoans.
- Information on mundane things (e.g. cockroaches).
- Studies on forestry pests from eastern Russia.

Annex 3

Experts consulted for this assessment		
Contact	**Organisation (current or prior affiliation)**	**Country**
Naima Barbouche	Institut National Agonomique de Tunisie	Tunisia
Michael Browne	Invasive Species Specialist Group (IUCN)	New Zealand
Christine Casal	World Fish Centre, FishBase project	Philippines
Robert Emery	Cooperative Research Centre for National Plant Biosecurity	Australia
Jennifer Forman Orth	University of Massachusetts, Boston	USA
Chad Hewitt	Australian Maritime College	Australia
Ryan Hill	Convention on Biological Diversity Secretariat	Canada
Lynn Jackson	GISP Secretariat	South Africa
Vyjayanthi Lopez	CABI Caribbean & Latin America	Barbados
Ralf Lopian	Vice-Chair, Commission on Phytosanitary Measures (International Plant Protection Convention) and Ministry of Agriculture & Forestry, Finland	Finland
Imene Meliane	International Union for Conservation of Nature, Marine Programme	Ecuador
Scott Miller	Smithsonian Institution	USA
Sean Murphy	CABI (GISP Board member)	UK
Geoff Norton	Centre for Biodiversity Information Technology	Australia
Jamie Reaser	Ecos Systems Institute (formerly GISP)	USA
Elizabeth Sellers	US Geological Survey – National Biological Information Infrastructure	USA
Annie Simpson	US Geological Survey – National Biological Information Infrastructure	USA
Kevin Thiele	Centre for Biological Information Technology	Australia
Terrence Walters	US Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine division of the Center for Plant Health Science and Technology	USA
Sergio Zalba	University of Argentina	Argentina
Silvia Ziller	The Nature Conservancy/Horus Institute/GISP Board	Brazil

Unless greater management steps are taken to prevent harmful introductions that accompany increased trade, invasive species will cause increased ecological changes and losses of ecosystem services in all scenarios.

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