GISP

The Global Invasive Species Programme

A Toolkit for the Economic Analysis of Invasive Species

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and Geoffrey Howard

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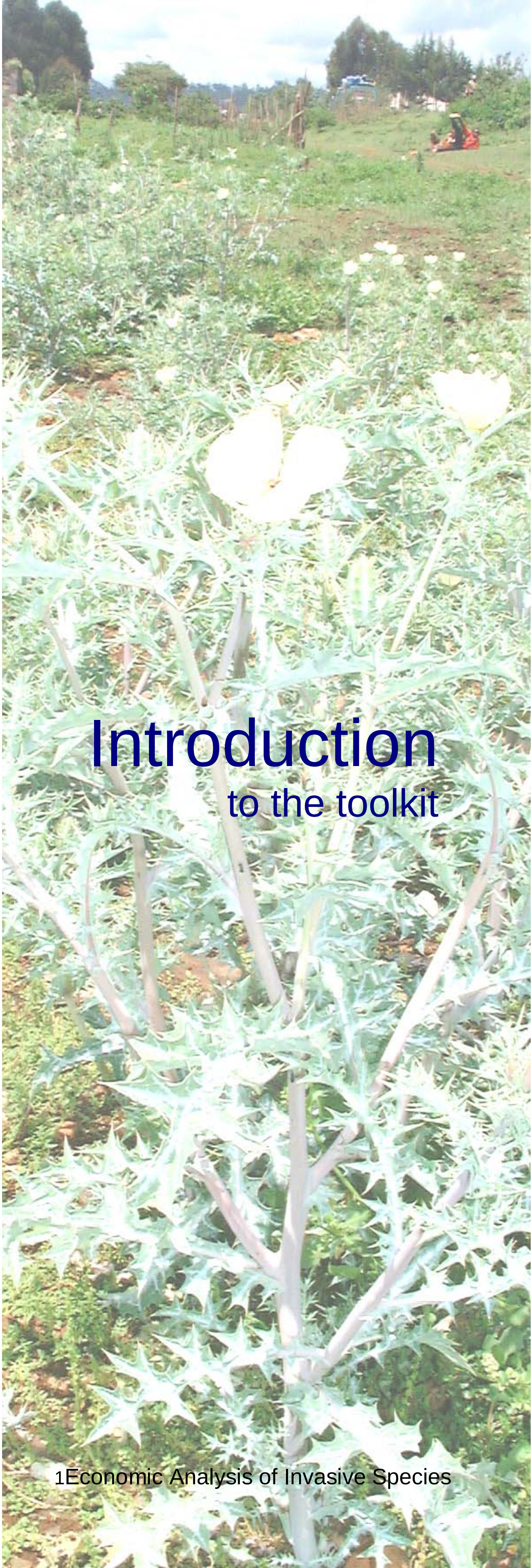


Introduction
to the toolkit

Understanding invasives as an economic issue

The issues associated with biological invasions have, traditionally, been seen as being the responsibility of biologists. However as invasives have become more and more widespread and their impacts on human systems have escalated, the scientific community has started to call increasingly for the input of economists and other social scientists.

In fact, invasive species are fundamentally an economic problem – in terms of their causes, effects and remedies. Most invasions can be linked to the intended or unintended consequences of economic activities, which in turn means that economic solutions are also required. At the same time the major (although not only) reason that invasives are considered a problem by human beings is because they ultimately impact on economic systems and undermine human wellbeing: by directly affecting particular sectors, sites or groups; by indirectly affecting economic processes and opportunities through their knock-on effects and secondary impacts; and due to the expenditures that are required to manage them.

Despite a growing recognition by the scientific community of the need for economics, and a rising awareness among economists of the importance of dealing with invasive species, the use of economic approaches and tools to better understand and address invasives remains a recent innovation. A small but steadily growing body of literature on the economics of invasives has emerged. Most of this has however been generated during the last decade and the vast majority of which refers to the problems associated with the spread of invasives in (mainly) North America and (to a lesser extent) Europe. In particular, there has been a focus on calculating the costs associated with invasives: it is only over the last few years that more in-depth economic analysis has started to be integrated with the natural sciences in order to model the causes and effects of invasives, and to assess the use and impacts of policies and other instruments which influence their spread.

Moving on from an initial focus on generating the numbers which would underline the massive economic costs associated with particular invasive species, it is now widely recognised that economics is to do with much more than just understanding the costs of invasives or the benefits of managing them. It also concerns understanding the complex causes of the introduction and spread of invasives, the links between human behaviour and natural processes, and finding solutions.

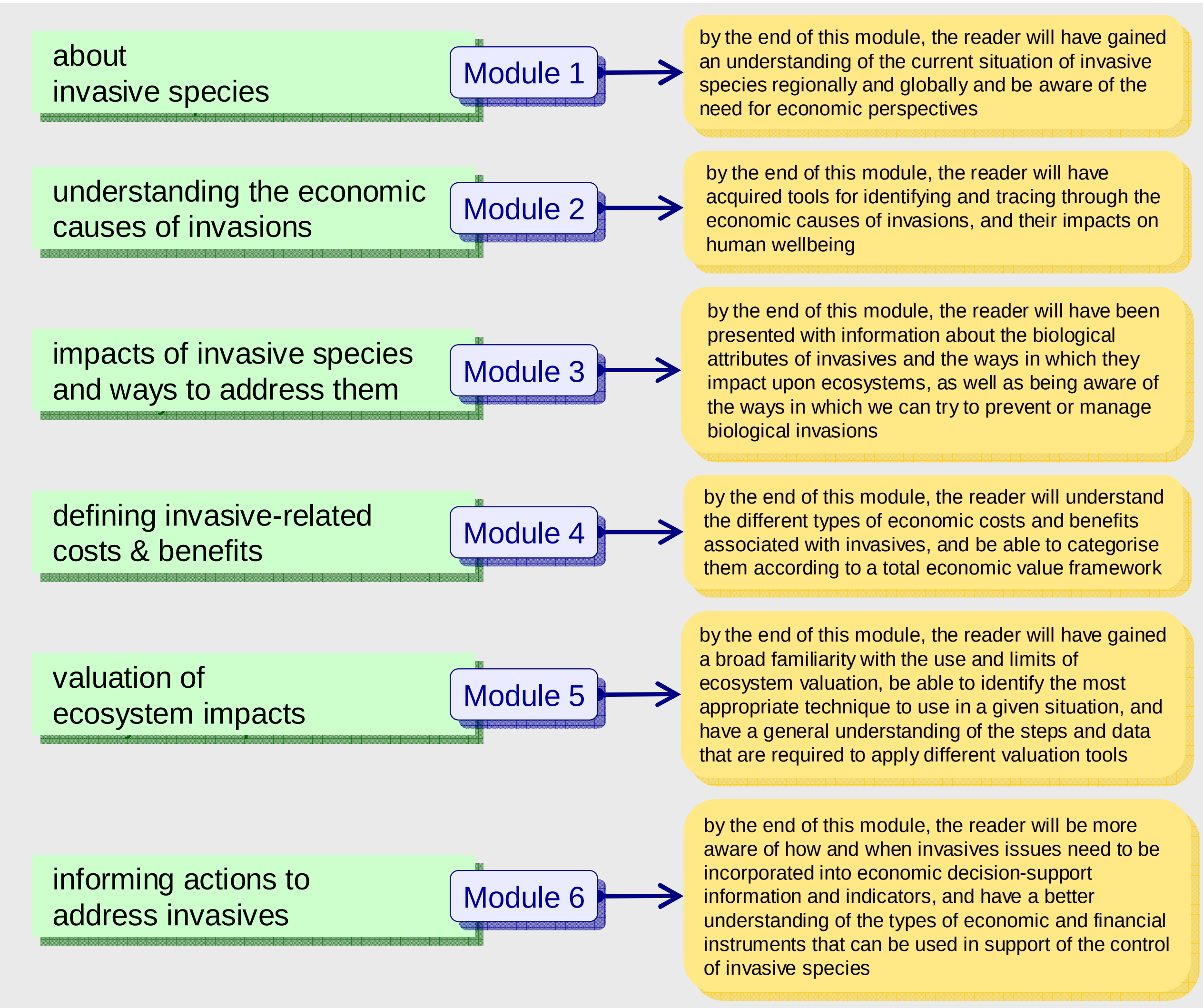
The toolkit

Although it is now widely acknowledged that economic analysis and the use of economic instruments are key to dealing with the problems associated with biological invasions, there remains little guidance as to how economic approaches and tools should be applied in practice. Invasive species have many unique and unusual characteristics which set them apart from other environmental and land use issues, meaning that analysis does not lend itself easily to conventional economics models. A more innovative and thoughtful approach is thus required, which is tailored to the specific issues, problems and features of invasives. Economic analysis needs also to be targeted to providing practical and policy-relevant techniques and information which can be used to support and inform real-world policy, planning and management.

The aim of this toolkit is to provide a clear, user-friendly guide to the application of economic approaches and tools to invasive species. It addresses the issues associated with identifying the factors which cause the spread of invasives, incorporating consideration of invasive species into economic planning and policy-making, and identifying economic tools and measures to support on-the-ground management actions designed to address biological invasions. This toolkit has been produced for use in training courses to be held in Africa. It is targeted primarily at economists working in research and planning – in universities, research institutions, government agencies and non-governmental organisations. However, it is intended that the toolkit will also provide guidance on economics tools and approaches to scientists who are working on invasive species management.

The toolkit employs a modular approach, and works through a series of iterative steps that can be followed in order to identify, understand, address and manage economic aspects of invasive species. The toolkit's component modules have been developed for delivery via a 3-day training course, and are accompanied by a workbook of real-world case studies from Africa which illustrate the ways in which economics approaches and tools have been applied to invasive species in practice. It is intended that in the future, similar workbooks can be produced for other regions.

The first part of the toolkit (Module 1) provides an introduction to invasive species as biological entities. It describes how and why they are important, as well as defining key terms and concepts in the science of invasion biology. Subsequent modules deal with the steps in economic analysis of invasive species: to understand the economic reasons why alien species are introduced, and become invasive (Module 2); establish the scope and level of the impacts of invasives and their management (Module 3); understand and define the economic costs and benefits of invasives (Module 4); value the economic effects of invasives on ecosystems and human wellbeing (Module 5); and support and inform decision-making and identify economic and financial instruments which can be used to address invasives (Module 6). The toolkit also contains a glossary of key scientific and economic terms, as well as a list of key readings on the economics of invasives.



About GISP

The toolkit has been produced under the auspices of the Global Invasive Species Programme (GISP). GISP was founded in 1997 as a small, mainly voluntary partnership programme, by three international organizations: The International Union for the Conservation of Nature (IUCN), CAB International (CABI), and the Scientific Committee on Problems of the Environment (SCOPE). In early 2005, GISP was constituted as a legal entity with Founding Members IUCN, CAB International, The Nature Conservancy (TNC), and the South African National Biodiversity Institute (SANBI). GISP is headquartered in Nairobi, Kenya at CABI Africa.

The GISP mission is to conserve biodiversity and sustain human livelihoods by minimising the spread and impact of invasive alien species. To this end, GISP seeks to:

- improve the scientific basis for decision-making on invasive species
- develop capacities to employ early warning and rapid assessment and response systems
- enhance the ability to manage invasive species
- reduce the economic impacts of invasive species and control methods
- develop better risk assessment methods, and
- strengthen international agreements.

In addition, GISP strives to:

- develop public education about invasive species
- improve understanding of the ecology of invasive species
- examine legal and institutional frameworks for controlling invasive species
- develop new codes of conduct for the movement of species, and
- design new tools for quantifying the impact of invasive species.

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The Global Invasive Species Programme

Module 1
about invasive species

Economic Analysis of Invasive Species

1A What this module covers

This module introduces invasive species as biological entities and describes how and why they are important.

By the end of this module, the reader will have acquired an understanding of the current situation of invasive species nationally, regionally and globally. It will raise awareness of the need for economic perspectives to be added to the ways in which we are trying to improve our understanding of how to tackle this local, national, regional and global problem that affects people's development, their livelihoods, health and well-being, as well as biodiversity upon which so many depend. The training will include an introduction to some of the technical terms used in discussing invasive species but does not expect the reader to be a biologist.

Biological invasions involve more rapid colonisation and spread of species into new areas than would have occurred naturally before our species reached today's levels of global travel, trade and general globalisation. The effects of biological invasions impact on many peoples' daily lives – even though they may not be aware of it. Thus we will use the first module to introduce the phenomenon of invasion, the actors involved, and begin to look at the impacts they have on us and our neighbours

1B Understanding invasive species - a biological and development issue

What is meant by "biological invasion" and why do we care?

Biological invasion occurs when a species enters a new environment, establishes itself there and begins to change the populations of species that existed there before, as well as disturbing the balance of plant and animal communities. Species move from one place to another as a result of natural processes and have done so since the beginning of life on earth. But these movements (due to wind and water currents, earth movements and continental shifts, new opportunities for expansion, etc.) have been limited by geographical barriers such as oceans and mountain. Such processes are regarded as natural phenomena which have brought about subtle changes to the fauna and flora and ecosystems of places around the world – but they are not the topic of this module. "Natural invasions" are the background changes that occur and have occurred irrespective of the presence of people. The change that brings us to this training course, and which makes us ask why we should care about biological invasions, is their extraordinary increase in frequency and impact since people began to move around the world so widely and in such large numbers. We will describe and illustrate how people have accidentally and intentionally moved species around the world with resulting biological invasions many times more frequent and more damaging than the natural background movement of species.

Human assistance and enhancement of movement of species have become most prevalent in the last few decades as globalisation and human trade, transport, travel and tourism have increased to present levels. The phenomenon of human assistance to species movement and resulting biological invasion has, however, been recognised for centuries and we have historical information of this happening for at least ten thousand years. But the "process" became more frequent in the last two centuries as means of travel became more sophisticated and effective and countries encouraged exploration, colonisation and global trade. It is now 50 years since a treatise on this topic was published by Charles Elton (Elton, C.S., 1958) and the realisation began to dawn that species spread and species invasions was having negative (as well as positive) impacts both on human development and the natural world of animals, plants and micro-organisms.

The following modules will discuss the economic costs (and occasional benefits) of biological invasions, but suffice to say that the cost to the global economy is in the trillions of dollars – if all available estimates are totalled for a year. This is because biological invasions affect all types of ecosystems (terrestrial, freshwater, marine and coastal) and are now know to occur in all continents, oceans and biomes. They have occurred and still are occurring in the wildest of ecosystems, in protected areas, in productive systems such as agriculture, forestry and fisheries and have been shown to be among the worst causes of ecosystem degradation (Millennium Ecosystem Assessment, MEA, see Module 3).

It may help to mention an example of a species invasion well-known to many in Africa: that of the **Water Hyacinth** a floating water plant from tropical America which has brought numerous problems to the freshwater systems of Africa since its introduction and invasion. Water Hyacinth (*Eichhornia crassipes)* is a common floating plant of the rivers, lakes and swamps of Central America and tropical South America where, in its natural habitat, it is not a problem to people or the ecosystems of the region. It has a very attractive purple and yellow flower which was the main reason that travellers collected it and brought it to other parts of the world where it was grown in “water gardens” and ponds in Europe and North America. From there, in the 1880s, it found its way (by human intervention) into several of the countries of Africa as a floral curiosity and attractive plant associated with water. Water hyacinth can reproduce from seeds (from the prolific flowers) and from the vegetative extensions from mother plants as well as plant remnants spread by people, wild and domestic animals, water and wind. It can also grow very fast in ideal conditions, doubling its area of occupancy in a matter of days. By the 1990s, this plant had appeared in the lakes, rivers and swamps of many tropical and sub-tropical African countries with devastating effects on water supply, water loss, aquatic travel and transport, hydropower generation, fisheries, human health and native biodiversity. The literature abounds with estimates of the costs of this invasion (which continues to spread) in many parts of Africa as well as the costs of its control and management - totalling billions of dollars across the continent and making permanent changes to wild biodiversity and people’s access and use of natural and man-made water systems. This is a classic example of an intentional introduction and then unintentional spread of a foreign species which became established and then has become invasive – with many negative impacts on people, their development and health as well as biodiversity.

Some definitions and steps to biological invasion

The Science of Invasion Biology has become well established and detailed as scientists study the mechanisms of invasion and try to predict which species will become invasive, where they will become invasive and why. Nevertheless it is still extremely difficult to predict this phenomenon with any accuracy. There are now quite a number of terms that have several different definitions depending upon the interests of the proposers and the complexity of the topic. In this course, we will adopt a simple set of definitions but recognise that there are others, more detailed and more complex, that can also apply.

One basic tenet of invasion is that the species concerned comes from “another place” – which, biologically, means that it is not part of the flora or fauna of the ecosystem concerned. To describe this “foreign-ness”, the term “ALIEN” has been used in relation to invasive species in many cases and serves to remind us that invasion is, of necessity, a production of non-native species. The concepts of ecosystem and foreign-ness will be described in the presentation in simple terms so that this course does not require the participants to become involved in the semantics of native (indigenous) versus foreign (exotic) terminology.

Box 1: key definitions

alien species	a species that has been introduced to a location (or area, or region) where it does not normally occur
invasive alien species (IAS)	an alien species that causes (or has the potential to cause) harm to the environment, economies and/or human health. This definition can also be applied to an “invasive species” (IS) where the alien adjective is assumed.

While we will continue to use these two definitions, it is sensible to mention that there are others that differ in detail. One that needs to be considered is that from the Convention on Biological Diversity (CBD) which is an international agreement on the conservation and use of biodiversity. It maintains that an IAS is an “alien species whose introduction and spread threatens ecosystems, habitats or species with socio-cultural, economic and/or environmental harm, and/or harm to human health”. This is a more detailed definition which links impacts of IAS on biodiversity to the human condition – including economics. The CBD convention text has a section on invasive species (Article 8 (h)) which states that “Each Contracting Party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species” – which is the definition of IAS from a different perspective. We will return to this definition and Article 8 (h) in Module 3.

How alien introduced species become invasive

Invasive biology has identified several stages that an alien organisms needs to go through before it is judged to be invasive. In summary, there are four major steps in the progression towards invasion:

Introduction, Establishment, Spread = Naturalisation, Spread = Invasion

Introduction is entry of an alien species into a new area (which can be a habitat, an ecosystem, a biome, a country or even a region of the earth – where it has not been native before). This process can be ***intentional*** – that is by the purposeful "hand of man" especially for use in, e.g., food production, agriculture, horticulture, forestry, agroforestry, fisheries, sport fishing, decoration, landscaping, pet and plant trade, biological control, zoological/botanical collections, research, etc. In contrast, it can be ***unintentiona***l when a species enters "by accident" as a result of movement with other commodities, as "hitch-hikers" on other species or activities, in travellers' belongings, clothes, luggage and so on. We will consider the various ways in which intentional introductions can be authorised or not but, clearly, unintentional introductions cannot be subject to authority – except to reduce the likelihood of their occurrence.

Establishment is when the organism that has been introduced survives long enough to develop a population in its new environment that is able to reproduce. An example would be the establishment of foreign weed species that survives in a new country in disturbed areas like roadsides, but which do not spread further.

Spread – Naturalisation is when the established animal, plant or microorganism starts to spread and reproduce without any assistance. It becomes part of the natural flora or fauna and "blends in" with native species

Spread – Invasion is when the naturalised alien species spreads to the disadvantage of other species (native or naturalised) and causes disruption of its new ecosystem in some way. This disruption will be a major topic of Module 3.

There are other designations of the steps or stages to invasion with subtle differences in the meaning of each term. Some are listed in Table 1 below for information – but we will use the four stages, above for simplicity and because of their wide use.

Table 1: designations of invasion status

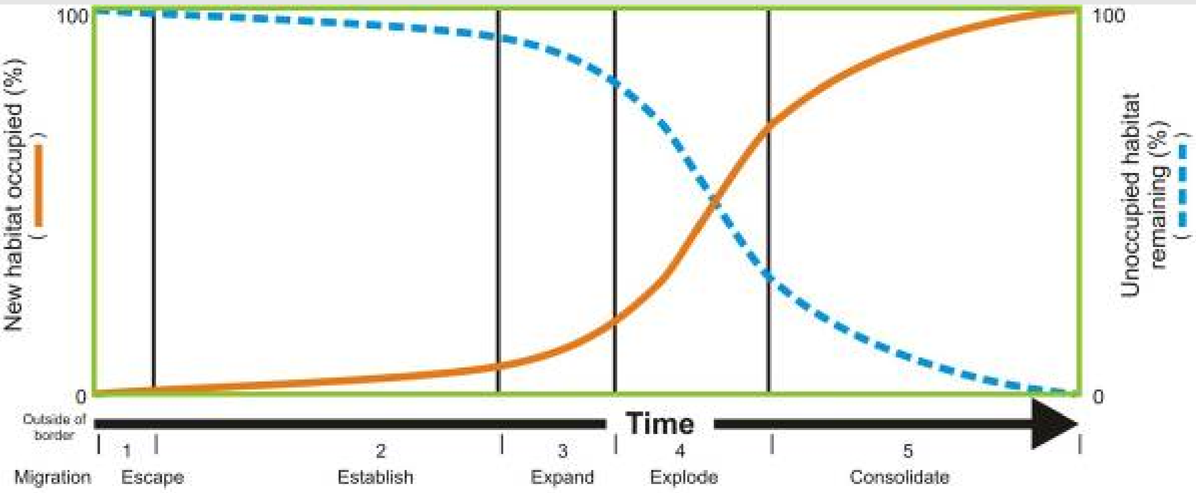
Category	Synonym	Definition
Alien	Exotic, introduced, non-native, non-indigenous	Species present due to intentional or unintentional introduction as a result of human activity
(Casual alien)	Waif, transient, occasional escapee, adventive, persisting after cultivation	Aliens that may flourish and even reproduce occasionally in an area, but do not form self-replacing populations and rely on repeated introductions for their persistence – such as garden plants grown only from imported seed
Naturalised	Established	Aliens that reproduce consistently and sustain populations over many life cycles without direct intervention by humans, but do not necessarily invade natural, semi-natural or human-made ecosystems
Invasive	Expanded, Consolidated	Naturalised species that reproduce often in large numbers and are able to spread over a large area, damaging native species.
(Weed/pest)	Harmful, problem, noxious	An anthropocentric term for plants, animals or other pests (not necessarily alien) that grow where they are not wanted and usually have detectable economic or environmental effects. 'Environmental weeds' are alien plants that invade natural vegetation
Transformer	Edificator (environment-forming plant)	Subset of invasives which change the character, condition, form or nature of ecosystems over a substantial area relative to the extent of that ecosystem

After Kumpel and Baillie, 2006 based on Richardson *et al*., 2000, Pysek *et al*., 2004 and McGeoch *et al*., 2006

Whatever the terminology or invasion category, there is a small probability that an introduced species will actually pass on to each successive stage of invasion. An occasionally used rule of thumb is that each step reduces the species by ninety percent of the numbers that reached it. Thus 10% of those species that are introduced actually become established; 10% of those that establish become naturalised and around 10% (or less) of those that become naturalised turn into invasives. Thus the chance of an introduced species becoming invasive is around 0.1% - some say as little as one in a million! This is fortunate as many thousands of species (or other taxa) are introduced to new ecosystems every year.

The time from introduction to invasion may vary considerably as progression from one stage to another is variable and different for species and new habitats/ecosystems. For some species, the time from introduction to naturalisation may be weeks of months, for others, such as trees, it may be years, decades or even centuries. Sometimes this is referred to as an "establishment" phase which is then followed by expansion of the range or impact of the new invasion until it becomes consolidated.

Figure 1: graph showing the phases of invasion over time



After Williams, 2003. Phases of invasions are expressed as a proportion of the habitat occupied by an invading species. The first four stages shown are equivalent to SPREAD (naturalisation and invasion) and are followed by a longer term "consolidation" by the invader.

From Figure 1 it is clear that if we want to address (or halt) the impact of an invading species, it will be cheaper (and probably easier) to do so at the very outset of this process from introduction to consolidation. This will be discussed further in Module 3, but already we can see that prevention of introduction is the best way to stop invasions, followed by action during the escape or early establishment phases – hopefully by eradication or containment. As time goes by and the invader expands and "explodes" (Figure 1) the economic and social cost and effort must increase while the value of the previously natural habitat decrease and the need for restoration will arise.

1C Movement and introduction of invasive species

How potentially invasive species move around

Potentially invasive species are sometimes able to move very long distances from continent to continent, across oceans and between regions. They can also move from country to country within a region and between neighbouring countries. Invasion is also possible through the movement of species within a country when they move from their origin (native range) to a new ecosystem or habitat.

The routes along which they move are termed **pathways** and the means they use to move are termed **vectors**. Classic (primary) pathways are trade routes – on land, ranging from ancient stock and trading routes to modern railways, roads and canals. Other pathways revolve around tourism and general travel where people and their belongings move for a range of different reasons. In both freshwater and the marine waters, the pathways are the shipping routes (which now reach every continent and almost every coastal city in the world). The same is true of rivers, canals and large lakes and sometimes connections between the freshwater and marine environments. These pathways lead to points (sometimes not points but areas or borders) of introduction. Once a species has been introduced to a new country or ecosystem, there are often secondary pathways which may be human-enhanced or may be natural. "Natural secondary" means of further distribution of introduced species are phenomena such as winds and storms, water currents, movement of native animals (mammals, birds, reptiles, fish, insects, crustaceans, molluscs, etc.). "Man-assisted secondary" movements are possible through pathways taken by agricultural and construction machinery, on-road and off-road vehicles, livestock movements, highways, local roads and even walking paths.

One can consider **trade** (at all levels) to be a pathway in itself because it does not always follow regular routes and yet is responsible for the movement of goods (and so likelihood of moving species) over short and long distances in many combinations of stages. Travel, transport and tourism are also considered as general pathways – and need to be considered when we discuss the prevention of invasions by managing pathways.

On the classic pathways of the four Ts (trade, transport, travel and tourism) there are many types of vectors – from the very vehicles and ships that move goods and people (in their insides as well as outsides), to the goods and people themselves. One way of thinking about this is to consider a large ship carrying goods and people from one continent to another. Along that pathway, there will be opportunities for species to move - on such vectors as:

- The outsides of the ship, especially those underwater (“hull fouling” by organisms that cling to the undersides and so are transported across the deep ocean (or lake) as well as moved from port to port;
- The ballast water tanks inside the vessel used for stabilising it with and without cargo – which can be taken up in rivers and ports or in the open sea and discharged anywhere a vessel needs to change its stability;
- The holds and other storage areas (including decks) where cargo is taken on, stored and then taken off again in port – possibly taking species along;
- The special case of steel containers which may have been loaded with goods at vast distances from ports then moved to other ports and possibly to further places by road, rail, canal or other means – along with species that may have entered then during loading;
- The people (crew and passengers) with luggage and clothes that may carry seeds or spores or small animals, etc. as well as soil on shows and boots, dust on machinery, etc., etc.
- Animals (such as birds and small mammals) that may inhabit the ship and move from port to port and
- Plants taken as souvenirs or plant parts taken as food – but which are still viable.

Commercial airliners, military and freight aircraft, interstate trucks, buses, trains and even bicycles can all become vectors of propagules of species that can be introduced and may become invasive.

Introductions

The introduction of an alien species to a new area is the most vital step towards invasion and the place where (we will see later) it can be stopped before invasion begins – so we need to study introductions

The actual process of **introduction** may take place at formal entry points to countries or regions or areas – such as ports, airports, transport terminals, passenger and freight stations and loading/unloading facilities – and in these instances there may be quarantine or other inspection facilities to manage the introductions (by stopping or authorising them). There are many other situations where borders or limits of ecosystems or biomes are crossed and where exchanges or introductions may take place in the complete absence of checks or observations on incoming species – be they whole organisms or propagules such as eggs, larvae, pupae, seeds, bulbs, other viable plant parts, etc.

Some species may be able to begin the processes of establishment and spread from the point of introduction (e.g. ants escaping from soil in imported plant pots and establishing a colony next to a port) or they may need to undergo secondary movement to a suitable habitat in the new environment. Thus the appearance of a new and recognisable species after introduction can be almost instantaneous or gradual or take a very long time – months, years, decades or even centuries. This is why it is important to be able to detect and/or recognise potentially invasive species (or their propagules) at the time and at the point of their introduction. Similarly it is important to have some idea of the potential invisibility of an introduced species – either from experience elsewhere or from research into the characteristics of invisibility (see below). In this case the risk of introduction of an invasive species may be reduced by recognition and risk assessment procedures.

1D Types of organisms that can become invasive

Which types of organisms are known as invasive species?

The taxa or types of organisms that can become invasive are animals (vertebrates and invertebrates), plants and micro-organisms (including those that are free-living as well as those that cause disease in plants, animals and people). Any of these organisms can become invasive as long as they are "new" to a particular ecosystem or area[1]. Any organism from this group of taxa is possibly capable of invasion if it is introduced to a new area and has some of the basic characteristics of invasiveness (see below). However, the actual development of invasiveness in a species of animal, plant or micro-organism will depend upon the suitability of the new ecosystem or area for that organism. Thus tropical species are unlikely to become invasive in the temperate zone – and vice versa, unless they are genetically modified. Forest species are unlikely to become invasive in grasslands, so the prediction of invasiveness of any alien species depends on a range of characteristics of itself and the ecosystem into which it is introduced.

Some common types of invasive organisms will be mentioned during the training while some examples are listed hereunder:

Micro-organisms – microscopic algae that form "algal blooms" in new areas; free-living protozoans that can become invasive in new ecosystems; plant and animal (and human) pathogens like viruses, bacteria and yeasts; fungal pathogens of both animals and plants

Plants – both higher and lower plant groups including mosses and liverworts, ferns and higher plants of many families – marine, freshwater and terrestrial. Two notable higher plants spreading across Africa will be discussed – *Prosopis* species (mesquite mainly from tropical America) and *Lantana camara* – also from tropical America.

Invertebrates – alien species from many phyla, including comb jellies (Ctenophora) and many other marine groups are known to be voraciously invasive in new areas; terrestrial and aquatic molluscs; many arthropods including marine and freshwater crustaceans, spiders, insect pests and disease vectors.

Vertebrates – many fish (often intentionally) introduced to new waters have become invasive in both freshwater and marine situations as have some amphibians (e.g. the notorious cane toad), reptiles (such as the Burmese python in the Everglades of the USA); many birds and both small and large mammals (e.g. the rabbits and wild horses of Australia).

What characterises invasiveness?

Invasiveness, or the propensity to become invasive under a range of ideal conditions and ecosystems, can be attributed to a range or combination of characteristics of organisms. These include:

- Capacity for rapid growth (and so expansion);
- Capacity to disperse widely (by propagules for a plant and by movement for animals);
- Large reproductive capacity – either by producing many offspring (or propagules) or by nurturing fewer progeny but with great efficiency;
- Broad environmental tolerance – being able to withstand a wide range of habitat pressures;
- Effective competition with local species – for food, space, light, water, resting, nesting, etc. Requirements.

[1] An "area" is not necessarily a geographical surface but can be a volume (of water or air) or a locality, say, within another organism (for a parasite or pathogen). Another subtlety is that a particular area can become changed by human or other means so that it becomes "alien" to the organisms within it – then they are "alien" to that ecosystem and can become invasive. An example is when overgrazing by livestock changes a pasture such that the balance of vegetation is lost and then some species (which are non-palatable to the livestock) can become dominant and invasive in their new situation.

1E Linking invasions to other environmental pressures

Considering the characteristics of the most successful invasive species (above), it is essential to assess the interaction between the impacts and spread of invasive species and the other recognised causes of ecosystem decline. The Millennium Ecosystem Assessment looked at hundreds of ecosystems around the world (Millennium Ecosystem Assessment, 2005) and came to the conclusion that the most important threats to ecosystems and their function, as well as the provision of ecosystem goods and services to mankind, were:

1. Habitat change, usually destruction for new human uses,
2. Climate change
3. Invasive Species
4. Over-exploitation of ecosystem resources
5. Pollution

(see Figure 1, Module 3).

Invasive species have the capacity to exacerbate their role in ecosystem degradation through combination with 1, 2, 4 and possibly 5, which further enhances their threat to biodiversity and the human condition.

Invasive species are often able to utilise changed habitats to establish and spread because they can enter and establish in a disturbed habitat more easily than into a system that is stable and so has resistance to the establishment of new species. This is why one finds a preponderance of invasive species in newly changed habitats (such as land cleared for agriculture or urban development and along roadsides and construction sites). A current example of this phenomenon is appearing where new plantations of biofuel crops and trees are being cultivated – often in areas cleared of native vegetation.

Climate change is already affecting native biodiversity which is often dependent upon a stable climate. When the temperature increases (even only slightly) and/or rainfall patterns change, most native species are slow to adapt to the new conditions – whereas invading species, by their very nature, are better able to adapt to the same changes and so will (and are already) spreading into areas where native biodiversity is affected.

Over-exploitation of habitats and ecosystems can lead to environmental degradation and an increase in “disturbed areas” – again, giving advantage to invasive species. Some invasive species are more tolerant of pollution than the native flora and fauna – so, again, they may gain the advantage in polluted areas.

These considerations are an important side-issue for biological invasions and should be borne in mind as we develop this subject further.

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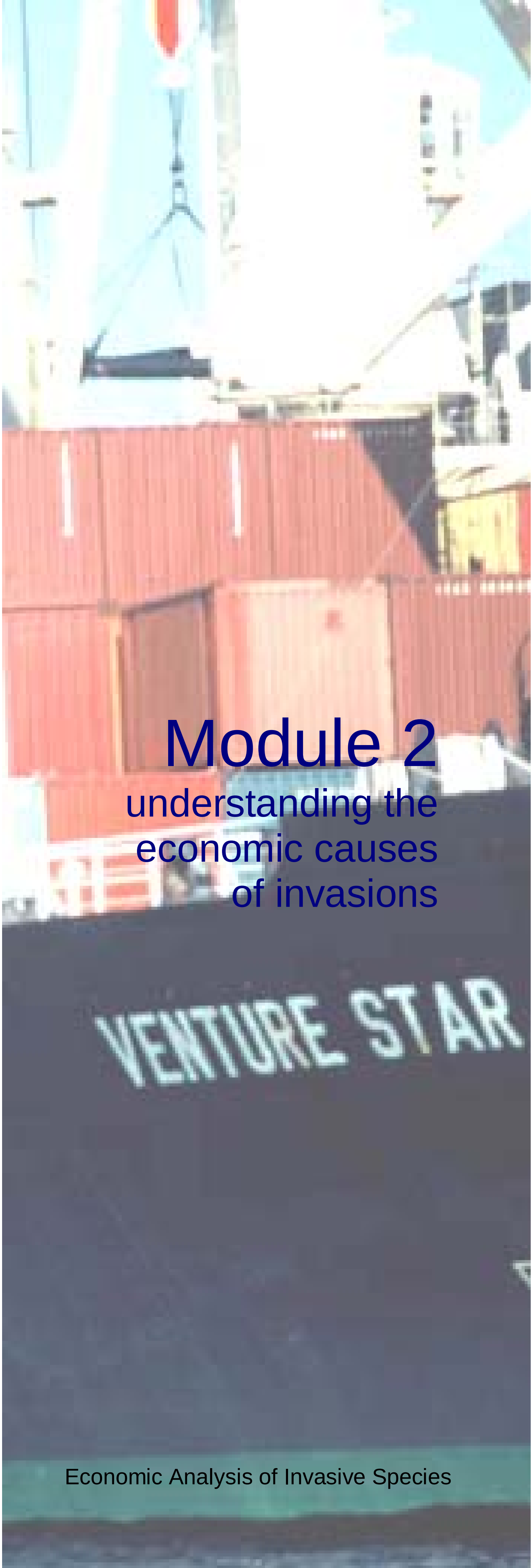


Module 2
understanding the economic causes of invasions

Economic Analysis of Invasive Species

2A What this module covers

The major focus of this module is on identifying the economic causes of invasions, and on understanding the economic conditions, forces and factors which either encourage or discourage movement through the steps in the progression to invasion. Emphasis is given to understanding these processes in economic terms: as externalities, and resulting from the various economic, market, policy and institutional failures which result in producers, consumers, investors and traders failing to take account of the costs of invasion when they carry out economic activities. The module presents two frameworks which can assist in the economic analysis of invasive species: one for tracing the economic causes of invasions, and one for understanding and analysing the links between invasive species, ecosystem services and human wellbeing.

By the end of this module, the reader will have gained an economic perspective on the problems and responses associated with the spread of invasives; understood how, why and to what ends economic tools can be used to analyse and address them; and acquired tools for identifying and tracing through the economic causes of invasions, and their impacts on human wellbeing.

2B Identifying the economic factors that lead to invasions

How economic conditions and forces prompt invasions

Invasions are the outcome of a very complex set of processes. Many of these processes are economically motivated – including the use of exotic species in a variety of economic activities, the conversion and fragmentation of habitat, the liberalisation and deregulation of markets, expansion in the trade of goods and services, and increasing mobility of people and things (Perrings 2000).

As described in module 1, there are three steps in the progression to invasion from introduction: establishment, naturalisation and spread, after which invasion may take place. Economic conditions and forces operate at each stage of this process, and may either expedite and encourage (or halt and discourage) transition to a situation where a species, once introduced, becomes invasive. Economic factors also determine the resilience of both human and natural systems to the effects of invasives: they may either undermine or strengthen human resilience, and also underpin the activities which degrade ecosystems (and reduce their resilience) as well as those which conserve them(and strengthen their resilience).

In this module we are primarily concerned with the economic causes of invasion (the conditions that expedite and encourage transition to a situation where a species, once introduced, becomes invasive). The final section of this toolkit (module 6) looks at economic and financial instruments that can be used to create the conditions which will halt, discourage or mitigate invasions.

When applying economic analysis to invasive species, a first step is to understand the economic conditions and forces which are leading to a species becoming invasive (or may do so in the future) in a given situation. It is important, from the start, to understand and distinguish between the direct and underlying economic causes of invasions (see Table 2). Each has different drivers and manifestations, involves different processes, originates from the actions (or inaction) of different groups, and requires different responses:

- Direct economic causes comprise those production and consumption activities which themselves introduce, establish and spread potentially invasive species.
- Indirect economic causes comprise the underlying economic, livelihood, market, price, policy and institutional conditions that permit or encourage people to behave in particular ways which introduce, establish and spread potentially invasive species, or which undermine the resilience of human and natural systems and thereby both increase the likelihood of invasions taking hold and exacerbate their effects.

Table 2: examples of the direct and indirect economic causes of invasions

Steps to invasion	Examples of indirect economic causes	Examples of direct economic causes
Introduction ↓ Establishment ↓ Spread ↘ naturalisation ↘ invasion	*Forces and conditions which determine trade, production and consumption practices and preferences, such as:* 1. Expanding domestic and international travel and tourism trade 2. High reliance of the economy on agriculture, forestry, fisheries and tourism 3. Market integration, expansion and globalisation 4. Subsidies to introduced species 5. Trade and investment incentives for economic activities which utilise or depend on introduced species 6. Consumer preferences for introduced species 7. High profitability and market demand for products which are based on introduced species, or use them as inputs 8. Low profitability and market demand for products which are based on non-introduced species, or use them as inputs 9. Inadequate penalties and fines against illegal transportation of introduced species *Forces and conditions which determine land and resource use practices and preferences, such as:* • High reliance of the economy on agriculture, forestry, fisheries and tourism • Economic and fiscal incentives encouraging land and resource uses which lead to reduced genetic diversity, increased use of agrochemicals, biodiversity loss, ecosystem degradation, conversion and fragmentation • Institutional and property rights regimes which discourage action • Lack of budgets and funding to control programmes	*Introduction of species for commercial purposes, such as:* • Fish and molluscs for aquaculture and mariculture • New (=alien) species for sport fishing • Agricultural seeds and crops • Livestock for meat, wool and fur • Food plants • Biofuel plants *Introduction of species for control purposes, such as:* • Insects, mites and fungi for biological control • Fast-growing foreign plants for landscape restoration *Introduction of species for lifestyle and aesthetic purposes, such as:* • Exotic pets • Foreign and modified Ornamental plants • New (= foreign) aquarium fish *Unintentional or accidental introductions via another economic activity, such as:* • Contaminated livestock, plants and aquatic species • Plant and animal "hitch-hikers" in freight, packaging or travellers' luggage • Ballast water • Dumping of unwanted waste, plants, fish or pets

Direct economic causes

A wide range of economic activities set in place and effect the move between the steps in the progression to invasion. While introductions of potentially invasive species may be intentional or unintentional (see module 3), the economic activities which directly cause them involve the transport and transfer of species into areas or conditions where they can become invasive or can spread to other areas and cause invasions.

Many of the items that humans produce and consume are based on (or use as inputs) introduced or imported species which have the potential to become invasive. Exotic species are increasingly used commercially. Examples include the use of potentially invasive species for mariculture, aquaculture, sport fishing, farming (including both crop and livestock production), biofuel production, or as foods. Other intentional introductions include plants and animals which are used for biological control and landscape restoration or are kept by people in aquaria, as pets, or are planted in their gardens.

Production, consumption and trade activities may also lead unintentionally to the introduction of invasive species. This may occur, for example, through the import of contaminated livestock, plants and aquatic species; by species "hitch-hiking" in freight, packaging or travellers' luggage and clothing; or being introduced into the environment via ships' ballast water; or when other wastes, unwanted pets, fish and plants are dumped into the surrounding environment.

As the reach of global markets grows and human demands and aspirations extend, so the incidence of invasions has risen. The increase in the problem of invasive species is seen as being one of the most striking consequences of globalisation (Perrings *et al* 2005a). Activities associated with trade and travel, in particular, are frequently cited as the most important cause of the spread of invasives (Horan *et al* 2002). The density of alien – and thus potentially invasive – plants has also been found to be positively correlated with the extent of terrestrial road networks, migration rates and importations, and the number of tourists (and the routes they use) coming to a country and then travelling around inside it (Vilà and Pujadas 2001).

Indirect economic causes

The probability of the establishment and the spread of invasives depends on people's behaviour and on their responses to threats (Perrings *et al* 2000). Although some invasive species are introduced unintentionally, in many cases people do not introduce, establish and spread invasive species for no reason: they do so for the economic benefits and profits they yield, as a result of having access to particular markets, and in order to fulfil their needs, tastes and aspirations. People are in turn encouraged or motivated to produce, consume and trade in particular ways (and involving particular species and products) due to a complex range of market, price, livelihood, policy and institutional conditions.

The indirect causes of invasions comprise the economic signals which shape people's behaviour and determine the composition and nature of the economy, influence consumer tastes and preferences, set commodity prices and input costs, shape producer profitability and the relative attractiveness of different investments and land uses, and facilitate travel and trade. They involve the use of various instruments such as subsidies, taxes and other fiscal instruments to promote investment, trade, production or consumption of particular products or to simulate activity in specific sectors. Other examples involve the use of import quotas and trade rules, multilateral agreements, as well as the range of institutional and regulatory arrangements under which economic activities are governed in a country. Indirect causes also include the more general economic context within which people operate, for example the reliance of an economy on sectors which introduce or use potentially invasive species (for example agriculture, fisheries and tourism), or livelihoods which operate in a situation where opportunities to generate and access food, cash and employment are limited and heavily dependent on activities which utilise potentially invasive species.

Economic policies and markets often fail as regards invasives because they set in place conditions which discourage producers, consumers, traders, investors, land managers and resource users from taking account of the risk of invasions, and from using their own native species for many purposes. The economic drivers of the steps in progression to invasion display many of the characteristics of classic market, policy and institutional failures. Although invasions incur high costs to the economy as a whole, or to other groups, the individual or company whose action sets in place the steps in the progression to invasion does not bear these costs: they are not incorporated into the prices and profits they face as they go about their economic activities. It is frequently far more profitable, cost-effective or cheaper for people to utilise potentially invasive species than to take the necessary safeguards to ensure that invasions do not result from their economic activities. Market, policy and institutional failures encourage people to ignore the wider economic consequences of their actions, meaning that potentially invasive species are more likely to be introduced and are less likely to be controlled (see module 3).

The underlying economic causes of invasions relate both to the conditions which encourage the introduction and spread of potentially invasive species, as well as those which undermine the resilience of human and natural systems and thereby increase both the likelihood of invasions taking hold, and exacerbate their effect. Examples of the former include rapid globalisation, trade liberalisation and the use of investment incentives which open up markets to products based on potentially invasive species. Examples of the latter include subsidies designed to promote the export of cash crops which reduce plant genetic diversity, and encourage the use of agro-inputs that lay agroecosystems open to invasion (Perrings 2000).

Treating invasives as externalities

The preceding section referred to the market, policy and institutional failures which underlie invasions: because they lead to a situation where the prices and profits that people face as they carry out their economic activities do not internalise the full costs of invasions to the wider economy (or the risk of invasions occurring), there are for the most part no economic incentives (or requirements) for individuals or companies to make decisions based on the likelihood of invasions occurring, or of these costs being incurred to them.

Essentially, invasions are usually the external effects of market transactions (Perrings 2002) – where market prices do not accurately reflect the full social and economic costs associated with invasions. As described in the preceding section, the individual or company who introduces or spreads a potentially invasive species typically does not bear the costs associated with their action (even though they capture many of the private benefits). These costs or losses are felt by others, by the wider economy, or even as trans-boundary effects, with no compensation provided for the damage caused.

Thus, in many ways, the problem of invasion embodies many of the characteristics of a typical economic externality, and can be treated as such both analytically and in terms of the measures that are required to address it. It should however be noted that one critical difference between invasives and externalities as conventionally understood in economics is that invasions, once set in motion, are largely self-perpetuating and often their impacts also increase over time (Perrings 2000) – "normal" externalities usually continue only if the source activity is perpetuated. This key difference is of less importance when identifying the economic causes of invasions – where there are a great many advantages in understanding invasives as the externalities which both cause and arise from market, policy and institutional failures – but means that many of the financial and economic instruments that are conventionally designed to deal with externalities are less well-suited to dealing with invasions (see module 6).

2C Using policy analysis matrices to trace the economic causes of invasions

The policy analysis matrix approach to identifying environmental effects

A thorough analysis of both direct and underlying causes is a key step in the economic analysis of invasive species. Although the exact impact of economic policies and instruments is extremely difficult to generalise and depends on a series of highly specific conditions, various tools are available to assist in this process. Perhaps the simplest tools, which can be applied in order to trace the economic causes of invasions, are those which are designed to guide the identification and analysis of economic policies and instruments in terms of their environmental effects.

One type of policy analysis matrix which can be easily modified to deal with invasives is the action-impact matrix (AIM), originally developed by the World Bank to show the relationships between economy-wide policies and the environment (see Munasinghe and Cruz 1994). Like other policy analysis matrices, the AIM strives to build a series of matrices through a stepwise procedure. The first matrix typically contrasts key environmental issues with biophysical and socio-economic indicators of change, and then considers underlying causes from economic factors such as market and policy failure. The second matrix then evaluates the general environmental impacts of specific macro-economic policies. The final matrix combines previous information: specific macro-economic policies are linked with particular environmental issues.

Applying policy analysis matrices to invasives

In this case, we are dealing with a very specific topic: the direct and underlying economic causes of invasions. For this reason a somewhat simplified series of steps can be undertaken to build a policy analysis matrix (which would conventionally cover a much wider range of environmental issues, and gauge the effects of reforms or changes in given economic policies or instruments). The scope and coverage of the component matrices used to trace the economic causes of invasions in a given situation will of course depend on the level of analysis being carried out: they might extend across all sectors and levels of scale, or focus on a particular sector, species or location. In the worked example below, we take the case of invasions occurring in the arable agricultural sector of a country.

A first step would be to list the key issues relating to invasives, and identify the direct causes associated with these. A simple matrix such as that outlined in Table 3 could be constructed, distinguishing between (a) issues relating to the introduction, establishment and spread of potentially invasive species, and (b) issues relating to the resilience of human and natural systems to invasions:

Table 3: example of policy analysis matrix #1: economic causes of agricultural invasions

Key issues	Direct causes
Issues relating to the introduction, establishment and spread of potentially invasive species	
Introduction and establishment of potentially invasive species	Cultivation of exotic crops
	Hitch-hiker species coming in with seed and food shipments
Spread of potentially invasive species	Road and boat transport of exotic species between sites
	… etc. …
Issues relating to the resilience of human and natural systems to invasions	
Invasion of species	Loss of biodiversity and ecosystem services
	Intensive monocropping
	High use of agro-chemicals
	… etc. …

A second step (Table 4) would be to describe the underlying economic conditions or motivations prompting the production, consumption, trade and investment behaviour which is leading to the risk of invasions:

Table 4: example of policy analysis matrix #2: economic causes of agricultural invasions

Direct causes	Underlying economic conditions or motivations
Issues relating to the introduction, establishment and spread of potentially invasive species	
Cultivation of exotic crops	• High consumer demand prompted by low prices • High producer profitability • Promotion of cash crop cultivation
Hitch-hiker species coming in with seed and food shipments	• Reliance on imported inputs • Low or non-existent penalties for illegal import of invasive species
Road and boat transport of exotic species between sites	• Urgency for speed of movement hence lack of inspection and cleaning of containers and transport vehicles, ships and aircraft
… etc. …	• ...
Issues relating to the resilience of human and natural systems to invasions	
Loss of biodiversity and ecosystem services	• Clearance of natural vegetation for monocrop farming
Intensive monocropping and high use of agro-chemicals	• Profitability of establishing single crops under intensive farming practices
… etc. …	• …

The final matrix (Table 5) then identifies the economic policies or instruments which set the particular conditions or motivations which lead to invasion:

Table 5: example of policy analysis matrix #3: economic causes of agricultural invasions

Underlying economic conditions or motivations	Economic policies or instrument
Issues relating to the introduction, establishment and spread of potentially invasive species	
High consumer demand prompted by low prices	• Over-valued exchange rate making imported goods and inputs relatively cheaper on the domestic market • High taxes on alternative commodities
High producer profitability Promotion of cash crop cultivation	• Subsidies and preferential credit for cash crop production • Export tax exemption for cash crops • High export and input taxes for alternative crops
Reliance on imported inputs	• Over-valued exchange rate making imported goods and inputs relatively cheaper on the domestic market • Import duty exemption for agricultural sector inputs
Low or non-existent penalties for illegal import of invasive species	• Unrealistic pricing of fines
Urgency for speed of movement hence lack of inspection and cleaning of containers and transport vehicles, ships and aircraft	• Low budgets for inspection • No requirement or penalty for cleaning containers and transport

Table 5: example of policy analysis matrix #3: economic causes of agricultural invasions	
Underlying economic conditions or motivations	**Economic policies or instrument**
… etc. …	• ...
Issues relating to the resilience of human and natural systems to invasions	
Clearance of natural vegetation for monocrop farming	• Low budgetary allocations to biodiversity conservation • Lack of clear property rights over natural ecosystems • Requirement that agricultural land is cleared to establish ownership • Relatively lower tax rates on agricultural land
Profitability of establishing single crops under intensive farming practices	• Artificially low market prices for alternative crops • Price support to farmers • Subsidies to fertiliser and pesticides
… etc. …	• …

Using the information generated by policy analysis matrices

Together, these matrices provide a clear, useful and systematic tool for tracing the direct and underlying economic causes of invasions. As well as generating information which is vital for understanding and communicating the economic dimensions of invasion in a particular case, they point to key needs and entry points for the design of economic and financial measures to address invasives (module 6).

2D Linking invasions to changes in human wellbeing

Ultimately, invasives are of economic concern because of their impacts on human wellbeing. Similarly, weighing up their relative costs and benefits to human wellbeing forms an integral part of the economic thinking and analysis that is applied when decisions are made by individuals, companies and governments, and when instruments are designed and implemented to manage invasives.

Invasives interfere with economic activities, and impact on human wellbeing, when they take over habitat usually occupied by other species: this occupation of space is what constitutes an invasion (Perrings 2002). In economic terms, a primary concern is assessing the incremental changes that occur when the invasive species interferes with the functioning of an ecosystem which yields a flow of economically valuable goods and services, and displaces (original, or native) species that are economically valuable. Studies of the impacts of alien plant invasions on mountain fynbos systems in South Africa for example found that invasives have had a major – and costly – impact on the provision of natural ecosystem services. The value of ecosystem services provided by fynbos under different management regimes, including consideration of water production, wildflower harvest, hiker visitation, endemic species and genetic storage, are thought to vary between vary from $0.9-16.7 million per km^2 – while the costs of clearing invasive plant species comprises only a tiny proportion (0.6-5%) of this value (Higgins *et* al 1997).

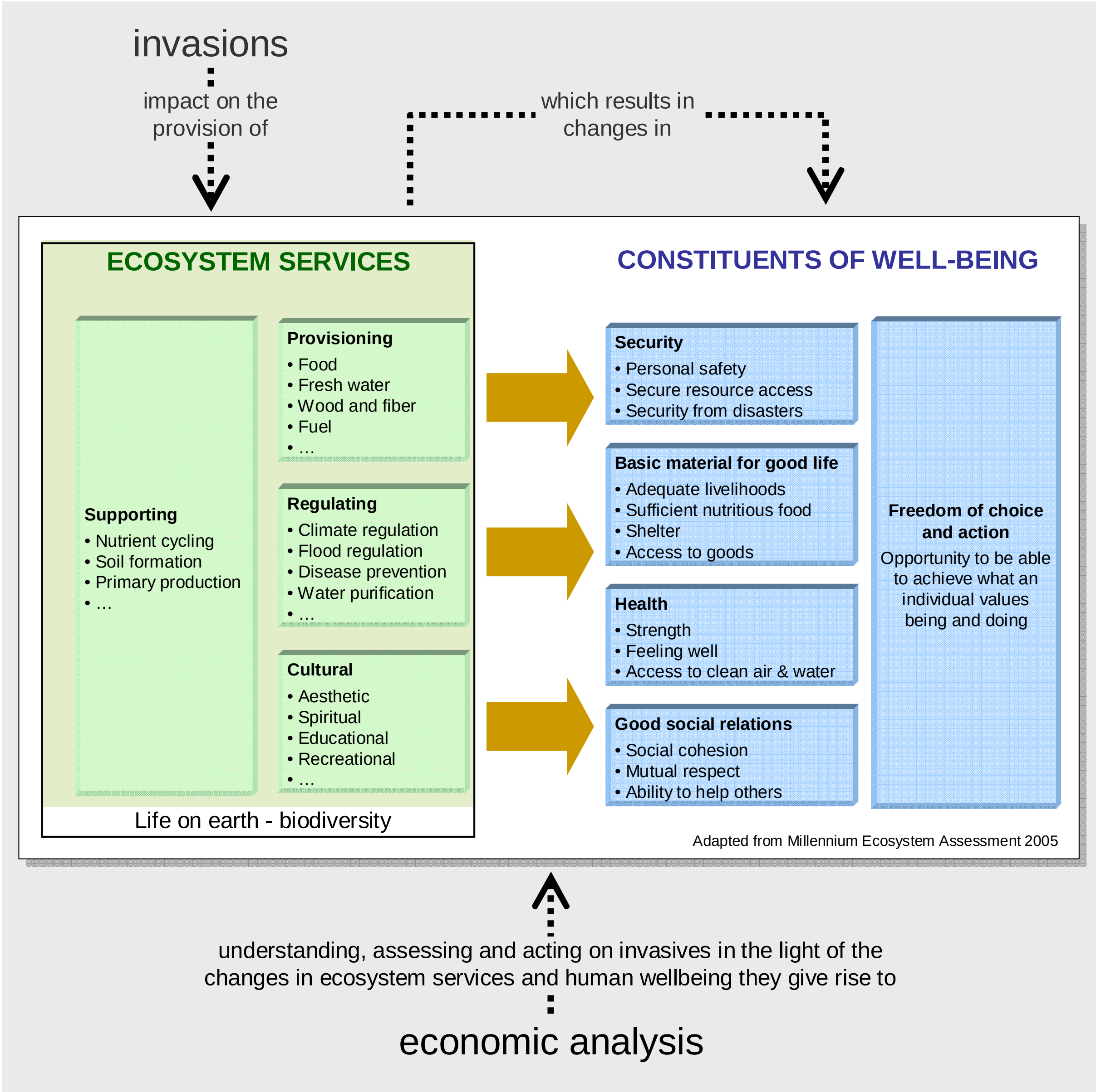
Here it should be noted that economic analysis rarely involves comparing a situation where there are no invasives with a situation where all space for natives has been replaced: rather it looks at levels and degree of invasion, and the consequent incremental changes in ecosystem service and function, and the marginal costs and benefits this gives rise to (the concept of marginality is further explored in Module 4F recognising the complexity of invasive costs and benefits).

Economic analysis of invasives therefore fundamentally considers the ways in which invasive species displace native species and occupy natural or human-modified ecosystems, and thereby change the ecosystem services that they provide and which in turn contribute towards human wellbeing. The recent Millennium Ecosystem Assessment provides an extremely useful framework for understanding and analysing the links between invasive species, ecosystem services and human wellbeing (Figure 2).

This framework allows us to trace through the impacts of invasive species on different economically valuable ecosystem services, including provisioning services such as food, shelter, water, timber, and fibre; regulating services that affect climate, floods, disease, wastes, and water quality; supporting services such as soil formation, photosynthesis, and nutrient cycling; and cultural services that provide recreational, aesthetic, and spiritual benefits.

It is within the context of an overriding concern with maximising human wellbeing that economic analysis is carried out, and used to understand and assess the range of possible economic causes, effects and responses to invasive species. Subsequent sections of this toolkit on the impacts of invasives (module 3), costs and benefits (module 4), valuation (module 5), and decision-making (module 6) all revolve around understanding, assessing and acting on invasives as they relate to changes in ecosystem services, and the marginal costs and benefits which are associated with changes in human wellbeing.

Figure 2: invasions, ecosystem services and human wellbeing



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Module 3

impacts of invasive species and ways to address them

Economic Analysis of Invasive Species

3A What this module covers

This module returns to the biological attributes of invasives and looks at the ways in which they impact upon ecosystems of various kinds and then examines the ways in which we can try to prevent or manage biological invasions. This is relevant to economists who are intending to estimate the total costs of invasions as well as the costs of their prevention and/or control. The module emphasises that all stages in the prevention and management of invasive species should have a scientific background to be effective – an extra cost when addressing invasions.

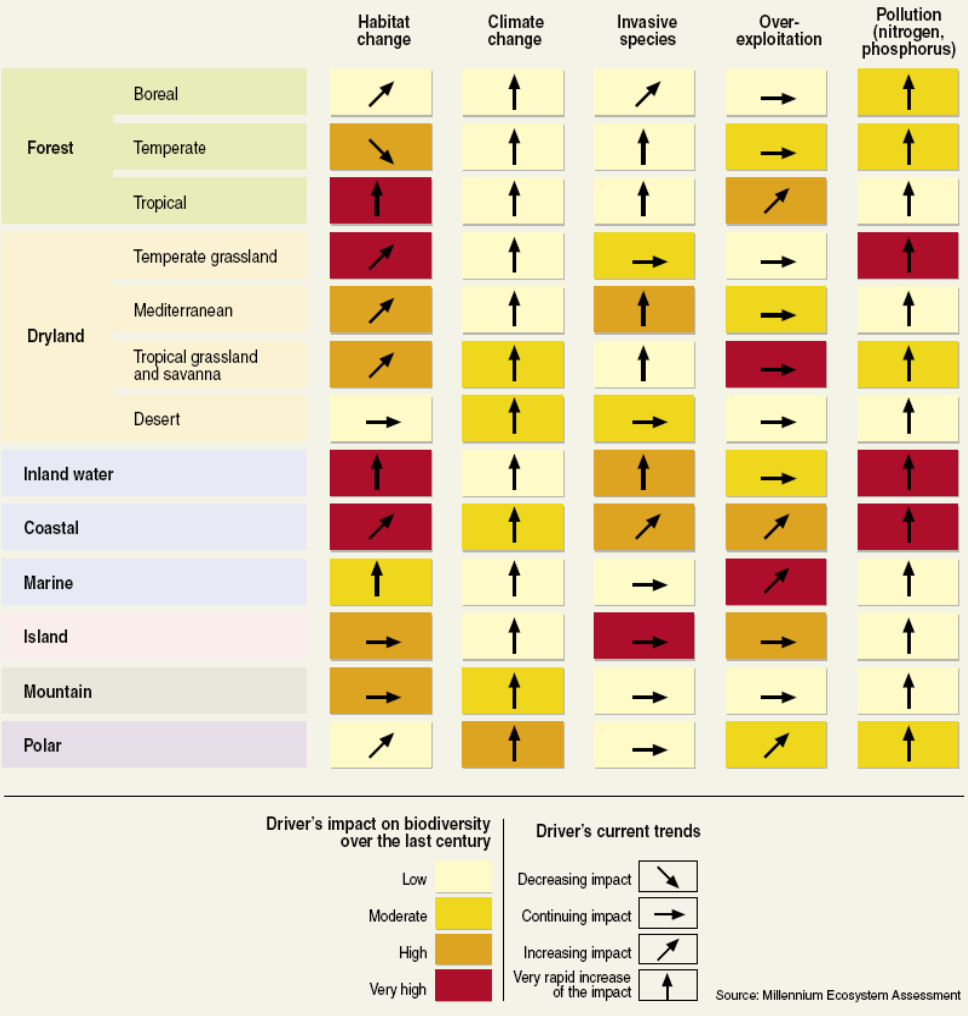
3B Understanding the impacts of invasive species

Invasive species and impacts on ecosystems

Module 1 introduced the topic of invasive species – what they are, the ways in which they spread, and how they can be a problem to human and ecological systems in general. We ended module 1 with a look at the interactions between invasives and other causes of ecosystem degradation – and now return to the Millennium Ecosystem Assessment and the major drivers of ecosystem degradation

Figure 3: drivers of ecosystem change as evaluated by the MA

The cell color indicates impact of each driver on biodiversity in each type of ecosystem over the past 50–100 years. High impact means that over the last century the particular driver has significantly altered biodiversity in that biome; low impact indicates that it has had little influence on biodiversity in the biome. The arrows indicate the trend in the driver. Horizontal arrows indicate a continuation of the current level of impact; diagonal and vertical arrows indicate progressively increasing trends in impact. Thus, for example, if an ecosystem had experienced a very high impact of a particular driver in the past century (such as the impact of invasive species on islands), a horizontal arrow indicates that this very high impact is likely to continue. This Figure is based on expert opinion consistent with and based on the analysis of drivers of change in the various chapters of the assessment report of the MA Condition and Trends Working Group. The Figure presents global impacts and trends that may be different from those in specific regions.



From Millennium Ecosystem Assessment, 2005

The above figure emphasises that invasive species are a serious threat to the integrity of ecosystems of all types, with continuing or increasing levels of impact. If that situation is then combined with climate change and enhanced by continuing habitat change, we can expect an increase in the severity of the impacts of invasive species in the future through a synergistic effect. The graphic shows that the biomes most affected by invasive species are islands, followed by inland (fresh) waters and drylands. However, all types of ecosystems are subject to invasion with the impacts increasing in most. This implies that the problem of biological invasions will continue to be a setback for both natural and man-made systems, and will continue to hold back biodiversity conservation, sustainable development and even human health. Therefore, it is imperative that we look a little closer at the types of impacts that invasive species have on natural and productive ecosystems, and then the ways to address those impacts – which then can be seen as backgrounds for economic analyses. Throughout the coming discussions, it is important to approach both the impacts and the management of invasions from a perspective of the ecosystems they invade and to ask the question: "why do we need to worry about invasions?" as well as "what should we be trying to achieve – is it ***no invasions*** or ***functioning ecosystems with intact biodiversity***?" The second question is particularly important as recent history tells us that many billions of dollars have been spent on relentless efforts to destroy or prevent biological invasions without first working out what is the expected end-product of the effort.

To this end, we will be using the "**ecosystem approach**"[2] as suggested in the "Guiding Principles for the implementation of Article 8 (h)[3]" of the Convention on Biological Diversity which states that "measures to deal with Invasive Alien Species should, as appropriate, be based on the ecosystem approach" (Guiding Principle 3, Decision VI/23 of the CBD). We refer to the Convention on Biological Diversity because it is the main Multilateral Environment Agreement between nations which is concerned with the conservation and management of biodiversity (including ecosystems) and so addresses invasive species, their threats to biodiversity (and so to people's livelihoods and development) as well as the ways of preventing or managing invasions.

The greatest threat from biological invasions is when they reach their peak, or expanded or consolidated state (see Figure 1, module 1), at which point they will have maximum negative effects on the impacted ecosystem. The effects of such invasion vary with the invading species (animals, plants and/or micro-organisms) and the ecosystems affected – and can include one or more of the following: replacement of natural vegetation or faunal assemblages through competition, exclusion, predation, parasitism, pathogenesis, alteration of micro-climate, nutrient availability and ecosystem cycles. These can have serious effects on ecosystem function and so consequent reduction of ecosystem goods and service to human well-being. These may be primary effects of the invading organisms or there may be secondary impacts from the changes they make to ecosystem function or the parasites and pathogens that they will inevitably bring from their origins.

In the following sections of this module, we will present examples of some types of invasions from a range of invading organisms in various different ecosystems – primarily from the ecological and biological viewpoints. This will enable an understanding of the consequences of biological invasions which we hope will make clear the need for economic assessment and the application of economic tools for further evaluation of the significance of these impacts. In later sections of this module we will look at the ways in which invasions can be prevented or alleviated – further actions that need economic consideration and evaluation.

3C Types of impacts of species invasions

There are very many impacts of invasive species on ecosystems recorded and described from many parts of the world as species move around and become invasive in new countries, areas and ecosystems. From the aesthetic and nature conservation viewpoint it is interesting to note that there are a relatively small number (hundreds as opposed to many thousands) of very aggressive invasive species that are becoming widespread as a result of this invasion. Each of these is able to suppress (or even

[2] The "Ecosystem Approach" is a strategy for the integrated management of land, water and living resources that promotes conservation and equitable use in a sustainable way (http//www.cbd.int/programmes/cross-cutting/ecosystems/) by considering all aspects of a functioning ecosystem and developing actions with well-defined objectives that consider the whole ecosystem and its users

[3] Article 8 (h) of the CBD states that "Each Contracting Party (to the Convention) shall, as far as possible and as appropriate … prevent the introduction of, control or eradicate those invasive alien species which threaten ecosystems, habitats or species.."

cause extinction of) native species and, thereby, reduce the diversity of life forms in the most heavily impacted areas. The eventual outcome of the spread of these most aggressive invasives is a “sameness” that is beginning to be seen in places with similar climates – as local diversity decreases and invasive species become more common – often the same species in comparable latitudes and similar environmental conditions.

The purpose of the following sections is to illustrate some types of impacts wrought by invasive species on natural and productive ecosystems by describing examples rather than making long lists of impact types. We will address this from the ecosystem perspective (using the “ecosystem approach”) with emphasis on the impacts rather than on the details of the species concerned – because there are so many alien species that have become invasive that to list them by types would be unhelpful in trying to understand the range of impacts.

Impacts of invasions in terrestrial ecosystems

Most of humanity lives in terrestrial ecosystems which were the first to be recognised as the target of alien invasive species. Explorers and seafarers travelling to new lands were often followed by colonists who wanted their new environments to “have some elements of home” – either for food or building materials, or for sport or aesthetics, and later for special situations related to climate, soils, predators, diseases, pests and even sport. These intentionally introduced species brought their own unintentional companions including parasites, pathogens and those associated with the way they were transported (in soils and other cultures). Two examples are described below:

Domestic pigs were brought to many countries to which they were foreign and in which they subsequently escaped and became wild (or “feral”) outside of the confines of newly established settlements – in many parts of the world (Oceania, the Americas and many island nations). The domestic pig (*Sus scrofa*) is able to revert to a wild and invasive animal in a very few generations and to become destructive to native vegetation, predatory of small animals and aggressive to other herbivores as well as people. Today millions of feral pigs have invaded both wild and farmed areas of Australia, parts of Asia and many oceanic islands to the continuing detriment of native plants, animals and their habitats as well as productive ecosystems. Feral pig control is difficult, expensive and often dangerous and continues to be a problem in many invaded areas.

Terrestrial plants, especially shrubs, have been equally destructive when spread to new ecosystems around the world. Hedge-plants, garden shrubs, flowering vines, soil improving and erosion-controlling plants have all been intentionally introduced and many others have come unintentionally with long-term and detrimental impacts on native vegetation, animal food and habitats and agriculture. Many such plants not only out-compete local species, dominate and change vegetation systems, and bring about environmental degradation – but can also release substances that restrict or completely stop the germination and growth of other plants.

Lantana camara is one such shrub from tropical South America that was introduced ti many African countries in the late 1800s as an attractive flowering bush and a hedge plant. Over the years it has been naturalised and then spread (mainly by birds) and is presently invasive in many tropical and sub-tropical parts of the Continent. This has caused suppression of native biodiversity, exclusion of pasture and forestry and poisoning of livestock – with enormous economic impacts in many countries.

Impacts of invasions in freshwater ecosystems

Inland water systems are known to be susceptible to aquatic plant invasions (submerged, emergent and floating plants) as well as from fish, aquatic arthropods such as crustaceans and insects, molluscs and a range of planktonic and microscopic organisms. Many come unintentionally (sometimes introduced by boats, fishing gear and shipping traffic) while numerous fish species have been intentionally moved about from lake to lake, river to river and country to country for fisheries enhancement, sport fishing and aquaculture. Aquatic plants with attractive flowers or foliage have been moved to enhance water gardens and floral industries and then have escaped into inland waters – as have many unintentionally introduced species.

The more aggressive alien fish have, in many cases, out-competed local species and caused problems by consuming freshwater plants, invertebrates and lower vertebrates such as amphibians and small and immature fish. This has reduced the diversity of many aquatic systems, brought exotic fish diseases and parasites to local species and quite often reduced the range of fishery species available to people. All manner of aquatic plants have moved around the world with many becoming invasive and bringing about great changes in vegetation, fisheries potential, aquatic species diversity and water quality

Impacts of invasives in marine ecosystems

Marine organisms have been moved around the coasts and oceans of the world for aquaculture (mariculture) for fish, marine invertebrates and marine plants ("seaweeds"). Unintentionally they have been brought from port to port and into the open sea through passage in ships' ballast water, as attachments to the submerged parts of vessels (biofouling), through waste and lost cargo from ocean-going ships and from coastal discharges of various types of wastes.

Classically, it is the small immature stages that move with ships and then escape to establish in new waters where they compete with or prey upon local species – be they lower invertebrates, arthropods and molluscs or fish. Marine algae kept separate for millions of years by continents and currents and water temperature barriers have moved to new areas, become invasive and suppressed the local fauna and flora of both shallow and deep waters – with negative impacts on species diversity, fisheries production and ecosystems health.

The same movement of organisms by ships and other boat traffic can be responsible for spread and introduction of species in freshwater – especially in large lakes and rivers that cover several countries and climatic regions.

Impacts of invasives on human development systems

Two examples will suffice to illustrate the impacts that can be caused by invasive species on human development and infrastructure.

The first is the "World's worst water weed", water hyacinth, mentioned in module 1. This tropical floating water plant from Central America has invaded water systems throughout the tropical world – in Asia, Africa and parts of tropical America. Apart from its impacts on biodiversity, water hyacinth as an invasive species:

- Increases evaporative water loss by as much as six times normal evaporation from open water and so infested water bodies lose water very quickly,
- Blocks water flow in streams, irrigation canals and drains causing serious problems of water supply and requiring frequent clearing,
- Infiltrates hydropower generation dams and turbines and requires expensive clearance and disposal,
- Prevents people and boats from accessing open water when the plants come ashore in vast mats and prevent ferries and freighters from reaching their harbours in infested waters,
- Provides sanctuary for snakes, crocodiles and other problem animals and prevents access to fish/fisheries,
- Encourages the growth of the vectors (intermediate hosts) of malaria and bilharzias,
- Suppresses the growth of other aquatic plants that provide shelter and breeding grounds for fish.

Another aquatic organism which has become invasive in many freshwater systems across the world is the Louisiana Crayfish, *Procambarus clarkii*. This species is a native of the southern Unites States which has been introduced to many countries as an aquaculture species for specialist food and as a predator for the snail intermediate hosts of bilharzias. In Asia, Africa, Europe and some South American and Caribbean countries, it has escaped from aquaculture and invaded water systems such as lakes, dams, ponds and slow rivers where it consumes aquatic vegetation, aquatic molluscs and crustaceans, small fish, amphibians and insects resulting in serious aquatic ecosystem changes and reduced fisheries. This invasive species also burrows into the banks of rivers and the edges of dams and lakes causing serious erosion and leakage of storage waters. The small benefits that it provides as a (often only specialist) food source are far outweighed by its destruction of many aquatic systems and their (often endemic) fauna, fisheries and water holding capacity.

Impacts on production ecosystems

Many species of animals and plants have been modified through domestication to become the food sources for humankind. Some of these were native to the areas where they were domesticated, others were introduced (and are still being introduced) for more and better food production through various forms of agriculture and farming involving crops, orchards, livestock and captive fisheries. Our first realisation of species invasions probably came from the pests, weeds and diseases of his farming and animal-keeping pursuits. All animals and plants have some pathogens and parasites and some of these became problems under domestication while others were alien species introduced by various means to become the pests, weeds and diseases associated with agriculture and livestock production today.

Classic examples of invasive species affecting production ecosystems are:

- The invasive shrub from tropical America, Mimosa pigra, dominating floodplains to the exclusion of native vegetation and fauna and the prevention of livestock rearing and fisheries in previously productive areas,
- The accidental introduction of the Larger Grain Borer, Prostephanus truncates, from the southern USA to Eastern and Western Africa in the early 1980s resulted in its spread and invasion in many grain growing areas where this beetle can destroy a large proportion of stored grain
- The appearance and spread of the H5N1 strain of avian influenza that has been spread around the world (by poultry infecting migratory birds) and the impacts on human health and the poultry industry in many countries of Asia, Africa and Europe.

Impacts of invasives on human health and welfare

Zoonosis is the term for a disease of animals that becomes a disease of humans after introduction to the human population as a pathogen. An animal disease can be considered as an invasive species when it comes into the human population from a different locality – as has happened with Ebola, SARS and, to a certain extent, HIV/AIDS. There is no need to dwell on the impacts of fatal disease on human populations as their impact is obvious.

Less obvious is the impact of invasive species that threaten human food security, livelihood security and general welfare. A classic example of this is the invasion of the American tree, mesquite (*Prosopis* spp.) in many drier regions of the world. *Prosopis juliflora* was introduced to several countries in the Horn of Africa and East Africa to control soil erosion in arid areas and to provide shade. After initial establishment and spread it became invasive and now covers many thousands (in some cases millions) of hectares of arid and semi-arid lands to the exclusion of other vegetation and normal land-use. The original land-use in these areas was pastoralism where livestock-keeping peoples maintained their herds and flocks and kept them fed on pasture that was on common land across vast areas. The advent of mesquite has meant that the pasture has gone and the area is covered by impenetrable spiny shrubs and trees with no access or food for livestock. Further, the thorns of prosopis cause wounds that fester and when livestock, in desperation, feed on the leaves, many fall sick, have problems breeding and produce unusable milk. In this way the prosopis invasion has robbed thousands of pastoralist peoples of their livelihoods and their livestock, left them without their range and support and, in some cases, affected their health as well.

A world-wide invasive species with significant impacts on human health and livelihoods is the (domestic) rat, especially the Black Rat (*Rattus rattus*) and the Brown Rat (*R. norwegicus*), both of which originated in Asia. These pests have spread to almost every human habitation on the planet and exist on numerous uninhabited islands as well. We know of rats as competitors for human food and as “nuisance animals” that infest houses and food stores. Rats can also be carnivorous and will feed on any small vertebrate or other animals when short of alternative food, thus causing damage to man’s domesticated animals and his pets. In some tropical and sub-tropical situations, these rats also carry and transmit the bacteria responsible for plague (*Yersinia pestis*) and a number of other zoonoses such as leptospirosis which affect human health.

Impacts of biological invasions on biodiversity and its conservation and management

Many alien species that become invasive have serious impacts on biodiversity with results that are often not seen as economically important – until one investigates the value of biodiversity and its support of people as well as its role as a significant component of any environment. Our definition of invasiveness (from the CBD) relates to negative impacts on biodiversity – with or without obvious economic consequences. In fact, because stable ecosystems play many roles in the environment and provide goods and services to people, it is logical that an invasion of wild biodiversity will have some measurable negative impact which this course is trying to relate to economics and economic tools.

There are many examples of the impacts of invasive species (themselves being animals, plants or micro-organisms) on all manner of ecosystems and their component biodiversity. Rather than delve into detailed case studies, we will list some general accounts of such invasions and the significance of the impacts to biodiversity conservation and management.

The continent of Australia has been invaded by many mammals (and birds) that were introduced for a range of purposes and have since escaped, become naturalised and continue to change the wild ecosystems of that country. Millions of rabbits and other herbivores such as pigs, cattle, water buffalo, horses, donkeys, goats, camels and deer are wild (feral) around that country as well as some predators such as cats, dogs, foxes and ferrets. Over the last 200 years these invaders have changed many vegetation types, caused desertification and erosion, changed water regimes and caused extinctions of significant numbers of native animals, many of which were endemic to Australia. .

Islands are particularly susceptible to biological invasions, no matter how small or large. Thousands of islands have lost native biodiversity through invasions by alien animals and plants – whether they are island nations, small island components of a country or uninhabited islets, even oceanic emergent rocks.

One of the most successful ways of conserving wild biodiversity is through the creation and management of protected areas. These can have a range of strictness of protection – such as “no-go areas” in strict nature reserves, national parks, World Heritage sites, Ramsar wetlands of International Importance, Biosphere Reserves, Important Plant, Biodiversity and Bird Areas and open nature reserves. Recent surveys have shown that almost all of these protected areas have invasive species in them which are gradually changing their native biodiversity to the detriment of some species of plants, some plant assemblages and some animals that depend upon them for shelter, food, etc.

3D Prevention of biological invasions

Addressing biological invasions

Article 8 (h) of the Convention on Biological Diversity instructs parties to “prevent the introduction of, control or eradicate those invasive alien species which threaten ecosystems, habitats or species”. In its Guiding Principles for carrying out that instruction, the CBD ranks the ways in which invasive species should be addressed as:

1. Prevention of their introduction
2. Eradication of an incipient or new invasion
3. Containment of a newly established invasion to prevent spread, and, if those approaches fail,
4. Management of the threats and impacts of an established invasion.

The first option (prevention) is both the cheapest and the most effective in stemming the rise of invasions and their consequences. The fourth is by far the most expensive and long-lasting approach and is not always effective in halting the effects of invasion. We will examine each of these options so that economic considerations can follow as to the costs of preventing and managing biological invasions. The first to consider is prevention which means that the process of introduction of an alien species (that may become invasive) is halted before the organism enters a new ecosystem, area, country or region. This can occur before it arrives at the place of entry, while it is in the process of moving along a pathway from its origin to the new ecosystem. If this fails, the second opportunity for prevention is to stop the introduction as it arrives and prevent it from entering the new area.

Prevention in/on pathways

There are many physical pathways along which an alien species may travel to a new locality – on land, in/on freshwater, in/on the sea or in the air. A pathway may also be a process in itself, such as travel, transport, tourism and trade which cause an organism to be transported. On each pathway there may be several vectors that assist the passage of the organism/species concerned. Some examples of pathways and ways to address movement along them are listed below:

Land-based pathways: roads, tracks, paths, railways, stock routes, migration routes
Vectors: vehicles, rolling stock, freight, travellers, strollers, domestic animals, wild animals, winds
Solutions: trade agreements, WTO, regional biosecurity agreements, industry best practices, responsible export practices

Freshwater-based pathways: lakes, reservoirs, dams, canals, streams, rivers, deltas, large wetlands
Vectors: ships, boats, other vessels, travellers, freight, currents, winds
Solutions: International ballast water convention, draft biofouling agreement, IMO, WTO, trade agreements, industry best practices, regional biosecurity agreements, Ramsar Convention, lake and river basin commissions

Marine-based pathways: international shipping, oceans, seas, estuaries, inter-ocean ship canals, storms
Vectors: all marine vessels (freight, passengers, fishing, exploration, sport, etc.), marine organisms, marine migration, winds, currents
Solutions: Ballast water convention, biofouling agreement, IMO, WTO, international and regional trade agreements, regional biosecurity agreements, UN Regional Seas Programme, industry best practices

Aerial pathways: all air transport (local, national, international), bird (and other flying animal's) migration, release of organisms into the atmosphere, aerosols, winds, storms
Vectors: aircraft, freight, passengers, luggage, flying animals,
Suggest: Civil aviation agreements, ICAO, airline and travel industry best practice, trade and biosecurity agreements

Prevention at sites of introduction

The actual prevention of intentional introductions of alien species to a new ecosystem or country depends upon several conditions: the capacity to inspect/assess each likely introduction, and the capacity and tools to decide if it should enter or not. This also applies to unintentional introductions although in that case there is no need to decide on allowing some entries – all can be stopped.

In theory, the site of introduction is the endpoint of a pathway. In the case of introductions to a country with a strong biosecurity system, this will probably be an airport, land border crossing or marine[4] port and is likely to be furnished with quarantine facilities and risk assessment procedures for evaluating arriving organisms. In such cases all arriving freight, luggage, personal effects and travellers (or a significant sample thereof) would be inspected, organisms checked for import against lists of acceptable and non-acceptable species and any on the second list would be removed and declared prohibited for import. They would then be disposed of in some way that ensured they did not (immediately or eventually) enter the country. Species not on any list would be held in quarantine pending a risk assessment and a decision on whether or not to allow importation. The prediction of risk of invasion after introduction is a technically-complex process involving prior history of invasion by the species in question together with other relevant factors such as the environmental conditions of the area intended for import. This requires scientific rigour involving:

- Correct/accurate identification of the species (or lower taxon)
- Application of the risk assessment process
- Availability and assessment of pertinent information about the species

[4] In this situation, "marine" applies to freshwater as much as oceans and seas because the practices of inland water transport are similar (though not identical) to those of marine shipping

- Availability and assessment of the relevant conditions of the ecosystem to which the species will be introduced
- Likely impacts of the species on target ecosystems – if it becomes invasive
- Benefits of introduction
- Available methods and costs of eradication/management if the species becomes invasive – or other mitigation measures

Once the risk assessment is complete, a decision to allow introduction (or not) is made by a competent, mandated authority and action is taken. Clearly these processes will involve significant monetary and non-monetary costs as well as scientific and technical capacity.

Many unintentional introductions and those that occur at non-entry point localities are unlikely to be subject to decisions as above – nor are those that occur into countries with limited biosecurity systems and insufficient technical capacity.

Prevention of establishment, naturalisation and spread

Once an organism has been introduced to a new area/ecosystem, the probability of its passing through the stages to invasion (see module 1, section 1B, Table 1 and Figure 1) are small – unless it is known to be a "likely invader" from experiences elsewhere. A species may be inadvertently or accidentally introduced which is likely to become invasive. Upon discovery of such an introduction, it is possible to prevent progress through the stages to invasion if it is recognised and action taken quickly. The main measures used are eradication and containment. **Eradication** refers to the destruction of the population of establishing species – including all living organisms and all development stages (adults, sub-adults, immatures, eggs, seeds, other vegetative propagules, etc.). This is sometimes possible under special conditions but mostly quite difficult to ensure that complete eradication has been achieved – especially with flowering plants that may set down a seed bank that is hard to destroy.

Containment is the process used to prevent further spread of a potentially invasive species and so reduce the risks of ecosystem degradation. This is used quite often to contain epidemics and epizootics of (human and animal) pathogens and parasites by the use of quarantine and restriction of movement of the hosts.

3E Managing invasions

Assessment and management of established invasions

Once an alien species has spread and established an invasion, the only courses remaining to ecosystem managers are: no action, or management of the invasion. Either way, an assessment is required to make the decision and then chart a course of action. The assessment of an established invasion (as defined in module 1 and the glossary) requires that its costs and benefits be examined in relation to the affected ecosystem and agreed values to people (goods and services) and the environment in general (e.g. nutrient cycling, microclimate stability, protection from extreme weather events, biodiversity conservation). Some low-impact invasions may be of more benefit than cost to the ecosystem and its users – especially if the invading species brings goods and services for people. In such cases it may be advantageous to stakeholders to allow the invasion to persist (while possibly managing it to reduce other costs).

If the assessment results in a decision to reduce the invasion or eliminate it, there are several options open to ecosystem managers towards this end. However, even at this stage, it is recommended that stakeholders be involved in a discussion about the objectives of lessening or removing an invasion so that further courses of action (using the ecosystem approach – see above) address the changes to the affected ecosystem rather than just eliminating the invading species. Species invasions may involve changes in the effected/impacted ecosystem which may leave it "open" for re-invasion by the same or different species once the initial invader has been removed. There are also situations where the invasion may provide goods and services to the people who use/own/manage the affected ecosystem such that removal of the invading species may not be the prime objective of all concerned – see below.

Types of management

The main types of management or control of species invasions are:

1. **Mechanical control** involves the physical removal of the invading species. This can involve manpower alone to uproot and/or burn and destroy plants (and their seeds) or hunt/trap adult and immature animals or destroy organisms affected by pathogens and parasites. It may also involve machinery and sophisticated equipment to enhance the mechanical control. This method of control is often preferred over others as it can have least impact on non-target species and ecosystem stability – but may take longer than required to meet the management objectives

2. **Chemical control** involves pesticides, herbicides, poisons and pharmaceuticals used to kill species of concern or eliminate them from host animals and plants. Impacts on non-target species and habitats may be of concern with this method unless specificity of action can be guaranteed or manipulated.

3. **Biocontrol** can be employed when an alien invasive species has become established without its natural controls in the form of specific parasites, predators and pathogens. These agents can then be imported to the ecosystem of concern and introduced to the invading species population for its control This method is more sustainable (in most cases) than the first two because once it is successfully applied, it should continue to be effective as the invading species and the biocontrol agents come to some form of equilibrium at an acceptable (low) level of the invading species. This means that there is a significant initial cost to establish the biological agents on/in the invading species, but little cost (apart from monitoring) after that.

4. **Integrated control** involves the use of more than one of the methods above to ensure management of the invasion and prevention of its spread. Classically, biocontrol would be used to reduce the population of the invading species to an acceptable level while mechanical and chemical control would enhance this by eliminating ”outlier” subpopulations and advancing fronts or otherwise difficult-to-control areas or groups.

Each of these methods has its economic costs and manpower and expertise requirements which have to be compared to each other and with the costs of “no action”. There is a great deal of information about control methods and there efficacy in both scientific and technical journals and websites as well as networks of people with experience of their use (e.g. references listed below and the Aliens-L listserve of ISSG).

Benefits of invasive species

Invasive species may bring benefits to ecosystem function and to people (as mentioned in module 2) as well as bringing negative impacts. Invasions inevitably increase the species diversity of an invaded area – at least initially – and may add vegetative or faunal benefits to an ecosystem. Invading animals may enhance the food availability of an area or may add to the elimination of existing unwanted species. Invading plants often have some attributes that are of benefit to the ecosystem and its stakeholders such as: adding new human or animal foods, adding sources of timber and fuelwood, producing new and needed plant products (such as resins, fruits, edible seeds), adding to the range of habitats for desirable species and positively altering the availability of water, sunlight or nutrients.

It is often the case that the benefits of invasions are outweighed by the costs to the ecosystem and its functions – but the reverse may be the case. In all cases, therefore, the costs and benefits should be discussed by stakeholders and agreed objectives developed before management or control of the invading species it initiated.

3F Ecosystem restoration after invasion

Restoration of invaded ecosystems – objectives and expectations

One objective of the management of an invaded ecosystem may be to return it to its status and function before the invasion began. This will first require a consideration of this end-point when developing methods for control of the invading species – to ensue that no damage is done to the ecosystem that would prevent its return to its former status. Another aspect to be considered is the actual condition and species content of the original ecosystem – both in terms of a preferred status to be returned and the ways to achieve that. For example, when a species-rich ecosystem (e.g., one valuable for biodiversity conservation) is invaded and species diversity is greatly reduced, it is important to know what/which species were present before the invasion in order to return them when the invasion has been eliminated or controlled. In some cases, a partial return to the original status of the ecosystem may be preferred because it contributes more desirable goods and services or provides a better habitat for desired species or vegetation types or animal associations.

Restoration ecology is a growing discipline which uses both native and exotic species to "speed up" return to the previous condition of the affected ecosystem. Clearly, ecosystem managers must be wary of introducing further invasive species in an attempt to restore an ecosystem function that has been removed by the invader.

3G References

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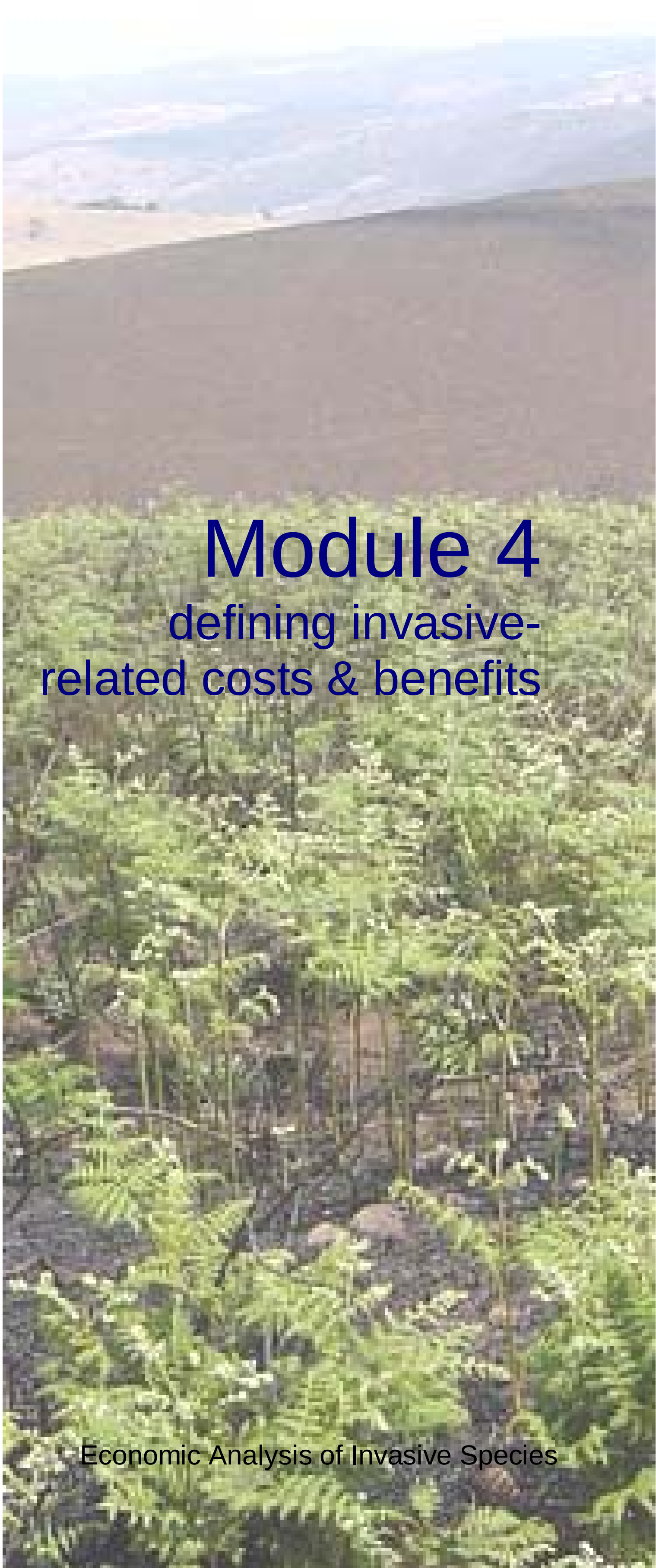


Module 4

defining invasive-related costs & benefits

Economic Analysis of Invasive Species

4A What this module covers

This module introduces the conceptual frameworks for understanding, defining and categorising the economic costs and benefits of invasive species. It describes both their direct production impacts and secondary and tertiary effects, as well as the positive benefits of invasives. The module proposes a typology of benefits, and introduces the total economic value framework as a guide for categorising the economic impacts of invasives in terms of their effects on the health and functioning of natural and human-modified ecosystems. It concludes by introducing key considerations in economic analysis which are necessary to bear in mind when dealing with invasives: the concepts of marginality, uncertainty and time, and the importance of looking at the distribution of costs and benefits.

By the end of this module, the reader will understand the different types of economic costs and benefits associated with invasives, and be able to categorise them according to a total economic value framework.

4B Looking at the impacts of invasives in economic terms

Module 3 described the wide array of impacts that invasive species can give rise to, ranging from effects on production systems (such as forestry, fisheries and agriculture), through development systems (such as water supply and quality, infrastructure and energy), human health and biodiversity, to the physical needs to manage and respond to invasions and the threat of invasions.

The current module builds on earlier sections by looking at the economic implications of invasives, and the damage they wreak in natural and human-modified ecosystems. Just as human (economic) activities are the main cause of invasions, so it is humans and their economies who experience major impacts. An understanding of the economic scope, magnitude and distribution of costs and benefits is therefore essential when dealing with invasive species.

Invasives give rise to both direct and indirect economic impacts. While their direct economic impacts can be seen primarily as on-site production impacts arising from the effects of the invasive on the host habitat or ecosystem, the indirect impacts are non host-specific and may cause much wider effects on markets, prices, health, nutrition, trade, the environment and public and private spending (Evans 2003, FAO 2001).

Box 2: direct and indirect economic impacts of invasives

- Direct production impacts arising from the effects of the invasive species on the host ecosystem.
- Secondary and tertiary effects on other sites, sectors and times in terms of markets, prices, health, nutrition, trade, the environment and public and private spending.

Direct production impacts

One source of difficulty is the sheer magnitude, and range, of direct economic impacts. The physical expenditures, alone, of addressing invasives are immense. For example government expenditures for the manual and chemical control of invasive trees which have reduced water supplies available for nearby communities, increased fire hazards and eliminated some native species in the South African Cape Floral Kingdom exceeds $40 million a year, and it is estimated that the costs of restoring the ecosystem may reach $2 billion (Turpie and Heydenrych 2000).

The on-site economic effects of invasives however extend far beyond direct control costs, and are not limited in space and time. The direct production impacts of invasives typically extend across numerous ecosystem services. For example plants which become invasive weeds may act on-site to exterminate native biodiversity, reduce land productivity, choke up water bodies, interfere with irrigation and hydropower development, destroy fisheries breeding and nursery areas, compete for land and other resources, destroy wildlife habitat, degrade pastures, undermine the food chain, interrupt ecological balance and processes, act as pests for crops and other plants, require more pesticide applications, compromise the beauty of landscapes, impinge on recreational areas, and so on. The economic impacts of invasive weeds on agriculture in Australia are for example estimated to be between $3.5 billion and $4.5 billion annually, including financial costs of control, losses in production, changes in net money revenue, and changes in welfare (Cacho *et al* 2008).

Secondary and tertiary economic effects

The multiplier effects and knock-on impacts that an invasion in one particular place has on other production and consumption systems, sites and times may be immense. For instance in New Zealand, the costs of invasive species are estimated to amount to about 1% of GDP (Bertram 1999). China's burgeoning trade and economic growth have triggered enormous environmental threats from an expanding list of biological invaders, thought to incur annual losses to the national economy of about $14.5 billion (Ding *et al* 2008).

A second challenge is therefore to incorporate the secondary and even tertiary economic effects of invasives – such as those occurring because of associated shifts in consumer demand, changes in the relative price of inputs, and off-site impacts arising from the loss of biodiversity and ecosystem services. These changes affect not just the site or sector where an invasion has taken place, but spread across other parts of the economy. Indirect impacts can be manifested in diverse ways: for example they can reduce land rental prices, diminish profits, lower tax revenues, lessen foreign exchange earnings, undermine employment, decrease food security, worsen human health, increase livelihood vulnerability, and compromise the achievement of economic development and sectoral policy goals.

Box 3: direct and indirect costs of leafy spurge in Montana, South Dakota and Wyoming

Leafy spurge (*Euphorbia esula L*) is an aggressive, persistent, deep-rooted perennial which is native to Europe and temperate Asia, but has become invasive across parts of the USA. Leafy spurge was first introduced in North America in the 19th century. The weed currently infests large amounts of untilled land in the Plains and Mountain states. Once established on untilled land, the weed spreads quickly, displacing native vegetation. Leafy spurge has unique characteristics that give it a competitive advantage over most indigenous plants and provide it with natural defences against cattle grazing. Leafy spurge can create serious economic losses for land managers and ranchers.

Wildlife recreation and soil and water conservation benefits lost to leafy spurge are around $800,000 a year in Montana, South Dakota and Wyoming. The total annual direct and indirect costs of the invasive on wildlands is $1.95 million. Costs to grazing lands are felt through reductions in carrying capacity and result in direct losses of $10.3 million a year and indirect costs of just under $24 million a year. Direct leafy spurge benefits control benefits are $19.1 million a year ($4.98 million in improving livestock carrying capacity, $11.74 million in increased livestock production expenditures, $1.8 million in wildlife-related recreational expenditures and $0.485 million in soil and water conservation. Indirect benefits from changes in business volume, personal income, retail sales and other economic activity are $39.3 million a year.

From Bangsund *et al* 1991, 1993, 1999, quoted in Stutzman *et al* 2004

The benefits of invasives

It is necessary to recognise, and factor into economic analysis, the fact that invasive species typically also yield market or non-material benefits – after all, this is usually why they are introduced and used in the first place. No assessment of invasive costs and benefits is complete without considering their positive values. As described above in module 3, invasive species may bring economic benefits (and indeed this is usually the reason they are introduced in the first place); in South Africa, for example, water hyacinth is used for both fodder and furniture, alien acacias were introduced as a source of fuelwood in biomes which have little woody vegetation, invasive mussels constitute a productive commercial fishery as well as providing food for gatherers (Turpie, *pers comm.*)

Linking biophysical impacts to economic change

Translating biophysical changes (in ecology, hydrology, biodiversity and other factors) into economic impacts is an extremely challenging undertaking. Estimating direct and indirect impacts requires a considerable amount of time and effort, and depends on extensive biological and non-biological information. In effect, tracking the economic impacts of invasives requires the specification of a series of dose-response relationships which link a given level of biophysical or ecosystem change with a particular level of economic change. Such relationships are extremely hard to quantify reliably, and often depend on numerous assumptions. It is difficult to understand, measure and predict invasions, which are typically subject to high levels of uncertainty, and involve complex interactions with other species, populations and natural communities, the natural environment and human systems.

Both the need for sound science and the limitations of biological and ecological explanation need to be borne in mind when trying to identify the likely economic impacts of invasives, as well as the considerable potential that exists for errors in measurement and quantification (Perrings *et al* 2000). The importance of ensuring that both scientific and economic data are sound, and the hazards of not doing so, are for example illustrated by the case of efforts to value the costs of the invasive European green crab (*Carcinus maenas*). Estimates of the crab's economic impact, which have been widely used to help justify recent public policy in the United States, were found to be based on data taken from the wrong geographic location, predictions of ecological effects appeared to rest on loose footing, and economic methods had been misapplied in constructing the estimate (Hoagland and Jin 2006). Module 3 provides detailed information about scientific aspects of the impacts of invasives.

Box 4: linking the biophysical impacts of alien invasive plant species in South Africa to changes in economic values

Analysis of numerous valuation studies carried out to assess the economic impact of alien invasive plants in South African ecosystems illustrates the variety of biophysical impacts and economic indicators that can be used to come up with monetary estimates of benefits and costs.

Topic	Biophysical impacts and economic indicators	Value of impacts
Impacts of alien plant invasions on water yield	Reduced water yield from invaded watersheds, prevention of water losses through clearing programmes	Clearing of invasive aliens would prevent losses of up to 30% of Cape Town's water supply at a cost of 1.3¢ per m^3
Costs and benefits of alien plant clearing programmes	Increased water yields resulting from clearing, compared to costs of operating water supply schemes	Clearing would yield water at 14% of the cost of developing a new water supply scheme
	Increased water yields from clearing of invaded watersheds and uneconomic plantations of alien trees	Clearing yields benefit:cost ratios of between 6:1 and 12:1 for clearing invaded watersheds, and between 360:1 and 382:1 for clearing uneconomic plantations
Relative costs of clearing programmes compared to costs of allowing alien plants to invade unchecked	Increased water resulting from clearing compared to increased losses from continued invasion	Costs of clearing invaded watersheds ranges between $4-13 million, and would increase to between $11-278 million if invasions continue unchecked
Broad survey of impacts of alien plants on water resources at a national scale	Use of water resource by invasive species	Costs to clear infestations vary between $412-996 million
Ecological-economic simulation model of mountain fynbos ecosystems	Consequences of invasion for water production, wildflower harvest, hiker and ecotourist visitation, endemic species and genetic storage	Managing alien plants increases value of hypothetical 4 km^2 area from $3-50 million
Cost-benefit analysis of black wattle (*Acacia mearnsii*)	Benefits of commercial crop values and other products, impacts from reduced water yield, increased fire risk and loss of biodiversity	Continued cultivation without control programmes yields a benefit:cost ratio of 0.4, while continued cultivation with clearing and/or biological control of seeds yields benefit:cost ratio of between 2.4 and 7.5
Cost benefit analysis of biological control of red water fern (*Azolla filiculoides*)	Loss of water resources and livestock for agricultural sector	Total losses estimated at $58 million for South Africa, control programme costs of $51,000, yielding a benefit:cost ratio of 1,130:1
Economic valuation of indigenous vegetation and impacts of alien infestations on the Agulhas Plain	Benefits from livestock, wildflower harvesting and nature-based tourism. Cost estimates for clearing invasives to prevent erosion of benefits	Benefits total $3 million annually and total costs to clear invasives amount to $5.6 million.
Analysis of the economic consequences of invasion on the use values of fynbos ecosystems	Value of harvesting wildflowers, recreational use in protected areas and water runoff, in pristine and densely invaded areas	Reductions due to invasions range from $2.3 - $9.7 per ha for harvest values and from $1-$3.8 per ha for recreational use. The value of lost water due to invasion is $163 per ha.

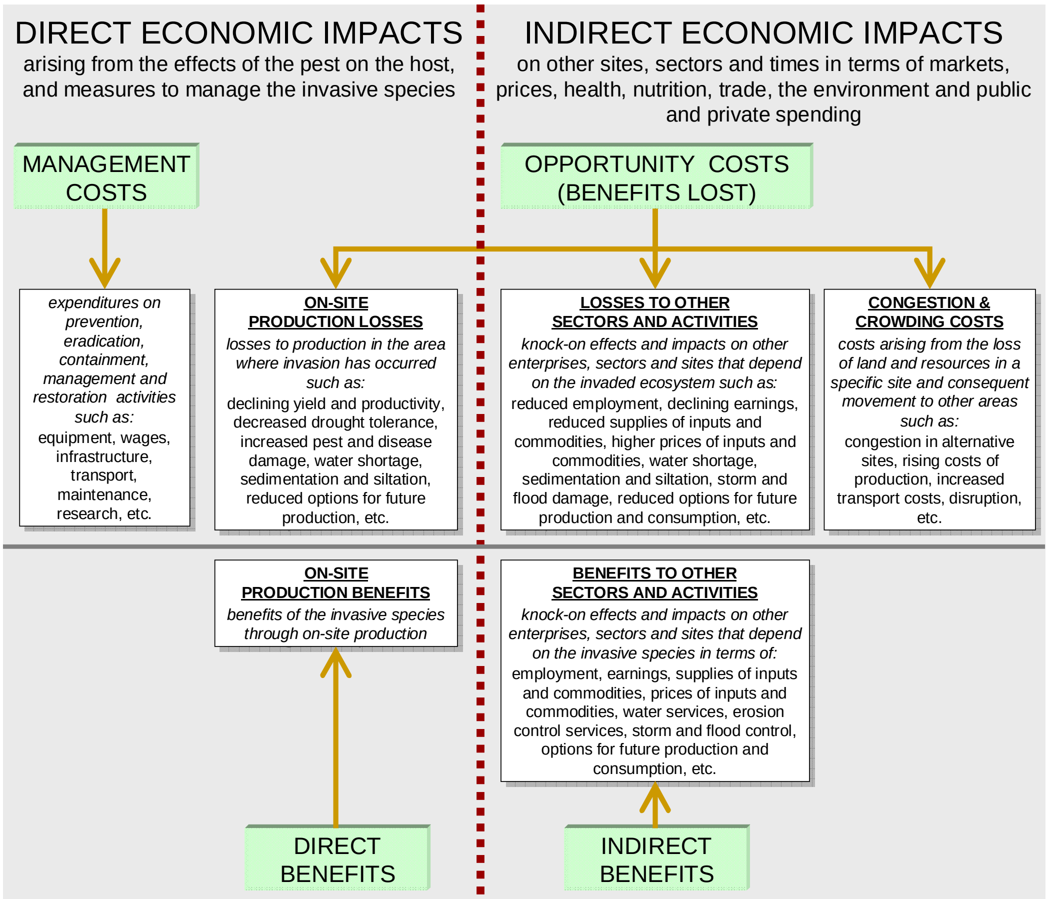
From various authors, summarised and cited in van Wilgen *et al* 2001

4C Defining the benefits and costs of invasives

A third stage in the economic analysis of invasives is therefore to work to define the economic costs and benefits that are associated with these impacts, after first identifying the direct and indirect economic causes of steps in the progression to invasion (module 2), and then establishing the scope and level of the impact of invasives (module 3). The following sections of this module provide a series of steps and frameworks for defining, categorising and elaborating the costs and benefits of invasives.

As described in module 2, costs and benefits arise because invasive species interfere with the functioning of natural or human-modified ecosystems which yields flows of economically valuable goods and services, and displace (original, or native) species that are economically valuable. The current section defines the categories of costs and benefits that need to be covered in the economic analysis of invasives. Following on from this, the toolkit will outline below (4D categorising invasive costs and benefits in terms of ecosystem values) a framework for analysing these costs and benefits in terms of changes in ecosystem-related values.

Figure 4: direct and indirect economic impacts of invasives



Defining the benefits and costs of invasives requires that both direct production impacts and secondary/tertiary effects are taken into account, and that the positive effects (benefits) as well as negative effects (costs) of invasive species are considered. As outlined above (4B looking at the impacts of invasives in economic terms), direct economic impacts arise from the effects of the invading species on the host habitat or ecosystem and measures to manage the invasive species, while indirect economic impacts refer to effects on other sites, sectors and times in terms of markets, prices, health, nutrition, trade, the environment and public and private spending (Figure 4). These include:

- Management costs. Direct physical expenditures on prevention, eradication, containment, management and restoration activities, such as spending made on equipment, wages, infrastructure, transport, maintenance, research, etc.
- Opportunity costs:
  - On-site production losses. The losses to production in the area where invasion has occurred through declining yield and productivity, decreased drought tolerance, increased pest and disease damage, water shortage, sedimentation and siltation, reduced options for future production, etc.
  - Losses to other sectors and activities. The knock-on effects and impacts on other enterprises, sectors and sites that depend on the invaded ecosystem, such as through reduced employment, declining earnings, diminished supplies of inputs and commodities, higher prices of inputs and commodities, water shortage, sedimentation and siltation, storm and flood damage, reduced options for future production and consumption, etc.

- Congestion and crowding costs. The costs arising from the loss of land and resources in a specific site and consequent movement to other areas, such as congestion in alternative sites, rising costs of production, increased transport costs, disruption, etc.

- On-site production benefits. The benefits of the invasive species through on-site production.

- Benefits to other sectors and activities. The knock-on effects and impacts on other enterprises, sectors and sites that depend on the invasive species in terms of employment, earnings, supplies of inputs and commodities, prices of inputs and commodities, water services, erosion control services, storm and flood control, options for future production and consumption, etc.

4D Categorising invasive costs and benefits in terms of ecosystem values

The problem of undervaluation

As explained earlier in the toolkit (see 2E linking invasives to changes in human wellbeing), a primary concern in economic analysis is assessing the incremental changes that occur when invasive species occupy a space and thereby interfere with the functioning of a (natural or human-modified) ecosystem which yields a flow of economically valuable goods and services, and displaces (original, or native) species or biological associations that are economically valuable. When we are looking at the opportunity costs or benefits which are lost as a result of invasive species, we are essentially quantifying changes in the status, composition and health of natural or human-modified ecosystems, in terms of the economic impacts of changes in the level and quality of services they yield.

The steps in the progression towards invasion are beset with problems of under-valuation. Ecosystem goods and services are persistently under-valued: in the statistics and figures upon which benefit-cost and profit-loss calculations are based, in the prices and markets people face, in economic policies and instruments, and thereby in the signals which drive producer and consumer behaviour. In many instances ecosystem services simply do not have a market price at all (for example clean air, water quality and flow regulation, protection against extreme weather events, landscape beauty or cultural significance). In other cases the products or commodities are assigned market prices that do not reflect their real value to society in terms of their component resources or associated costs of production, or have characteristics of public goods which mean that they are not adequately allocated or priced by the free market. This presents particular challenges for valuation, which are addressed in module 5 of this toolkit.

Given this tendency to under-valuation, it is hardly surprising that ecosystems are allowed to be modified, converted and taken over by invasives in the interests of other more 'productive' land and resource management options which appear to yield much higher and more immediate profits. The issues associated with the market, policy and institutional failures which result from under-valuation have already been described (in module 2C identifying the economic causes of invasions): because the full costs of invasives are not internalised into people's behaviour and decisions when they undertake economic activities they tend to ignore the wider economic consequences of their actions, meaning that potentially invasive species are more likely to be introduced and are less likely to be controlled.

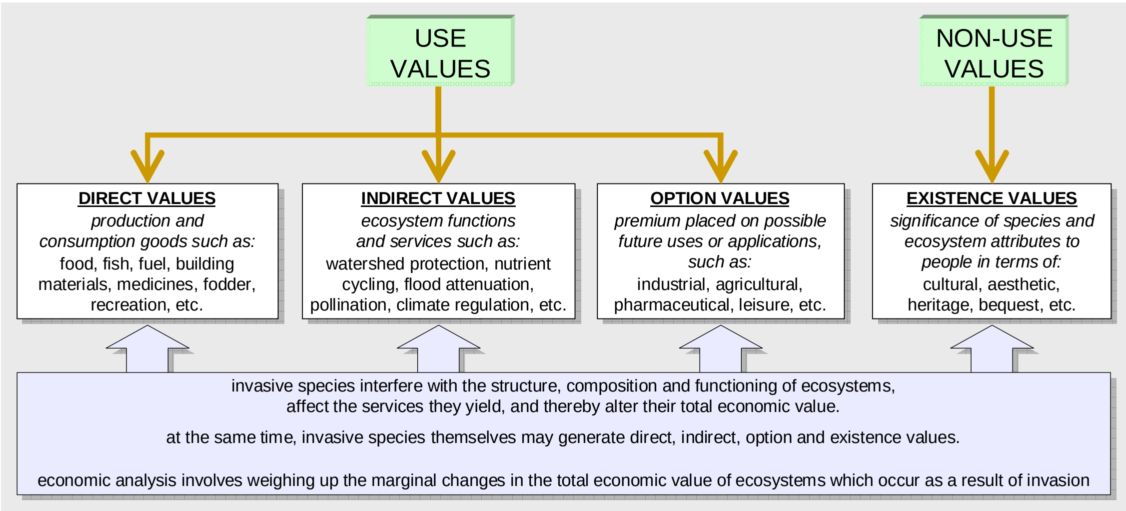
The total economic value framework

It is important to ensure that these problems of under-valuation (and consequent under-estimation of economic impacts) are overcome when defining the non-management costs and benefits of invasives. One reason for the persistent under-valuation of ecosystem services (and frequent under-estimation of invasive economic impacts) is that, traditionally, concepts of economic value have been based on a very narrow definition of benefits. Economists have tended to see the value of ecosystems only in terms of the raw materials and physical products they generate for immediate production and consumption (especially focusing on commercial activities and profits). These direct uses however represent only a small proportion of the total value of ecosystems, which generate economic benefits far in excess of just physical products or marketed commodities. Work carried out in South Africa for example indicates that invasive species may have in total reduced the value of goods and services provided by fynbos ecosystems by over $11.75 billion (Van Wilgen *et al* 2001). Confining concepts of ecosystem value to direct benefits alone would constitute a huge underestimation, and covers only the tip of the proverbial iceberg.

Over the last decade or so, the concept of total economic value (Figure 5) has become one of the most widely-used frameworks for identifying and categorising ecosystem benefits (Pearce 1990, Barbier *et al* 1997). Instead of counting only easily observable commercial values, it also encompasses subsistence and non-market values, ecological functions and non-use benefits. As well as presenting a more complete picture of the economic importance of ecosystems, it can be used to demonstrate clearly the high and wide-ranging costs associated with their degradation as a result of invasion, which extend beyond the loss of direct values.

Such a framework provides a useful tool for the economic analysis of invasives, and for defining and thinking through their economic effects: all of the components of total economic value are impacted when invasions take place. Invasive species interfere with the structure, composition and functioning of ecosystems, affect the services they yield, and thereby alter their total economic value. At the same time, invasive species themselves may generate direct, indirect, option and existence values. Economic analysis involves weighing up the marginal changes in the total economic value of ecosystems which occur as a result of invasion.

Figure 5: the total economic value of ecosystems



Looking at the total economic value of a natural or human-modified ecosystem essentially involves considering its full range of characteristics as an integrated system — its resource stocks or assets, flows of environmental services, and the attributes of the system as a whole (Barbier 1994). Broadly defined, total economic value includes:

- **Direct values.** The raw materials and physical products that are used directly for production, consumption and sale — at both subsistence and commercial levels. Examples include food, fish, fuel, building materials, medicines, fodder and recreational resources.

- **Indirect values.** The ecological functions which maintain and protect natural and human systems and provide essential life support. These obviously vary for different types of ecosystems, but include services such as watershed protection, nutrient cycling, pollination, flood attenuation, micro-climate regulation.

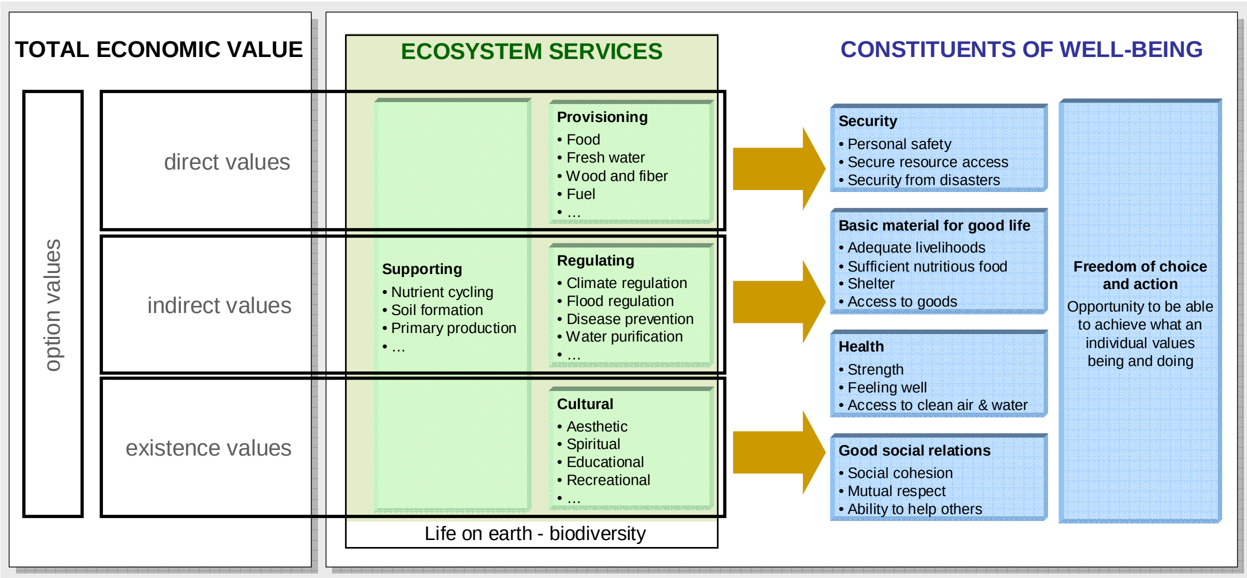
- **Option values.** The premium placed on maintaining ecosystems, landscapes, species and genetic resources for future possible uses which have economic value. By definition, many future use options cannot be known now, because they have not yet been identified, discovered or developed. Examples include new industrial, agricultural or pharmaceutical applications of wild species; future tourism and recreational developments; and novel possibilities for resource utilisation.

- **Existence values.** The value of ecosystem attributes and their component parts, regardless of current or future possibilities to use them. Ecosystems provide sites and landscapes, and contain a range of plant and animal species, which people value simply because they exist — not just because of the products and services they generate. Examples include historical or cultural sites and artefacts; aesthetic appeal; considerations of local, national or global heritage; and perceptions of bequest for future generations.

It should be emphasised that the different elements of total economic value are not necessarily additive. In many cases the use of an ecosystem to gain a particular type of value may preclude, or lessen, the opportunity of gaining other values. For example, extraction of particular resources or direct values may make an ecosystem less attractive to recreational visitors, or may diminish possible future option values.

The concept of total economic value (which essentially defines and categorises the different benefits of ecosystems, and allows the full range of non-management costs and benefits of invasives to be defined) can be easily linked to the more dynamic framework of the Millennium Ecosystem Assessment which depicts the links between ecosystem services and human wellbeing, described earlier in the toolkit (see 2E linking invasives to changes in human wellbeing). Each component of total economic value corresponds clearly to different categories of ecosystem services, including direct values (provisioning services), indirect values (supporting and regulating services), cultural services (existence values), and their possible uses and applications in the future (option values) (Figure 1).

Figure 6: relating total economic value to the ecosystem service-human wellbeing framework



Adapted from Millennium Ecosystem Assessment 2005

4E A checklist for identifying the costs and benefits of invasives

Bringing together the definitions and categorisation of costs and benefits covered in the preceding sections of this module, simple matrices can be constructed to assist in identifying the costs and benefits of invasives. These checklists are a particularly useful tool to ensure that the full range of direct and indirect costs and benefits are covered in economic analysis, and related to ecosystem services and human wellbeing. They also provide the background information that is required prior to undertaking valuation, covered in the next module (5 applying economic valuation techniques to invasives).

Two different matrices or checklists are required, and presented: one for identifying invasive benefits, benefits lost and opportunity costs; and one for identifying the direct management costs of invasives. In the worked example below, we take the case of the invasion of an aquatic plant into a wetland area.

A simple checklist such as that outlined in Table 6 can be used to identify and trace through invasive benefits, benefits lost and opportunity costs, as manifested through changes in different elements of total economic value and ecosystem services. It should be noted that although the worked example covers a wide range of on and off-site impacts, in reality many economic analyses will not be tracing the effects of invasives throughout the whole economy – more commonly, analysis would be focusing on a particular sector, stakeholder group or group of impacts. It should also be mentioned that this checklist does not include existence values (cultural services): although these impacts are critical, and of major concern, they lie outside the scope of economic analysis and cannot be quantitatively measured or adequately addressed by the methods presented in this toolkit.

Table 6: checklist of invasive benefits and costs

Source of impact	Economic benefits	Economic indicators	Economic benefits lost (opportunity costs)	Economic indicators
On-site production impacts				
Direct values (provisioning)	Rainfed cash crop production	• Farmer income • Farmer employment	Decline in fisheries Decline in irrigated crop production Loss of medicinal plants Loss of livestock pasture Loss of plants used for fuel	• Loss of income from fisheries • Loss of income from irrigated crops • Loss of income from livestock • Loss of livelihood diversity • Reduced nutrition • Reduced health • Shifts in energy source
Indirect values (supporting & regulating)	Some level of vegetative cover which assists in flood control and wastewater purification	• Protection of fields, houses and infrastructure from flooding • Water quality	Loss of vegetation leading to reduced fish breeding and nursery habitat Choking of waterways leading to loss of flood control services Decline in water quality from increased pesticide applications Loss of wildlife habitat Loss of landscape beauty	• Loss of fisheries income and employment • Increased damage to fields, houses and infrastructure from floods • Increased costs of water purification • Increased water-borne disease costs • Loss of income from wildlife and recreational visitors
Option values	Continuing cash crop production	• Farmer income • Farmer employment	Loss of opportunities for recreational development Loss of gene pool	• Loss of future income and employment
Impacts on other sectors and activities				
Direct values (provisioning)	Supply of cash crops	• Supply of food crops • Government revenues • Export earnings	Decline in supplies of other crops, fish and livestock products	• Higher prices for fish and crop foods • Loss of government revenues from fisheries • Loss of foreign exchange earnings from exports
Indirect values (supporting & regulating)	Some level of vegetative cover which assists in flood control and wastewater purification	• Protection of downstream infrastructure from flooding • Maintenance of downstream water quality	Loss of vegetation leading to reduced fish breeding and nursery habitat Choking of waterways leading to loss of flood control services Decline in water quality from increased pesticide applications Loss of wildlife habitat Loss of landscape beauty	• Reduced government revenues from recreational visitors • Increased costs to clear and manage waterways • Increased damage costs from flooding
Congestion and crowding effects				
Congestion and crowding	-	-	Increased pressure on remaining irrigation land Increased pressure on remaining pasture land Increased demand for alternative fuels Increased use of alternative recreational sites	• Increased travel costs to other recreational sites • Decrease in visitor experience due to crowding at other recreational sites • Higher prices of alternative fuels • Reduced livestock productivity due to exceeded carrying capacity • Reduction in irrigated farm area in alternative lands

A second checklist, outlined in Table 7, allows the direct management costs associated with an invasive species to be identified and elaborated. Here it should be noted that although the worked example covers all aspects of invasive management costs, in reality economic analysis will most commonly be focusing on only one or two of these management interventions.

Table 7: checklist of invasive direct management costs	
Actions required	**Cost components**
Prevention costs	
Quarantine of imported species	• Scientific and enforcement staff • Rental of premises at port and airport • Office supplies and equipment
Containment costs	
Phytosanitary controls	• Scientific and enforcement staff • Rental of premises at port and airport • Office supplies and equipment
Border checks	• Scientific and enforcement staff • Rental of premises at port and airport • Office supplies and equipment
Eradication costs	
Physical removal of invasive plants	• Machinery • Staff • Fuel
Biocontrol measures	• Import of biocontrol agent • Equipment • Staff • Transport
Management costs	
Research and monitoring	• Equipment • Travel • Staff
Periodic clearance of invasive plants	• Machinery • Staff • Fuel
Restoration costs	
Clearing of choked waterways	• Machinery and other equipment • Staff • Fuel
Replanting of wetland vegetation	• Purchase of seedlings and planting materials • Scientific staff • Manual labour • Fuel • Scientific monitoring
Restocking of fisheries	• Purchase of stock • Scientific staff • Manual labour • Fuel • Scientific monitoring

4F Recognising the complexity of invasive costs and benefits

As mentioned at the start of this module, both the science and the economics of invasives are highly complex, and subject to massive uncertainty. One aim of this toolkit is to provide a series of practical steps and tools which can be used to undertake the economic analysis of invasives, in the face of these complexities and uncertainties. This section introduces three important considerations in economic analysis which are dealt with in subsequent modules of the toolkit, but need to be borne in mind from early stages of analysis.

The need to consider marginal benefits and costs

Economic analysis is rarely comparing a situation where all space for native species has been replaced by invasive species (Perrings 2002), or where all ecosystem services have been lost. Rather, it addresses levels and degrees of invasion and control, and incremental changes in the quality and quantity of provision of ecosystem services and in associated economic indicators. For this reason, it is important to bear in mind that it is marginal costs, benefits and changes which are being considered when one deals with the economics of invasions: the change in economic value associated with a unit change in output, consumption or other economic choice variable. Economic analysis is concerned with assessing trade-offs and comparing relative costs and benefits, so as to improve decision-making: it examines the options at the margin that the decision-makers actually face. The concept of marginal values is dealt with in detail in the next module on valuation (module 5).

Incorporating uncertainty and the time factor

It is important to be aware of time considerations in the economic analysis of invasives. Although incorporating dynamism and looking at changes over time is a normal part of economic analysis, invasives have special characteristics which mean that dealing with the time dimension is more difficult than would normally be the case. The timing of impacts from invasive species is highly context-specific: impacts may be short-term and temporary, or may be permanent and irreversible. At the same time the nature of economic impacts, and manifestations of costs and benefits, of invasives typically vary over time, for different groups, in different places, and at different steps in the progression to invasion. A final consideration is the high level of uncertainty associated with the spread and impacts of invasive species, and their interactions with both host ecosystems and human systems. Invasives show a very unusual – and hard to predict – trajectory as compared to other environmental costs and benefits. Economic tools to deal with time, uncertainty and risk are dealt with in detail in the subsequent module on decision-making tools (module 6).

The importance of assessing the distribution of benefits and costs

Distributional issues are typically of key concern in the economic analysis of invasives. Although a major preoccupation is to distinguish between benefits and costs that accrue to the individual or company who is responsible for using or introducing the invasive species and those which are borne by the wider economy, it is also important to disaggregate economic impacts between different sub-groups within these broader categories. Examples include the distribution of costs and benefits between different socio-economic groups, sectors, levels of scale, sites and time periods.

Box 5: economic costs and benefits of invasive species in Africa

A recent study by GISP assessed the economic impacts of five invasive alien species in different areas of Africa, and found that at an individual level, the costs were significant. The study findings raise particular concerns about the economic impacts of invasive species on poor, vulnerable communities including farmers and fisherfolk, as well as on commercially important sectors

Invasive species	Study country	Economic impacts per unit area or per capita (US$/year)
Nile tilapia (*Oreochromis niloticus*)	Uganda	-$0.57 to +$3.4 per fisher
Water hyacinth (*Eichhornia crassipes*)	Central African Republic	-$429 per gill net fisher, -$127 per palm wine collector, +$351 per spear fisher
	South Africa	-$159 per fisher
Larger grain borer (*Prostephanus truncatus*)	Benin	-$18 to -$350 per farmer
	Ghana	-$28 to -$124 per farmer
Parthenium weed (*Parthenium hysterophorus*)	South Africa	-$13.5 per small-scale farmer, -$27.1 per commercial farmer
Triffid weed (*Chromolaena odorata*)	South Africa	-$59.3 per hectare

From Wise *et al* 2007

Distributional analysis is important both from an equity perspective, as well as being necessary to identify which groups are bearing net costs and benefits as the result of an invasion and therefore require the introduction of some kind of economic instrument or corrective measure (such as compensation, price or market interventions or policy reform – see module 6). In relation to equity concerns, economic analysis is not value-free, but is carried out in a particular social, political and decision-making context where impacts on specific groups, sectors or economic goals are deemed to be particularly important. A critical concern is, for example, the impact of invasives on poorer and more vulnerable groups in society, and the overriding preoccupation with ensuring that the poor are not negatively impacted either by the introduction of an invasive species or by the management intervention that is employed to address it. Here, distributional concerns may also be key when looking at the positive economic impacts of invasives. Analysis of the role of alien invasive species in rural livelihoods in the Eastern Cape, South Africa found, for example, that poor local households make widespread consumptive use of invasives for food, fodder and building materials, as well as trading them for income – even though the same species plays havoc on commercial farmland nearby (Shackleton *et al* 2007).

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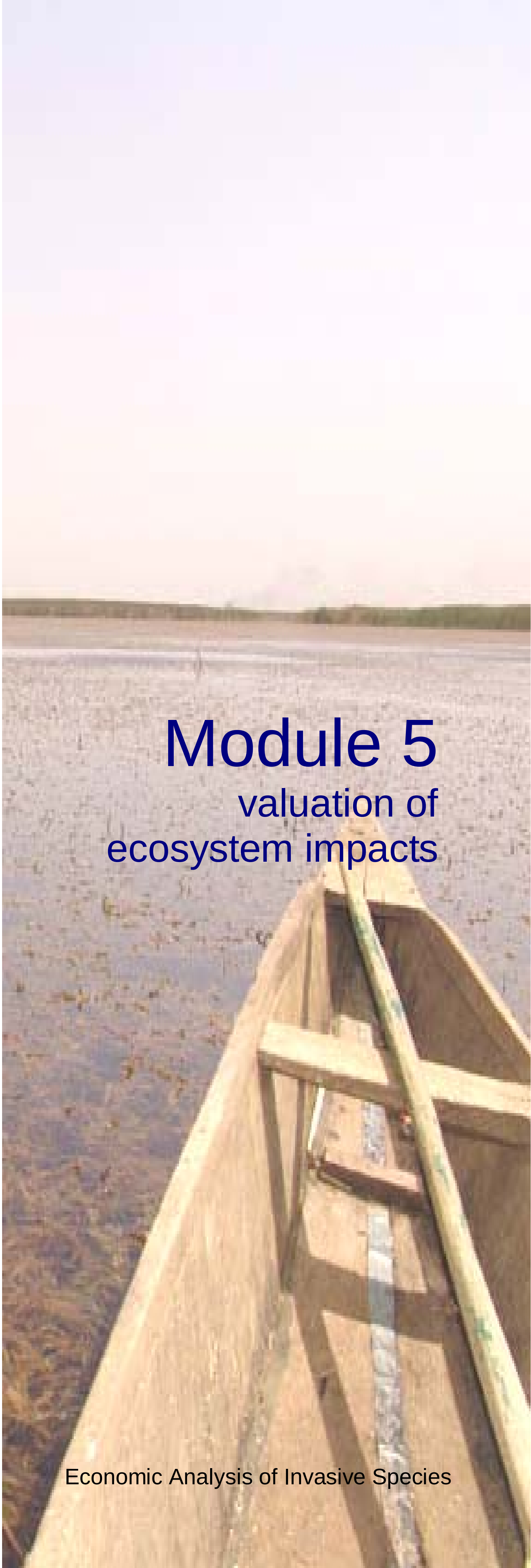
The Global Invasive Species Programme



Module 5
valuation of ecosystem impacts

Economic Analysis of Invasive Species

5A What this module covers

This module looks at the different methods that can be used to value the impacts (both positive and negative) of invasive species – as reflected in changes in ecosystem services. Information is provided about the most commonly-used ecosystem valuation methods, including their relevance and use for invasives, data collection and analysis requirements, steps in application, and the applicability, strengths and weakness of each technique. Further references to the literature are given which point the reader towards detailed guidance on how to apply each valuation method. The module also discusses briefly some of the limitations to valuation, and the difficulties involved in valuing the impact of invasive species.

By the end of this module, the reader will have gained a broad familiarity with the use and limits of ecosystem valuation, be able to identify the most appropriate technique to use in a given situation, and have a general understanding of the steps and data that are required to apply different valuation tools.

5B Seeing valuation as a means to an end

As described in Module 4, the economic analysis of invasive species is concerned with measuring the effects of invasions as manifested through their impacts on the quality and quantity of services provided by a given ecosystem, which in turn affects economic indicators. It also addresses the costs and benefits arising from actions taken to tackle problems of invasion. Although valuation can be an extremely interesting exercise, and a large body of literature has emerged citing large figures for the economic value of ecosystem services and the economic costs of invasive species, it is important to remember that valuation is not an end in itself, but rather a means to an end – better and more informed decision-making. However high the costs of invasive species or the value of ecosystems services are demonstrated to be in theory, this has little meaning unless it actually translates into changes in real-world policy and practice.

Valuation is an important step in the economic analysis of invasive species, and provides key information for decision-making (see Module 6). As described below (5C Coping with price distortions and market failures), it comprises a set of tools for ensuring that those goods and services and costs and benefits that are traditionally excluded from economic decision-making (or remain unreflected in market prices) are taken into account when policies, programmes and projects are planned. Valuation provides a means of articulating and communicating the impacts of invasions in terms of their effects on economic indicators, including broader measures of human wellbeing as well as private profits and losses.

Box 6: making the case for invasives control in South Africa - the importance of economic arguments, and the need for better economic methods and data

The recognition of the economic consequences of alien invasive plants in terms of water-supply costs was pivotal in the establishment of the Working for Water programme, which has spent over R3 billion in dealing with the problem while simultaneously addressing poverty relief. Given competition from other social development projects for future funding, however, there is a need to justify further alien control programmes and to maximise efficiency within the programme. This requires valuing the biodiversity benefits of alien control and improving of the evaluation methods used. The concept of ecological goods and services has been a useful political tool, but the resource-economics concept of the Total Economic Value of biodiversity forms a more useful analytical framework. Studies on the impacts of alien invasive plants in South Africa initially concentrated on water losses, but more recently have included values of direct consumptive and non-consumptive use, option and existence value, and other indirect measures. Secondary effects such as downstream changes in aquatic ecosystem functions have not been assessed. Studies have varied in their scale and scope, as well as in the 'currency' of evaluation (such as financial or economic). Several approaches have been used for valuing water losses, with initial estimates having been the most conservative. Estimates of non-water benefits have frequently involved extrapolation from site-specific investigations within the study area, or been estimated from estimates at the regional level. None of the contingent valuation studies used has been applied following internationally accepted guidelines. In water-yielding catchments, alien control programmes are easy to justify in economic terms. In other areas, this may be more difficult. Cost–benefit analyses to date have tended to include the full financial costs of clearing, whereas, in reality, the opportunity cost of labour is close to zero, and economic costs are therefore much smaller. Benefits, which accrue later, tend to be underestimated from lack of information on biodiversity values and by high discount rates. Future studies will need to address the right questions using the appropriate methods, incorporate both ecological and economic dynamics, express values in the right 'currency', and use a discount rate that reflects the rights of future generations. The quality of this research will, in turn, depend on relevant ecological enquiry.

From Turpie 2004

Although economic measures are not the sole influence when public and private decisions are made (and here it should be noted that other criteria such as politics, public opinion, personal tastes, culture, laws and regulations all have a critical role to play), they typically hold considerable sway as indicators of what is deemed the “best” way to invest funds, use land and allocate resources. For these reasons, valuation provides a convincing argument for the need to take action to address invasives. It is also a good way of expressing the costs and benefits of invasive species in terms that can be judged alongside other economic sectors and activities, when trade-offs are calculated and decisions are made about how to proceed with policies, programmes and projects.

5C Predicting and measuring impacts: the limits of science

Valuation looks at the impacts of invasions, as well as the costs and benefits of measures designed to counter them. Regardless of the specific technique that is used, valuation requires that quantitative estimates are made of past, current and/or future changes in the level and quantity of ecosystem services arising from the presence of invasive species, and their effects on economic stocks, flows and processes – so that these changes can in turn be translated into monetary indicators of cost and benefit.

Modules 3 and 4 explained the high degree of uncertainty that characterises ecological and biological models of invasion, as well as the unique characteristics of invasives species and their trajectories of invasion which make prediction so difficult. Before the introduction of a species, or in its early stages, it is very difficult to predict whether it will become invasive or not. Even after an invasive species is established, and when invasion occurs, the path it will follow and the impacts it will cause depend on a complex series of natural and management factors, and are rarely the same at two different times or in two different sites.

Just as data on the biophysical impacts of invasive species tend to be imprecise, a high level of speculation is typically involved when predicting their likely economic effects – especially when this requires forecasting consumers’ and producers’ future tastes, preferences and values, or deals with impacts which are very intangible in physical terms. As described above (4F recognising the complexity of invasive costs and benefits), economic analysis addresses levels and degrees of invasion and control: it is concerned with incremental changes and with marginal costs and benefits, which present particular challenges in estimation (Evans 2003).

Here, it is important to emphasise that while on the one hand every effort should be made to ensure that economic analysis is based on the most credible and best possible scientific data (and to underline that economists cannot do this by themselves: valuation requires collaboration between social and natural scientists), data and knowledge constraints should not be taken as reasons to avoid valuation. The precautionary approach, as contained in Principle 15 of the Rio Declaration on Environment and Development and reiterated in the Convention on Biological Diversity, is particularly relevant: “where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation”.

Valuation of the impacts of invasives is often by necessity inexact, and the resulting figures should be seen as representing the best estimates at a particular point in time, given existing knowledge, available data and current conditions. Some level of (both economic and scientific) uncertainty is unavoidable, and it is inevitable that certain assumptions will have to be made (and should be made explicit) during the course of the valuation exercise.

5D Coping with price distortions and market failures

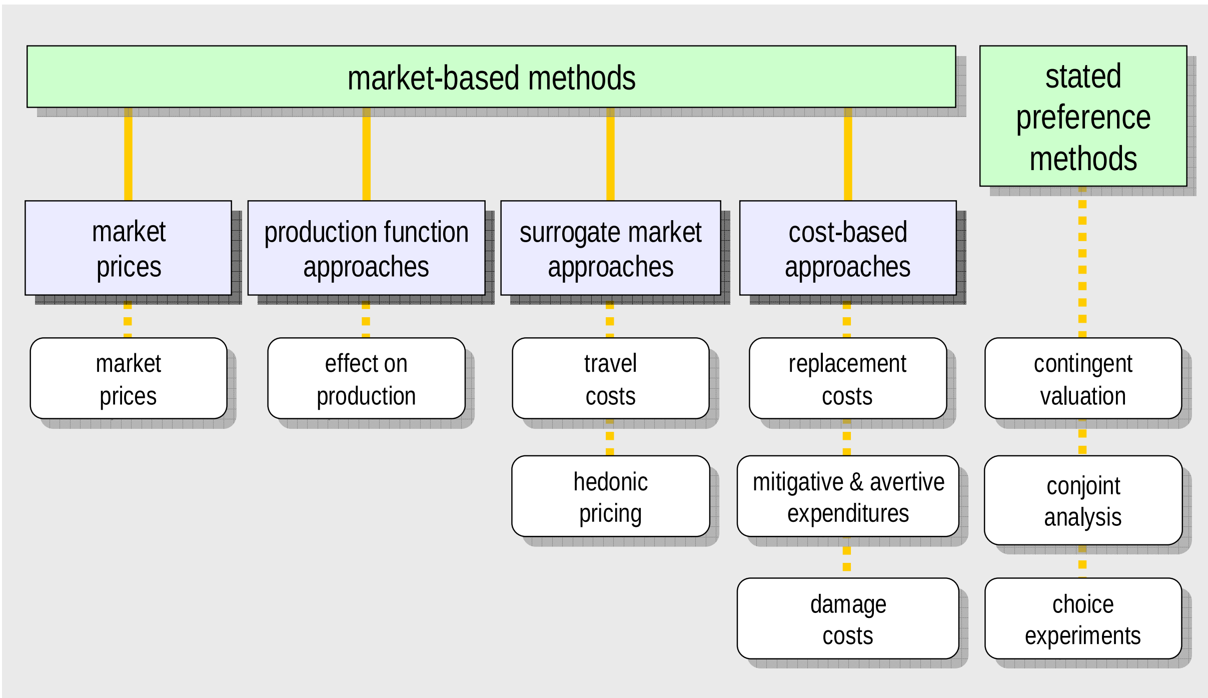
The basic aim of valuation is to determine people’s preferences: how much they are willing to pay for particular goods and services, and how much better or worse off they would consider themselves to be as a result of changes in their supply. In an ideal situation, the market equilibrium for goods and services would establish clearing prices that reflect accurately social preferences, and internalise the full costs and benefits of invasives. However, as we have described above (see 2C identifying the economic causes of invasions), a plethora of distortions and failures beset both ecosystem services and invasive species – this, indeed, is one of the major reasons why the market cannot be relied upon to deal with the problems associated with invasive species, and why some form of government or collective intervention is almost inevitably required (see Module 6).

An important point to bear in mind is that the reason why policy, market and price distortions and failures result in invasions is because prices and markets send the wrong signals to producers and consumers about the "real" costs and benefits of their actions. The total economic value of ecosystem services (see 4D categorising invasive costs and benefits in terms of ecosystem values) is not reflected in the prices that consumers, producers and traders face as they carry out their economic activities. The "full" valuation of the changes in ecosystem services associated with invasives is therefore an important element in identifying, and correcting, these distortions.

Ecosystem valuation is not a straightforward undertaking, as in most cases the analyst cannot rely on market prices as an accurate reflection of social preferences and economic values – as would be the case in more conventional economic analysis. Many ecosystem goods and services do not have markets or are subject to markets which are highly distorted or irregular. In such cases, alternative valuation techniques must therefore be applied which do not rely on uncorrected market prices (Emerton and Bos 2004). The following sections of this module describe a range of commonly-used ecosystem valuation methods, and explain how they can be applied to invasive species. A number of publications provide detailed guidance on environmental valuation methods, including Emerton and Bos 1994, Hufschmidt *et al* 1983 and Winpenny 1995. Rietbergen-McCracken and Abaza 2000 and Dixon and Hufschmidt 1986 provide examples of the application of valuation techniques to the environment.

5E A summary of ecosystem valuation methods

Figure 7: ecosystem valuation methods



From Emerton and Bos 2004

A wide range of techniques now exist to value the different components of the total economic value of ecosystems, the most commonly-used of which can be broadly categorised into five main groups (Figure 7):

- **Market prices:** this approach looks at the market price of ecosystem goods and services (described in section 5F below).
- **Production function approaches:** these approaches, including effect on production (section 5G), attempt to relate changes in the output of a marketed good or service to a measurable change in the quality of quantity of ecosystem goods and services by establishing a biophysical or dose-

response relationship between ecosystem quality, the provision of particular services, and related production.

- **Surrogate market approaches:** these approaches, including travel costs (section 5H) and hedonic pricing (section 5I), look at the ways in which the value of ecosystem goods and services are reflected indirectly in people's expenditures, or in the prices of other market goods and services.

- **Cost-based approaches:** these approaches, including replacement costs (section 5J), mitigative or avertive expenditures (section 5K) and damage costs avoided (section 5L), look at the market trade-offs or costs avoided of maintaining ecosystems for their goods and services.

- **Stated preference approaches:** rather than looking at the way in which people reveal their preferences for ecosystem goods and services through market production and consumption, these approaches ask consumers to state their preference directly. The most well-known technique is contingent valuation (section 5M), while less commonly-used stated preference valuation methods include conjoint analysis and choice experiments (section 5N).

5F Market price techniques

Overview of the method and its application to invasive species

The simplest, most straightforward and commonly-used method for valuing any good or service is to look at its market price: how much it costs to buy, or what it is worth to sell. In a well-operating and competitive market these prices are determined by the relative demand for and supply of the goods or services in question, reflect their true scarcity, and equate to their marginal value.

In theory, market price techniques are applicable to any ecosystem good or service that can be freely bought or sold. They are particularly useful for valuing the resources and products that are harvested directly from ecosystems. Examples of their application to invasive species include looking at direct on-site impacts on marketed goods, for example:

- When invasive species replace other species which yield marketed products or resources (for example crops, livestock products, timber or fish);
- When invasive species themselves yield marketed products or resources (for example crops, biofuels, livestock products, timber or fish).

Data collection and analysis requirements

There are three main steps involved in collecting and analysing the data required to use market price techniques to value ecosystem goods and services:

- Find out the quantity of the good used, produced or exchanged;
- Collect data on its market price;
- Multiply price by quantity to determine its gross value, deducting any costs incurred in collecting, producing or trading it in order to determine its net value.

These data are generally easy to collect and analyse. Market information, including historical trends, can usually be obtained from a wide variety of sources such as government statistics, income and expenditure surveys, or market research studies. In many cases it will be necessary to supplement these secondary sources with original data, for example through performing market checks or conducting some form of socio-economic survey.

When applying this technique it is important to ensure that the data collected covers an adequate period of time and sample of consumers and/or producers. Factors to bear in mind include the possibility that prices, consumption and production may vary between seasons, for different socio-economic groups, at different stages of the marketing or value-added chain, and in different locations.

Applicability, strengths and weaknesses

The greatest advantage of this technique is that it is relatively easy to use, as it relies on observing actual market behaviour. Few assumptions, little detailed modelling, and only simple statistical analysis are required to apply it. A major constraint, as outlined above (section 5F) is that market prices cannot, in many cases, be taken as accurate indicators of the value of ecosystem goods and services – in which case an alternative valuation method must be used.

Box 7: application of market price valuation techniques to the local use of freshwater wetland species in the Zambezi Basin, Southern Africa

The Zambezi River runs through Angola, Zambia, Botswana, Namibia, Zimbabwe, Malawi and Mozambique in Southern Africa. It is associated with a large number of wetlands, which yield a wide range of economically valuable goods and services. Wetland-dependent products and services include flood recession agriculture, fish, wildlife, grazing, forest resources, natural products and medicines and ecotourism.

A study was carried out to estimate the value of the Zambezi's wetland goods using market price techniques. First, an inventory of the products and services was made for each wetland. Market prices were then used to calculate the value derived from each wetland. Crops and livestock were valued at their production value, and fish catches were valued according to their local sale price. Tourism earnings and utilisation charges were used to calculate the value of wildlife, and the market price of wetland products was applied to natural resource use. Donor contributions were assumed to reflect biodiversity conservation values. Inputs and other production costs were deducted from these figures, so as to yield the marginal value of wetland resources.

Total use values were extrapolated through making assumptions about the extent and intensity of wetland land and resource use. This yielded a marginal value of $145 million a year for the 10 major wetlands in the Zambezi Basin, or an average of $48 per hectare.

From Seyam *et al* 2001

5G Effect on production techniques

Overview of the method and its application to invasive species

Even when ecosystem goods and services do not themselves have a market price, other marketed products often rely on them as basic inputs. For example, downstream hydropower and irrigation depend on upper catchment protection services, fisheries on upstream nursery and breeding habitat, crop production on insect pollination services, and many sources of industrial production utilise natural products as raw materials. In these cases it is possible to assess the value of ecosystem goods and services by looking at their contribution to other sources of production, and to assess the effects of a change in the quality or quantity of ecosystem goods and services on these broader outputs and profits.

Effect on production techniques can thus be used to value ecosystem goods and services that clearly form a part of other, marketed, sources of production – for example watershed protection and water quality services, or natural resources that are used as raw materials. Examples of their application to invasive species include looking at the changes in output that occur when invasive species impact on the provision of particular goods and services which are required for offsite or downstream production, for example:

- When invasive species replace other species which yield marketed products or resources which are used as inputs for other production processes, such as natural pesticides or pollinators, or raw materials;
- When invasive species interfere with natural habitat for species which are commercially important offsite such as bird and fisheries breeding and habitat;
- When invasive species introduce human, plant or animal diseases and pests;
- When invasive species interfere with or choke water supplies which are required for downstream irrigation, fisheries, hydropower or urban water supplies;
- When invasive species lead to changes in soil fertility, or lead to soil erosion.

Data collection and analysis requirements

There are four main steps involved in collecting and analysing the data required to use effect on production techniques to value ecosystem goods and services:

- Determine the contribution of ecosystem goods and services to the related source of production;
- Specify the relationship between changes in the quality or quantity of a particular ecosystem good or service and output;
- Relate a specified change in the provision of the ecosystem good or service to a physical change in the output or availability of the related product;

- Estimate the market value of the change in production.

Effect on production techniques rely on a simple logic, and it is relatively easy to collect and analyse the market information that is required to value changes in production of ecosystem-dependent products (see above, market price techniques).

The most difficult aspect of this method is determining and quantifying the biophysical or dose-response relationship that links changes in the supply or quality of ecosystem goods and services with other sources of production. For example, detailed data are required to relate catchment deforestation to a particular rate of soil erosion, consequent siltation of a hydropower dam and reduced power outputs, or to assess exactly the impacts of the loss of wetland habitat and water purification services on local fisheries production. To be able to specify these kinds of relationships with confidence usually involves wide consultation with other experts, and may require situation-specific laboratory or field research, controlled experiments, detailed modelling and statistical regression.

Applicability, strengths and weaknesses

Effect on production techniques are commonly used, and have applicability to a wide range of ecosystem goods and services. Their weakness relates to the difficulties that are often involved in collecting sufficient data to be able to accurately predict the biophysical or dose-response relationships upon which the technique is based. Such relationships are often unclear, unproven, or hard to demonstrate in quantified terms. Simplifying assumptions are often needed to apply the production function approach.

An additional concern is the large number of possible influences on product markets and prices. For example, in some cases changes in the provision of an ecosystem good or service may lead not just to a change in related production, but also to a change in the price of its inputs or outputs. That product may become scarcer, or more costly to produce. In other cases consumers and producers may switch to other products or technologies in response to ecosystem change or to a scarcity of ecosystem goods and services. Furthermore, general trends and exogenous factors unrelated to ecosystem goods and services may influence the market price of related production and consumption items. They must be isolated and eliminated from analysis.

Detailed guidance on how to apply this valuation method can be found in in Dixon *et al* 1986, Hufschmidt *et al* 1983 and Winpenny 1991.

Box 8: application of effect on production valuation techniques to the agricultural costs of pollinator decline

Effect on production techniques were used to value the vulnerability of world agriculture to pollinator decline. Among the main crops that contribute to human food, some, such as most cereals, do not depend on insects for their pollination, while others can be highly or totally dependant on insect pollination, such as many fruits, vegetables and stimulant crops. Pollinator species are highly susceptible to the impacts on invasive species, as a result of both direct predation as well as changes in habitat.

This study measured the economic impact of pollinators on agricultural output the use of dependence ratios quantifying the impact of a lack of insect pollinators on crop production value. It considered the 100 crops used directly for human food worldwide as listed by FAO. A bioeconomic approach was applied to calculate the economic value of the impact of pollinator loss as well as the overall vulnerability of the agricultural output to such a loss. This decrease in the production value can result from a reduction in yield as well as in quality.

The variables used for each crop in each world region were the quantity produced, the quantity consumed, the dependence ratio of the crop on insect pollinators and the price of crop per unit produced in the region. So defined, the agricultural vulnerability to pollinator decline depends upon crop dependence to pollinators, and farmers' capacity to adapt to pollinator decline. The study calculated the vulnerability of a crop, and of the agricultural industry in a given region when faced with pollinator decline.

The study found that the total economic value of pollination worlwide amounted to €153 billion, which represented 9.4% of the value of world agricultural production used for human food in 2005. In terms of welfare, the consumer surplus loss were estimated between €96 and €263 billion based upon average price elasticities of -2 to -1, respectively. Vegetables and fruits were the leading crop categories in value of insect pollination with €50.9 and €50.6 billion, respectively, followed by edible oil crops, stimulants, nuts and spices. The production value of a ton of the crop categories that do not depend on insect pollination averaged €151 while that of those that are pollinator-dependent averaged €761.

From Gallai *et al* 2007

5H Travel cost techniques

Overview of the method and its application to invasive species

Ecosystems often hold a high value as recreational resources or leisure destinations. Even when there is no direct charge made to enjoy these benefits, people still spend time and money to visit ecosystems. These travel costs can be taken as an expression of the recreational value of ecosystems. We can use this technique at the whole ecosystem level, taking into account all of its attributes and components in combination, or for specific goods or services such as rare wildlife, opportunities for extractive utilisation of products such as fishing or resource collection, or for activities such as hiking or boating that are related to its services.

Travel cost techniques are thus most commonly applied to ecosystems that have a recreational value. Examples of their application to invasive species include looking at the changes in tourism and recreational earnings which occur when invasive species make a site less or more attractive to visitors, for example:

- When the habitats being invaded are used for recreational purposes such as hiking, camping, fishing, boating or are considered to have particular landscape beauty, which is compromised by the presence of invasive species.

Data collection and analysis requirements

There are six main steps involved in collecting and analysing the data required to use travel cost techniques to value ecosystem goods and services:

- Ascertain the total area from which recreational visitors come to visit an ecosystem, and divide this into zones within which travel costs are approximately equal;
- Within each zone, sample visitors to collect information about the costs incurred in visiting the ecosystem, motives for the trip, frequency of visits, site attributes and socio-economic variables such as the visitor's place of origin, income, age, education and so on;
- Obtain the visitation rates for each zone, and use this information to estimate the total number of visitor days per head of the local population;
- Estimate travel costs, including both direct expenses (such as fuel and fares, food, equipment, accommodation) and time spent on the trip;
- Carry out a statistical regression to test the relationship between visitation rates and other explanatory factors such as travel cost and socio-economic variables;
- Construct a demand curve relating number of visits to travel cost, model visitation rates at different prices, and calculate visitor consumer surplus.

Travel cost techniques depend on a relatively large data set. Quite complex statistical analysis and modelling are required in order to construct visitor demand curves. Basic data are usually collected via visitor interviews and questionnaires, which make special efforts to cover different seasons or times of the year, and to ensure that various types of visitors from different locations are represented.

Applicability, strengths and weaknesses

The travel cost method is mainly limited to calculating recreational values, although it has in some cases been applied to the consumptive use of ecosystem goods.

Its main weakness is its dependence on large and detailed data sets, and relatively complex analytical techniques. Travel cost surveys are typically expensive and time consuming to carry out. An additional source of confusion is that several factors make it difficult to isolate the value of a particular ecosystem in relation to travel costs, and these must be taken into account in order to avoid over-estimating ecosystem values. Visitors frequently have several motives or destinations on a single trip, some of which are unrelated to the ecosystem being studied. They also usually enjoy multiple aspects and attributes of a single ecosystem. In some cases travel, not the destination *per se*, may be an end in itself.

Detailed guidance on how to apply this valuation method can be found in Dixon *et al* 1986, Hufschmidt *et al* 1983 and Winpenny 1991.

Box 9: application of travel cost valuation techniques to improved environmental quality on freshwater recreation in the USA

The Conservation Reserve Programme (CRP) in the United States aims to mitigate the environmental effects of agriculture. A study was carried out to see how non-market valuation models could help in targeting conservation programmes such as the CRP. One component of this study focused on the impacts of improved environmental quality on freshwater recreation. This study was based on data generated by surveys that had been carried out to ascertain the value of water-based recreation, fishing, hunting and wildlife.

These surveys sampled 1,500 respondents in four sub-State regions who were asked to recall the number of visits made over the last year to wetlands, lakes and rivers where water was an important reason for their trip. The cost of these trips was imputed using the travel cost method. The influence of CRP programmes on improved environmental quality and on consumer welfare was then modelled.

The study found that the combined benefit of all freshwater-based recreation in the US was worth slightly over $37 billion a year. The contribution of CRP efforts to environmental quality, as reflected in recreational travel values, was estimated at just over $35 million, or about $2.57 per hectare.

From Feather *et al* 1999

5I Hedonic pricing techniques

Overview of the method and its application to invasive species

Even if they do not have a market price themselves, the presence, absence or quality of ecosystem goods and services influences the price that people pay for, or accept for providing, other goods and services. Hedonic pricing techniques look at the difference in prices that can be ascribed to the existence or level of ecosystem goods and services.

Hedonic pricing techniques are most commonly used to examine differences in property prices and wage rates between two locations which have different environmental qualities or landscape values; the former has the most obvious application to invasives. Examples of their application to invasive species include looking at the changes in property prices which might occur due to changes in the landscape wrought by invasives, for example:

- When the habitats being invaded have particular landscape beauty, and are associated with premium property prices;
- When the invasion leads to difficulties accessing residential areas, or interferes with the provision of utilities such as water supplies.

Data collection and analysis requirements

There are five main steps involved in collecting and analysing the data required to use hedonic pricing techniques to value ecosystem goods and services:

- Decide on the indicator to be used to measure the quality or quantity of an ecosystem good or service associated with a particular job or property;
- Specify the functional relationship between wages or property prices and all of the relevant attributes that are associated with them, including ecosystem goods and services;
- Collect data on wages or property prices in different situations and areas which have varying quality and quantity of ecosystem goods and services;
- Use multiple regression analysis to obtain a correlation between wages or property prices and the ecosystem good or service;
- Derive a demand curve for the ecosystem good or service.

Hedonic pricing techniques require the collection of a large amount of data, which must be subject to detailed and complex analysis. Data are usually gathered through market observation, questionnaires and interviews, which aim to represent a wide variety of situations and time periods.

Applicability, strengths and weaknesses

Although hedonic pricing techniques can, in theory, be applied to any good or service they are most commonly used within the context of wage and property markets.

In practice, there remain very few examples of the application of hedonic pricing techniques to ecosystem goods and services. One reason for this, and a weakness in this technique, is the very large data sets and detailed information that must be collected, covering all of the principal features affecting prices. It is often difficult to isolate specific ecosystem effects from other determinants of wages and property prices.

Another potential problem arises from the fact that this technique relies on the underlying assumption that wages and property prices are sensitive to the quality and supply of ecosystem goods and services. In many cases (and especially in developing countries) markets for property and employment are not perfectly competitive, and ecosystem quality is not a defining characteristic of where people buy property or engage in employment.

Detailed guidance on how to apply this valuation method can be found in Dixon *et al* 1986, Hufschmidt *et al* 1983 and Winpenny 1991.

Box 10: application of hedonic pricing valuation techniques to value urban wetlands in the USA

This study aimed to value wetland environmental amenities in Portland metropolitan region, Oregon. It used hedonic pricing techniques to calculate urban residents' willingness to pay to live close to wetlands. The study used a data set of almost 15,000 observations, with each observation representing a residential home sale. For each sale information was obtained about the property price and a variety of structural, neighbourhood and environmental characteristics associated with the property, as well as socio-economic characteristics associated with the buyer.

Wetlands were classified into four types – open water, emergent vegetation, forested, and scrub-shrub – and their area and distance from the property were recorded. The first stage analysis used ordinary least squares regression to estimate a hedonic price function relating property sales prices to the structural characteristics of the property, neighbourhood attributes, and amenity value of nearby wetlands and other environmental resources. The second stage analysis consisted of constructing a willingness-to-pay function for the size of the nearest wetland to a residence.

Results showed that wetland proximity and size exerted a significant influence on property values, especially for open water and larger wetlands.

From Mahan 1997

5J Replacement cost techniques

Overview of the method and its application to invasive species

It is sometimes possible to replace or replicate a particular ecosystem good or service with alternative products or infrastructure. For example, constructed reservoirs can replace natural lakes, sewage treatment plants can replace wetland wastewater treatment services, and many natural products have artificial alternatives. The cost of replacing an ecosystem good or service with such an alternative or substitute can be taken as an indicator of its value in terms of expenditures saved.

Replacement cost techniques can be used to value ecosystem goods and services that have the potential be at least partially substituted by other products or by technologies. Examples of their application to invasive species include looking at the changes in output that occur when invasive species impact on the provision of particular goods and services which can be replaced by alternative sources, for example:

- When invasive species replace other species which yield marketed products or resources, and these species or products have to be sourced from elsewhere or replaced by other products;
- When invasive species compromise water quality and supplies, requiring alternative sources of water supply or purification;
- When invasive species lead to changes in soil fertility, necessitating the application of artificial fertilisers;
- When the invaded ecosystem provided pollination services, which have to be replaced artificially;
- When the invaded ecosystem provided soil erosion control services, which have to be replaced by artificial soil erosion control structures.

Data collection and analysis requirements

There are three main steps involved in collecting and analysing the data required to use replacement cost techniques to value ecosystem goods and services:

- Ascertain the benefits that are associated with a given ecosystem good or service, how it is used and by whom, and the magnitude and extent of these benefits;
- Identify the most likely alternative source of product, infrastructure or technology that would provide an equivalent level of benefits to an equivalent population;
- Calculate the costs of introducing and distributing, or installing and running, the replacement to the ecosystem good or service.

Data collection is relatively straightforward, and usually relies on secondary information about the benefits associated with a particular ecosystem good or service and alternatives that are available to replace it. In most cases this can be ascertained through expert consultation and professional estimates, supplemented with direct observation.

Applicability, strengths and weaknesses

Replacement cost techniques are particularly useful for valuing ecosystem services, and have the great advantage that they are simple to apply and analyse. They are particularly useful where only limited time or financial resources are available for a valuation study, or where it is not possible to carry out detailed surveys and fieldwork.

The main weakness of this technique is that it is often difficult either to identify all the goods and services provided by an ecosystem or find perfect replacements or substitutes for ecosystem goods and services that would provide an equivalent level of benefits to the same population. In some cases this results in ecosystem under-valuation, as artificial alternatives generate a lower quantity or quality of goods and services. Yet this technique may also lead to the over-valuation of ecosystem benefits, as in some instances the replacement product, infrastructure or technology may be associated with secondary benefits or additional positive impacts. The reality of the replacement cost technique is also sometimes questionable: we may question whether, in the absence of a well-functioning ecosystem, such expenditures would actually be made or considered worthwhile.

Detailed guidance on how to apply this valuation method can be found in Dixon *et al* 1986, Hufschmidt *et al* 1983 and Winpenny 1991.

Box 11: application of replacement cost valuation techniques to wetland water quality services in Nakivubo Swamp, Uganda

This study used replacement cost techniques to value the wastewater treatment services provided by Nakivubo Swamp, Uganda. Covering an area of some 5.5 km^2 and a catchment of over 40 km^2, the wetland runs from the central industrial district of Kampala, Uganda's capital city, passing through dense residential settlements before entering Lake Victoria at Murchison Bay.

One of the most important values associated with Nakivubo wetland is the role that it plays in assuring urban water quality in Kampala. Both the outflow of the only sewage treatment plant in the city, and – far more importantly, because over 90% of Kampala's population have no access to a piped sewage supply – the main drainage channel for the city, enter the top end of the wetland. Nakivubo functions as a buffer through which most of the city's industrial and urban wastewater passes before entering nearby Lake Victoria, and physically, chemically and biologically removes nutrients and pollution from these wastewaters. These services are important – the purified water flowing out of the wetland enters Lake Victoria only about 3 kilometres from the intake to Ggaba Water Works, which supplies all of the city's piped water supplies.

The study looked at the cost of replacing wetland wastewater processing services with artificial technologies. Replacement costs included two components: connecting Nakivubo channel to an upgraded sewage treatment plant which could cope with additional wastewater loads, and constructing elevated pit latrines to process sewage from nearby slum settlements. Data were collected from the National Water and Sewerage Corporation, from civil engineering companies, and from a donor-funded water supply and sanitation project that had been operating in a nearby urban wetland area. It also took into account the fact that some level of intervention would be required to manage Nakivubo more efficiently for water treatment, mainly through extending and reticulating the wastewater channels that flow into the swamp. These costs were deducted when wetland benefits were valued.

The study found that the infrastructure required to achieve a similar level of wastewater treatment to that provided by the wetland would incur costs of up to US$2 million a year in terms of extending sewerage and treatment facilities.

From Emerton *et al* 1999

5K Mitigative and avertive expenditure techniques

Overview of the method and its application to invasive species

When an economically valuable ecosystem good or service is lost, or there is a decline in its quantity or quality, this almost always has negative effects. It may become necessary to take steps to mitigate or avert these negative effects so as to avoid economic losses. For example, the loss of upstream catchment protection can make it necessary to desilt reservoirs and dams, the loss of wetland treatment services may require upgrading water purification facilities, and the loss of ecosystem flood control may require the construction of flood control barriers. These mitigative or avertive expenditures can be taken as indicators of the value of maintaining ecosystem goods and services in terms of costs avoided.

Mitigative and avertive expenditure techniques can thus be used in cases where the effects of the loss of ecosystem goods and services can be clearly offset, averted or mitigated by undertaking particular investments or market actions. Examples of their application to invasive species include looking at the cost of responding to or remediating the ecosystem damage or change that has been caused by invasives, for example:

- When the invasive species replace important food species, requiring drought or famine relief to maintain local nutrition and food security;
- When the invaded ecosystem provided flood attenuation services, which require the introduction of measures to mitigate or avert the effects of flooding on downstream settlements;
- When the invasive species act as pests or diseases on plants, animals or humans, requiring vaccination or disease control measures to be set in place;
- When the invaded ecosystem provided soil erosion control services, necessitating the installation of silt trapping and sediment removal structures downstream.

Data collection and analysis requirements

There are four main steps involved in collecting and analysing the data required to use mitigative or avertive expenditure techniques to value ecosystem goods and services:

- Identify the negative effects or hazards that would arise from the loss of a particular ecosystem good or service;
- Locate the area and population who would be affected by the loss of the ecosystem good and service, and determine a cut-off point beyond which the effect will not be analysed;
- Obtain information on people's responses, and measures taken to mitigate or avert the negative effects of the loss of the ecosystem good or service;
- Cost the mitigative or avertive expenditures.

Data collection and analysis is relatively straightforward, and usually relies on a combination of interviews, surveys, direct observation and expert consultation.

Applicability, strengths and weaknesses

Mitigative or avertive expenditure techniques are particularly useful for valuing ecosystem services. In common with other cost-based valuation methods, a major strength is their ease of implementation and analysis, and their relatively small data requirements.

As is the case with the replacement cost technique, the mitigative or avertive measures that are employed in response to the loss of ecosystem goods and services do not always provide an equivalent level of benefits. In some cases it is also questionable whether in fact such expenditures would be made or would be seen as being worth making. An additional important factor to bear in mind when applying this technique is that people's perceptions of what would be the effects of ecosystem loss, and what would be required to mitigate or avert these effects, may not always match those of "expert" opinion.

Detailed guidance on how to apply this valuation method can be found in Dixon *et al* 1986, Hufschmidt *et al* 1983 and Winpenny 1991.

Box 12: application of mitigative & avertive expenditure valuation techniques to wetland flood attenuation services in Sri Lanka

This study used avertive expenditure techniques to value the flood attenuation services of Muthurajawela Marsh in Sri Lanka. Muthurajawela is a coastal peat bog which covers an area of some 3,100 hectares, running alongside the Indian Ocean between 10-30 km north of Colombo, Sri Lanka's capital city. One of its most important functions is its role in local flood control.

The study first involved investigating the biophysical characteristics of the marsh, and their relationship to local flooding patterns. Data were obtained from hydrological surveys, which estimated the maximum water storage capacity of the marsh at 11 million cubic metres, with a maximum discharge of 12.5 cubic metres per second and a retention period of more than 10 days. Analysis of historical rainfall and streamflow data found that during the rainy season large volumes of water enter the wetland system, from rainfall, through run-off from surrounding higher grounds and via floodwaters from the Dandugam Oya, Kala Oya and Kelani Ganga Rivers. Muthurajawela buffers these floodwaters and discharges them slowly into the sea. The value of these services was calculated by looking at the flood control measures that would be necessary to mitigate or avert the effects of wetland loss. Consultation with civil engineers showed that this would involve constructing a drainage system and pumping station, deepening and widening the channels of water courses flowing between the marsh area and the sea, installing infrastructure to divert floodwaters into a retention area, and pumping water out to sea. Cost estimates for this type of flood control measure were available for Mudu Ela, a nearby wetland that has recently been converted to a housing scheme. Here infrastructure had been installed to ensure that a total of 443 acres of land remains drained, in order to reclaim an area of 360 acres.

Extrapolating the capital and maintenance costs from Mudu Ela to Muthurajawela gave an annual value for flood attenuation of more than $5 million, or $1,750 per hectare of wetland area.

From Emerton and Kekulandala 2002

5L Damage cost techniques

Overview of the method and its application to invasive species

Ecosystem services frequently protect other economically valuable assets. For example, the loss of catchment protection services may result in increased downstream siltation and flooding, which leads to the destruction of infrastructure, settlements and agriculture. Such damage costs can be taken to represent the economic value of ecosystems in terms of expenditures avoided.

Damage cost techniques can thus be used in cases where the effects of the loss of ecosystem goods and services incurs clear economic damages. Examples of their application to invasive species include looking at the cost caused to infrastructure and production when invasives interfere with the goods and services provided by a particular ecosystem, for example:

- When the invaded ecosystem provided flood control services, and the consequent increase in the incidence and severity of flooding leads to damages to houses, roads and agricultural production;
- When the invaded ecosystem provided water purification services, and the consequent decline in water quality leads to human health impacts;
- When invasive species act as pests or diseases on plants, animals or humans, leading to increased medical expenditures and losses in productivity.

Data collection and analysis requirements

There are four main steps involved in collecting and analysing the data required to use damage cost techniques to value ecosystem goods and services:

- Identify the protective services of the ecosystem, in terms of the degree of protection afforded and the on and off-site damages that would occur as a result of loss of this protection;
- For the specific change in ecosystem service provision that is being considered, locate the infrastructure, output or human population that would be affected by this damage, and determine a cut-off point beyond which effects will not be analysed;
- Obtain information on the likelihood and frequency of damaging events occurring under different scenarios of ecosystem loss, the spread of their impacts and the magnitude of damage caused;
- Cost these damages, and ascribing the contribution of the ecosystem service towards minimising or avoiding them.

Data collection is for the most part straightforward, usually relying on a combination of analysis of historical records, direct observation, interviews and professional estimates. Predicting and quantifying the likelihood and impacts of damage events under different ecosystem scenarios is however usually a more complex exercise, and may require detailed data and modelling.

Strengths and weaknesses of the method

Damage cost techniques are particularly useful for valuing ecosystem services. There is often confusion between the application of damage costs avoided and production function approaches to valuation. Here it is important to underline that whereas this technique deals with damage avoided such as from pollution and natural hazards (which are typically external effects), change in production techniques usually relate to changes in some input such as water (typically internalised).

A potential weakness is that in most cases estimates of damages avoided remain hypothetical. They are based on predicting what might occur under a situation where ecosystem services decline or are lost. Even when valuation is based on real data from situations where such events and damages have occurred, it is often difficult to relate these damages to changes in ecosystem status, or to be sure that identical impacts would occur if particular ecosystem services declined.

Detailed guidance on how to apply this valuation method can be found in Dixon *et al* 1986, Hufschmidt *et al* 1983 and Winpenny 1991.

Box 13: application of damage cost valuation techniques to invasive alien plants in South Africa

Invasion by alien plants increases the negative impacts of fires by increasing fuel loads and fire intensities, making fires more difficult to control and increasing the risk of damage. The more intense fires also cause severe damage to soils, leading to soil loss, severe soil erosion during rainstorms and damage to infrastructure due to flooding.

The economic impacts of alien plant Invasions in South Africa were valued by looking at damage costs caused. Examples of the costs associated with fires include a wildfire on the Cape Peninsula in March 1999 that created water-repellent conditions in an invaded area which formerly had no overland flow. Flooding followed heavy rains in April 1999, and resulted in cleanup costs of more $ 150,000. This estimate excludes the associated flood damage to 30 dwellings, which probably totalled at least another $150,000. These impacts did not occur to adjacent areas that were not invaded. In another example, two wildfires burnt 8,000 ha on the Cape Peninsula in January 2000, where insurance claims amounted to $5.7 million. Most houses and structures that were damaged were in areas invaded by alien plants, where fire intensities were much higher than in adjacent uninvaded areas. The direct costs of fighting the fire were not documented, but exceeded $ 0.5 million.

From van Wilgen *et al* 2001

5M Contingent valuation techniques

Overview of the method and its application to invasive species

Absence of prices or markets for ecosystem goods and services, of close replacements or substitutes, or of links to other production or consumption processes, does not mean that they have no value to people. Contingent valuation techniques infer the value that people place on ecosystem goods and services by asking them directly what is their willingness to pay (WTP) for them or their willingness to accept compensation (WTA) for their loss, under the hypothetical situation that they could be available for purchase.

Contingent valuation methods might for example ask how much people would be willing to see their water bills increase in order to uphold quality standards, what they would pay as a voluntary fee to manage an upstream catchment in order to maintain water supplies, how much they would contribute to a fund for the conservation of a beautiful landscape or rare species, or the extent to which they would be willing to share in the costs of maintaining important ecosystem water services. Examples of their application to invasive species include looking at the non-market values that people place on ecosystems that run the risk of invasion, and assessing people's perceptions of option values for particular sites, species or products, for example:

- When the invasive species replaces species, or interferes with an ecosystem, which are objects of national heritage, special scientific interest, or international significance;
- When the invasive species replaces species, or interferes with an ecosystem, which may have future use values such as for hunting, leisure, as a gene pool;
- When the invasive species replaces species, or interferes with an ecosystem, which people wish to conserve for future generations.

Data collection and analysis requirements

There are five main steps involved in collecting and analysing the data required to use contingent valuation techniques to value ecosystem goods and services:

- Ask respondents their WTP or WTA for a particular ecosystem good or service;
- Draw up a frequency distribution relating the size of different WTP/WTA statements to the number of people making them;
- Cross-tabulate WTP/WTA responses with respondents' socio-economic characteristics and other relevant factors;
- Use multivariate statistical techniques to correlate responses with respondent's socio-economic attributes;
- Gross up sample results to obtain the value likely to be placed on the ecosystem good or service by the whole population, or the entire group of users.

Most contingent valuation studies are conducted via interviews or postal surveys with individuals, but sometimes interviews are conducted with groups. A variety of methods are used in order to elicit people's statement or bids of their WTP/WTA for particular ecosystem goods or services in relation to specified changes in their quantity or quality. The two main variants of contingent valuation are:

1. dichotomous choice surveys, which present an upper and lower estimate between which respondents have to choose; and
2. open-ended surveys, which let respondents determine their own bids.

More sophisticated techniques are also sometimes used, such as engaging in trade-off games or using take-it-or-leave it experiments. The Delphi technique uses expert opinion rather than approaching consumers directly.

Applicability, strengths and weaknesses

A major strength of contingent valuation techniques is that, because they do not rely on actual markets or observed behaviour, they can in theory be applied to any situation, good or service. They remain one of the only methods that can be applied to option and existence values, and are widely used to determine the value of ecosystem services. Contingent valuation techniques are often used in combination with other valuation methods, in order to supplement or cross-check their results.

One of the biggest disadvantages of contingent valuation is the large and costly surveys, complex data sets, and sophisticated statistical analysis and modelling techniques that it requires. Another constraint arises from the fact that they rely on a hypothetical scenario which may not reflect reality or be convincing to respondents.

Contingent valuation techniques require people to state their preferences for ecosystem goods and services. They are therefore susceptible to various sources of bias, which may influence their results. The most common forms of bias are strategic, design, instrument and starting point bias.

- Strategic bias occurs when respondents believe that they can influence a real course of events by how they answer WTP/WTA questions. Respondents may for instance think that a survey's hypothetical scenario of the imposition of a water charge or ecosystem fee is actually in preparation.
- Design bias relates to the way in which information is put across in the survey instrument. For example, a survey may provide inadequate information about the hypothetical scenario , or respondents are misled by its description.
- Instrument bias arises when respondents react strongly against the proposed payment methods. Respondents may for instance resent new taxes or increased bills.
- Starting point bias occurs when the starting point for eliciting bids skews the possible range of answers, because it is too high, too low, or varies significantly from respondents' WTP/WTA.

With careful survey design, most of these sources of bias can however be reduced or eliminated.

Detailed guidance on how to apply this valuation method can be found in Carson and Mitchell 1989.

Box 14: application of contingent valuation techniques to watershed drought mitigation services in eastern Indonesia

This study focused on the watershed catchment protection services provided by Ruteng National Park in eastern Indonesia. It used contingent valuation techniques to assess the economic value of drought mitigation for local farmers. This derived farmers' willingness to pay for watershed catchment protection services in terms of incremental agricultural profits arising from drought mitigation.

Surveys were carried out in order to provide socio-economic information about the agricultural populations living around the National Park. Households were then questioned directly to elicit their willingness to pay for drought mitigation services. Contingent valuation questions were introduced with a standard description of National park institutions and management, so as to ensure that respondents received homogeneous information. This was followed by several opinion questions designed to remind farmers about their environmental constraints and substitution possibilities, and drought mitigation services were described. Willingness to pay bids were elicited through a payment vehicle based on a fee to be collected by National Park officials for the protection of the watershed. All households in the survey were asked if they would be willing to pay an annual fee for drought mitigation services, and depending on their response a follow-up question was asked about higher or lower fees.

Responses found that farmers were aware of, and interested in, their environmental conditions, and the way in which these were linked to water availability. Respondents were willing to pay initial and subsequent annual fees for drought control services. Various socio-economic characteristics and environmental conditions were found to have a statistically significant effect on responses. Farmers expecting increases in profits through higher rice revenues were willing to pay more for these services, as were wealthier and more educated households who mark up their perceived benefits from drought control. In contrast, farmers living in watersheds with higher levels of forest cover and greater rainfall were willing to pay less, perhaps because they perceived less need for forest protection and were not exposed to droughts.

Overall, the study found that mean annual stated illingness to pay for drought mitigation services was between $2-3 per household, equivalent to about 10% of annual agricultural costs, 75% of annual irrigation fees, or 3% of annual food expenditures.

From Pattanayak and Kramer 2001

5N Other stated preference methods: conjoint analysis and choice experiments

Other stated preference valuation methods include conjoint analysis and choice experiments. Due to their complexity in terms of data needs and analysis, and because there exist very few examples of their application to ecosystem services, these methods are not described in detail here.

Conjoint analysis was originally developed in the fields of marketing and psychology, in order to measure individuals' preferences for different characteristics or attributes of a multi-choice attribute problem. In contrast to contingent valuation, conjoint analysis does not explicitly require individuals to state their willingness to pay for environmental quality. Rather, conjoint asks individuals to consider status quo and alternative states of the world. It describes a specific hypothetical scenario and various environmental goods and services between which they have to make a choice. The method elicits information from the respondent on preferences between various alternatives of environmental goods and services, at different price or cost to the individual.

Choice experiments techniques present a series of alternative resource or ecosystem use options, each of which are defined by various attributes including price. Choice of the preferred option from each set of options indicates the value placed on ecosystem attributes. As is the case for contingent valuation, data collection and analysis for choice experiments is relatively complex. Usually conducted by means of questionnaires and interviews, choice experiments ask respondents to evaluate a series of "sets", each containing different bundles of ecosystem goods and services. Usually, each alternative is defined by a number of attributes. For example, for a specific ecosystem this might include attributes such as species mix, ecosystem status, landscape, size of area, price or cost. These attributes are varied across the different alternatives, and respondents are asked to choose their most preferred alternative. Aggregate choice frequencies are modelled to infer the relative impact of each attribute on choice, and the marginal value of each attribute for a given option is calculated using statistical methods.

Detailed guidance on how to apply these valuation methods can be found in Haab and McConnell 2003 and Louviere *et al* 2000.

Box 15: application of conjoint analysis techniques to river quality in Kruger National Park

Development and resource allocation decision processes are increasingly under pressure to take environmental values into account in order to reach optimal economic outcomes. In South Africa new techniques are needed to incorporate environmental values into environmental impact assessment and in the allocation of water resources under the National Water Act, both of which require the comparison of alternative scenarios with varying impacts on the environment. This study on the tourism value of rivers in the Crocodile Catchment was the first case study to develop methods for incorporating the economic values of the goods and services provided by functioning aquatic ecosystems into such decision processes. The current tourism value of these rivers was considered in terms of revenues to Kruger National Park (visitors' on-site expenditure), contribution to the economy (visitors' on-site and off-site expenditure) and recreational value, including consumers' surplus. The effect of a change in river quality was determined using a joint contingent valuation - conjoint valuation approach.

The conjoint analysis sought to ascertain the relative value of different attributes of a river. A multi-factor evaluation approach was taken, where respondents were presented with a combination of a representative range of relevant river attributes (the number of crocodiles and hippos, number of waterbird species, diversity of the riverscape, and density of riparian trees), and four levels were defined for each. The levels of these attributes will vary depending on ecological catchment management practices and are appropriate for use as indicators of change. With four attributes and four attribute levels, there are 256 possible combinations. Of these, 16 were chosen using an approximation to an extended centre point design. Both a worst case (worst on all attributes) and an ideal case (best on all attributes) were included. The *status quo* formed one intermediate point, while the remaining 13 intermediate combinations (better and worse than the status quo) were randomly generated. The 16 scenarios were distributed among five questionnaire versions, including the *status quo* scenario in each. The pristine (ideal) and heavily degraded (worst case) river scenarios were each only included in one of the five survey versions. Each respondent rated four scenarios (three relative to the *status quo*). In order to take into account the scaling effects of the different ranges of scenarios offered in each survey version, mean scores for scenarios from the five survey versions were adjusted so that the status quo score in each version was equal to the status quo score in the version containing the ideal scenario. The relationship between the different levels of the attributes and the response (score) was examined using a generalised linear version of multiple regression. The four attributes (croc/hippo, waterbirds, riverscape, and trees) were entered as terms to be fitted to the response variable This model produced the best fit in comparison to other combinations of designated continuous and categorical variables. A utility score was generated from the above model for any combination of attribute values representing riverine conditions. Two contingent valuation-style questions provided values for the 'ideal' and 'worst' scenarios relative to the status quo: (1) If all of the rivers in the Kruger National Park (KNP) dried up completely, so that there were no crocodiles, hippos or waterbirds present, there were no riverine trees, but everything else in the park were the same, would you spend less time in Kruger Park? Please estimate how much; (2) Consider the fact that the rivers in the Park are used upstream, and are presently not in their original state. If, hypothetically, the rivers were to be restored to their original state - that is, they contained high numbers of crocodiles, hippos, waterbirds, etc, diverse habitats, including lots of riverine trees, do you think that you would spend more time in Kruger Park? Please estimate how much. In order to convert utility scores to monetary values, we regressed the three utility scores for the 'worst', 'status quo' and 'ideal' scenarios against their corresponding value in terms of resultant visitor expenditure (both in terms of average expenditure per trip and total annual revenue generated in the KNP).

It was estimated that the current value of KNP tourism is about R136 m in terms of on-site expenditure, R267 m in terms of economic impact, or all expenditure related to visiting the park, and R1 bn in terms of consumers' surplus. The latter two values can be added to calculate total recreational value. It was found that about 30% of tourism business would be lost if rivers were totally degraded. Thus, rivers within the Crocodile Catchment, which takes 22% of KNP visitor-nights, contribute R9 m to KNP revenues and have a total annual recreational use value of about R85 m., including off-site expenditure and consumers' surplus. The conjoint analysis generated an equation which is able to predict the change in trip expenditure, or total KNP revenue, associated with changes in levels of any of the four attributes considered. Appearance of the riverscape has the greatest influence on recreational use value, followed by waterbird diversity, aquatic megafauna and riparian tree density. Such models can be used in water allocation decision processes when attribute levels associated with alternative management scenarios are predicted by aquatic ecologists.

From Turpie and Joubert 2001

5O The applicability and limitations of economic valuation

Ecosystem valuation generates useful and convincing information because it helps to highlight the costs and benefits (and cost-bearers and beneficiaries) of invasive species, that have in the past often been ignored in economic analysis. However, as mentioned at the beginning of this module, it is not the only factor determining whether invasive species are integrated into decision-makers' agendas. It is important to bear in mind that valuation only provides a set of tools with which to make better and more informed decisions. As such, it has a number of shortcomings and weaknesses.

The need for information from other disciplines

One important consideration to bear in mind is that the valuation of ecosystem services is not a stand-alone exercise. An exercise to value the impacts of invasives has little meaning, and is likely to have only limited accuracy, unless it is based on a sound appreciation and good information about biological, ecological, hydrological, institutional and social aspects of ecosystem management and responses to invasives. In particular, valuation studies require data which relate ecosystem status to service provision, as well as detailed information about the allocation of rights, responsibilities and access to ecosystem goods and services.

Partial information and unquantifiable benefits

Valuation is, of necessity, partial. It can deal much more easily with goods and services that are marketed, or are linked to markets; to some extent, the problems associated with invasives are only "interesting" in economic terms if the space that is being invaded is otherwise occupied by species that yield a flow of economically valuable goods and services (Perrings 2002). Valuation also does not always accurately represent the full value of ecosystems. It presents estimates, or narrows calculations down to a range of possible values. In many cases valuation methods actually under-estimate the worth of ecosystem services: Ecosystems work on such a large scale and in such intricate ways, their services cannot be replicated effectively by technology or their impacts extend well beyond effects on other marketed products and indicators. Finally, some ecosystem values will always be unmeasurable and unquantifiable because the necessary scientific, technical or economic data are not available.

Other ecosystem benefits relate to attributes such as human life, cultural or religious significance, where valuation raises serious ethical questions. To some extent ecosystem valuation may even be dangerous when it focuses attention only on financial or cash benefits at the expense of other types of values that cannot (or should not) be valued. The economic valuation of ecosystems is essentially a utilitarian approach, and has shortcomings as regards cultural, intrinsic and primary aspects of value.

The transferability of specific findings

It would also be a mistake to think that the results of ecosystem valuation studies are always definitive, exact or transferable between different situations and locations. They are usually based on a particular person's or group's perception of what a particular ecosystem service is worth at a specific point in time and place. Valuation is not necessarily universally valid, or extrapolable between different groups, areas, ecosystems or over time.

Bias in valuation

Valuation exercises also tend to be heavily influenced by the aims and purposes for which they are carried out. For example, the desire to demonstrate significant economic losses from invasive species or to promote a particular course of response sometimes means that results are biased towards finding high values. When valuation studies are carried out they actually may over-estimate the worth of ecosystem services, or make unwarranted assumptions about the impacts of invasives by not properly establishing the biophysical linkages between ecosystems, invasive species and the economy.

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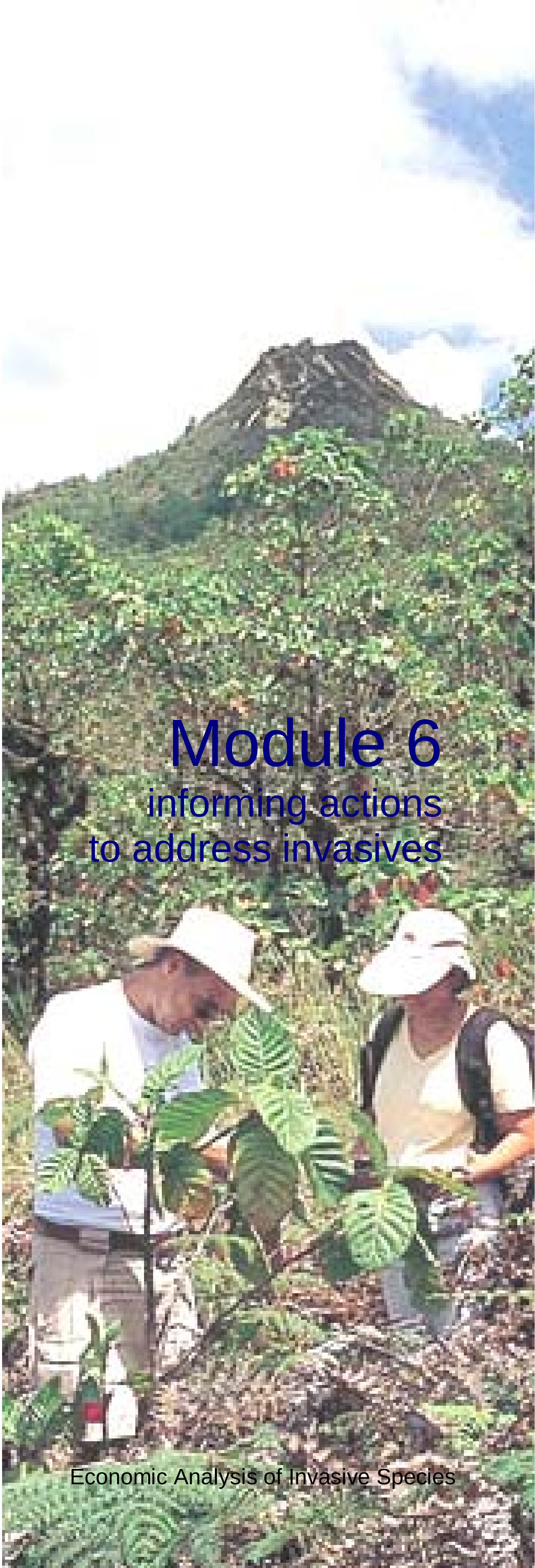
GISP
The Global Invasive Species Programme



Module 6
informing actions to address invasives

Economic Analysis of Invasive Species

6A What this module covers

This module outlines the types of management interventions that are commonly employed to deal with invasive species. It describes the economic tools that are used to support and inform decision-making, and identifies the ways in which invasives can be addressed. The module also deals briefly with the various economic and financial instruments that can be used to curb the spread of harmful invasives, and to reinforce measures to prevent, eradicate, contain or manage them.

By the end of this module, the reader will be more aware of how and when invasives issues need to be incorporated into economic decision-support information and indicators, and have a better understanding of the types of economic and financial instruments that can be used to help plan for the control of invasive species.

6B Addressing invasives through management interventions

Management interventions as public goods

Because the market cannot be relied upon to deal with the problems associated with invasives (see sections 2C identifying the economic causes of invasions and 5D coping with price distortions and market failures), some form of deliberate intervention is almost inevitably required to manage them. Like other policy and market failures, the social costs associated with invasive species usually justify such public or collective action in the interests of the common good.

The prevention, control and management of invasions display many of the characteristics of classic public goods (Perrings 2000). Public goods are characterised by non-excludability, and non-rivalry in consumption. Any action taken to manage or control invasives benefits broader society, beyond the individual or group who initiates the action. On the one hand this means that it is almost inevitable that the management of invasions will be under-provided by the market, as there are weak incentives for individuals to provide for the control of invasives (either due to the fact that those who introduce or spread invasives do not themselves face costs and losses from their actions, or because others will also benefit and so beneficiaries hope that others will pay the costs for “free-riding” behaviour). At the same time, it means that a major focus in the use of economic decision-support tools is on balancing the public costs and benefits associated with invasives (see sections 6C and 6F), and on ensuring that these values are internalised into private decision-making (see section 6G).

A typology of interventions to address invasives

Figure 8: typology of interventions to address invasives

Interventions targeting the steps to invasion			
Steps to invasion	**Type of intervention**	**Aim of the intervention**	**Examples**
Introduction ↓	Prevention	stopping introductions	quarantine, blacklists, inoculation, trade or import bans, land use restrictions
Establishment ↓	Eradication	destroying or removing a new invasion	physical removal, chemical eradication, biocontrol measures
Naturalisation/Spread ↓	Containment	stopping a new invasion from further spreading	confinement of the species, phytosanitary controls, border checks
Invasion	Management Restoration	of established invasions of affected ecosystems	periodic clearance, revegetation/repopulation with native species, landscape restoration
Interventions targeting ecosystem resilience			
Biodiversity conservation; Protected areas; Sustainable land and resource management; … etc. …			

Before looking in detail at the way in which economic tools and indicators can be used to support and inform decision-making in relation to the management of invasives, it is useful to first consider the range of interventions which are employed to address invasives at different stages in the progression to invasion. A broad categorisation of interventions can be defined which includes actions designed to prevent potentially invasive species being introduced in the first place, those aiming to remove new invasions, actions to curtail the further spread of an existing invasion, through to interventions which are concerned with managing and mitigating the effects of invasions which have already become established and with improving the resilience of ecosystems to damage and invasion (Figure 8). Each type of intervention requires quite different management actions, has different economic cost and benefit implications, and typically varies in the level of direct expenditures it incurs.

It is also useful to distinguish between types of intervention which are concerned with mitigation, and those which are targeted towards adaptation. While the former are designed to influence the probability of a particular outcome occurring and have the effect of reducing the likelihood that an invasive species will establish and spread (such as through eradication or control), the latter aims to affect the value of a particular outcome occurring and involves some change in behaviour in order to reduce the impact of the species' establishment and spread (Shogren 2000, Perrings 2002). Another important distinction is between *ex post* and *ex ante* measures: the former involve actions undertaken before a species is introduced (prevention), while the latter involve actions which take place after the species has become invasive (eradication, containment, management and restoration).

6C Tools for weighing up invasive costs and benefits

Economic analysis provides important information to assist decision-makers to arrive at rational, beneficial and effective decisions as regards invasive species. This includes both justifying the need to take action to address invasives, as well as choosing the "best" option for managing them. Management interventions incorporate actions designed to prevent, eradicate, contain and manage invasive species themselves, as well as those aiming to improve the resilience of ecosystems to damage and invasion.

Box 16: weighing up the benefits and costs of invasives

Benefits	Costs
Brush-tailed possums from Australia were introduced to New Zealand between 1858 and 1900 to establish a fur trade, but in New Zealand they have fewer competitors, fewer predators, and fewer parasites than in their native Australia, so they have successfully spread and have sometimes reached densities ten times greater than in their native Australia. They have been a bonanza for the fur industry.	The Australian brush-tailed possums introduced into New Zealand have caused considerable damage to native forests, changing forest composition and structure through the defoliation and progressive elimination of favoured food plants. Note that none of these costs are particularly relevant to those interested primarily in the benefits from furs. In an effort to control these possums, New Zealand is working on bio-control agents, including the possibility of a genetically-engineered immunocontraceptive virus. This innovative approach could have profound implications elsewhere in the world, showing that some problems may lead to solutions which have considerable global value.
A number of woody plants from various parts of the world, such as acacias from Australia, were introduced into South Africa in the middle of the 19th century for purposes of dune stabilization, tannin extraction, and firewood. This appears to have been an economically successful invasion, with the greater Capetown region alone supporting a 30 million Rand charcoal and firewood industry.	As a result of the introduced species, South Africa's highly-endemic Cape Flora is under serious threat and the watersheds are becoming less productive, potentially causing a considerable increase in the price of water.
In the Thar Desert of India, the Meso-American tree *Prosopis juliflora* was introduced 70 years ago and has become the dominant flora around human habitats. With its dense green vegetation, this tree is very useful in checking soil erosion, reducing the dryness of the desert air, giving shelter to several species of wild animals, and providing legumes which are relished by wild as well as domesticated animals. It meets 85 percent of firewood demands of rural people.	While *Prosopis juliflora* has been a boon to people in the Thar Desert who need firewood and fodder, it overwhelms other flora in the area, thereby reducing the range of products available to local people and reducing biodiversity.
The Triclad flatworm *Platydemus manokwari*, first described from New Guinea in 1963, is a successful predator of the giant African snail *Achatina fulica*, so it was transported as a biological control agent to areas where the African snail had become established in the Pacific.	The Triclad flatworm now poses a serious threat to the native gastropod fauna of the Pacific region. This is especially troubling because the Pacific has seen a remarkable radiation of the snail family Partulidae, and some 24 of these are on the 1994 IUCN Red List of Threatened Animals. The Triclad flatworm has become established on Guam, Saipan, Tinian, Rotar, and Palau.
Water hyacinth *Eichhornia crassipes* was introduced into China from South America in the 1930s and was spread through mass campaigns in the 1950s to the 1970s as an ornamental plant, to provide livestock food, and to control pollution through absorbing heavy metals.	In China, the water hyacinth has become the worst weed in many aquatic habitats, leading the loss of species of both plants and animals. In Dianchi Lake, just outside of Kunming, Yunnan, the total number of fish species has declined from 68 to about 30 and Chinese scientists attribute this to water hyacinth. Reduction of the lake area as a result of the water hyacinth infestation has also caused notable climatic changes in Kunming.

From McNeely 1996, 2001

Most basically, decision-making involves considering the perceived trade-offs, and relative costs and benefits, of different courses of action. From an economic perspective, the maximum condition requires that the marginal costs of prevention, eradication, containment or management/restoration be at least equal to the marginal benefits occurring from that action (Perrings 2002). In the case of invasive species, this typically involves weighing up the direct costs of the management action and the economic benefits of the invasive species itself against the negative economic impacts that invasion gives rise to (see section 4C defining the benefits and costs of invasives). In addition to the wide range of other (non-economic) criteria that are used to judge the relative merits and demerits of undertaking a particular course of action, economic considerations and measures form an important part in calculating trade-offs and in making decisions.

This toolkit has outlined the various techniques that can be used to value invasive costs and benefits (see Module 5), as well as emphasising that the primary focus in economic analysis is on looking at incremental changes and considering the marginal costs and benefits of different levels of degree of invasion and control (see section 4F). Factoring these values into the economic measures and indicators that are used to represent and weigh up trade-offs is a way of improving the information base upon which decisions are made, and of ensuring that invasive-related costs are considered alongside and on comparable terms with the other economic costs and benefits that are conventionally included in decision-making.

The paragraphs below describe briefly two of the most commonly-used economic decision-support tools: cost-benefit analysis and cost-effectiveness analysis, as well as outlining a third tool which combines economic and non-economic measures and is often used to weigh up ecosystem-related costs and benefits: multicriteria analysis.

Cost-benefit analysis

Cost-benefit analysis (CBA) remains the most commonly used decision-making framework for assessing and comparing economic and financial trade-offs. It is a standard tool for appraising and evaluating programmes, projects and policies and one that is a required part of many government and donor decision-making procedures. It is also a framework into which invasives values can easily be integrated.

CBA judges alternative courses of action by comparing their costs and benefits. It assesses their profitability or desirability according to net present benefits – the total annual benefits minus total annual costs for each year of analysis or project lifetime, expressed as a single measure of value in today's terms (achieved by applying a discount rate, as described below in section 6D incorporating the time dimension).

CBA presents three basic measures of worth, which allow different projects, programmes or policies to be assessed and compared with each other:

- Net Present Value (NPV) is the sum of discounted net benefits (i.e. benefits minus costs), and shows whether a project generates more benefits than it incurs costs.
- Benefit-Cost Ratio (BCR) is the ratio between discounted total benefits and costs, and shows the extent to which project benefits exceed costs.
- Internal Rate of Return (IRR) is the discount rate at which a project's NPV becomes zero.

In general, a course of action can be considered to be worthwhile if its NPV is positive and its BCR is greater than one, and if its IRR exceeds the discount rate. A positive NPV and a BCR greater than one means the project generates benefits that are greater than its costs. An IRR above the discount rate means that the project generates returns in excess of those which could be expected from alternative investments.

Other things being equal, the higher the NPV, BCR or IRR of a course of action, the more desirable it can be considered to be in economic or financial terms. Bringing invasives values into these quantified measures enables them to be counted alongside the other costs and benefits that are considered when assessing the desirability of following a given course of action. It enables a more informed choice to be made between different investment, land or resource use options by considering the full range of invasive-related impacts.

Detailed guidance on how to apply cost-benefit analysis can be found in Irvin 1978, ODA 1988 and Winpenny 1991.

Box 17: cost benefit analysis of control of the Ruffe in the Great Lakes, USA

The Ruffe (*Gymnocephalus cernuus*) is a fish which has invaded the Great Lakes of North America , as well as many other regions, of the US. It competes with native fish for food and habitat. Its ability to displace other species in newly invaded areas is due to its high reproductive rate, its feeding efficiency across a wide range of environmental conditions, and characteristics that may discourage would-be predators. Control measures include the use of toxins, trawling and ballast water management. A cost benefit analysis was carried out for a proposed 11 year control programme. The total costs were calculated at $13.6 million. Benefits were estimated based on the value of both the commercial and sport fishery impacts over a 50 year time period, giving a present value of between $119 million and $1 billion.

From Leigh 2003

Cost-effectiveness analysis

Cost-effectiveness analysis (CEA) is a sub-set of cost-benefit analysis in which a particular outcome is taken as given, and the analyst seeks to identify the least-cost means of achieving this goal. It is particularly useful where the benefits of undertaking a particular course of action are unquantifiable, or where a specific goal has already been set (for example eradicating a particular invasive species from a given area). Taking the benefits from particular actions as given, CEA involves calculating all the costs of attaining the specified objective, discounting them, and pointing to the option with the lowest NPV.

Detailed guidance on how to apply cost-effectiveness analysis can be found in Irvin 1978, ODA 1988 and Winpenny 1991..

Box 18: cost effectiveness analysis of control of oyster drills (*Ocinebrellus inornatus*) in Willapa Bay, USA

Oyster drills (*Ocinebrellus inornatus*) are an economically important aquaculture pest that has been accidentally introduced worldwide. The direct-developing marine snails cause economic harm by preying on small oysters. A cost effectiveness analysis was carried out to determine the least costly set of strategies that will prevent established invaders from continuing to increase the Willapa Bay, Washington State.

The analysis explores the relative contributions of reproduction, juvenile survival and adult survival to population growth of the invading species through population elasticity analysis, and showed how to identify the combination of life stage interventions that will minimize the total cost of halting population growth. The only control technologies currently available are based on manual removal. In terms of a two-stage life cycle, the destruction of egg capsules reduces fecundity, and the collection of adults reduces adult survival. Analysis showed that a mixed strategy should be pursued whenever the marginal cost of a proportional reduction in adult survival is approximately 0.25 to 0.45 times the cost of changing fecundity. As egg capsule removal becomes more expensive relative to adult drill removal, the optimal strategy shifts to targeting only adults while the total annual cost of control per unit of invaded area increases.

Currently, control efforts target adults, the phase that is easiest to remove, despite its lower population elasticity. Likewise, the cost effectiveness analysis suggests that intervention in adult survival is optimal except during periods of peak reproduction.

From Buhle *et al* 2005

Multi-criteria analysis

Although both cost-benefit analysis and cost-effectiveness analysis are influential tools, economic and financial measures are typically only one of a number of criteria used to weigh up decisions relating to invasives. There will always be certain values that cannot (or should not) be expressed in monetary terms, and there are many non-economic factors that need to be incorporated and considered in decision-making.

Multi-criteria analysis provides a useful, and increasingly common, tool for integrating different types of monetary and non-monetary decision criteria. It has been developed to deal with situations where decisions must be made taking into account multiple objectives, which cannot be reduced to a single dimension. Several authors recommend the use of multi-criteria analysis for decisions related to invasives (see for example Binimelis *et al* 2006).

Multi-criteria analysis is usually clustered into three dimensions: the ecological, the economic and the social. Within each of these dimensions certain criteria are set, so that decision-makers can weigh the importance of one element in association with the others. Here, monetary values and CBA measures can be incorporated as one of the various criteria to be considered, and weighed against the others in decision-making.

Detailed guidance on how to apply multi-criteria analysis can be found in Winpenny 1991.

Box 19: examples of the application of multi-criteria analysis to invasives

- In decision-support processes to compare riparian revegetation options in Scheu Creek catchment in north Queensland, used to evaluate alternative management options, and to accommodate the conflicting views of various stakeholder groups. Clear differences were found in the rankings of revegetation options for different stakeholder groups with respect to environmental, social and economic impacts. (Qureshi and Harrison 2001).
- To evaluate the environmental impacts of adoption of genetically modified organisms on wildflowers as a symbol of the complexity of evaluating environmental qualities and risks (Aslaksen and Ingeborg Myhr 2007).
- To analyse trade-offs among conflicting objectives for controlling feral pigs in Hawaii (Maguire 2004)

6D Incorporating the time dimension

Modelling the trajectory of invasions

Invasive species typically show an unusual, and hard to predict, trajectory. As discussed in Module 1 of this toolkit, the time taken for a species to move from introduction to invasion typically varies considerably, as progression from one stage of invasion to another is variable and different for species and new habitats/ecosystems. Further, a complex set of variables determine whether a species will become established in a given area, how it will impact on native species and ecosystem functions, and what the magnitude of its impacts will be. These variables relate both to the characteristics of the invading species itself as well as to the condition of the ecosystem, how it is used, and for what purposes.

The spatial and biophysical trajectory of invasives usually requires detailed scientific data and models (which are in turn almost inevitably subject to high degrees of uncertainty – see section 6E below). The economist must be particularly aware that the level of costs and benefits will vary considerably at different stages in this trajectory of invasion, both in terms of the benefits associated with the invasive species itself as well as the costs (and sometimes cumulative knock-on effects) associated with its establishment and spread.

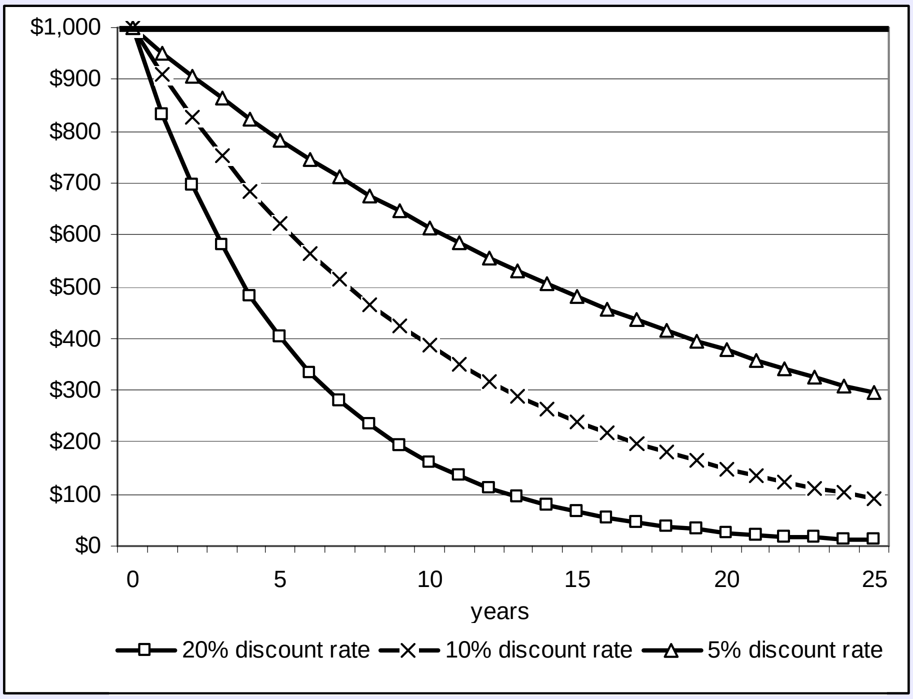
The costs of addressing invasions also vary over time, at different stages in the progression to invasion. In most cases *ex post* prevention measures are both the easiest and cheapest to undertake, followed by action during the escape or early establishment phases. As time goes by, management and control efforts (as well as broader economic costs) become more and more expensive to undertake. For example a study of the costs of control and management of invasive alien plants under the South African Working for Water Programme found that expenditures were significantly lower, and cost efficiency higher, when invasions were treated early. Very scattered invasions were between 3 and 25 times cheaper to clear than closed canopy stands, and cost efficiency in terms of generating extra water yield were much higher for low levels of invasion than for denser invasions (Marais and Wanneburgh 2007).

Using a discount rate

Time is a key factor in any economic analysis, and is of particular importance to invasives. As discussed above, there is typically considerable variation in both the magnitude and type of costs and benefits incurred at different stages of the invasion process. When investigating the stream of costs and benefits involved in addressing invasives, it is necessary to ensure that analysis incorporates a sufficiently long time period to capture all these values and impacts, as well as taking steps to express these future costs and benefits as a single measure of value which can be judged and compared between the different decision-making options being considered (each of which typically involves a series of costs and benefits which accrue at different times in the future).

The conventional way of dealing with time in economic analysis is to apply a discount rate in order to bring future costs and benefits to their equivalent value today – as explained in earlier sections of this module on cost-benefit and cost-effectiveness analysis (see 6C tools for weighing up invasive costs and benefits). Discounting is essentially the inverse of applying a compound interest rate, and gives values relatively less weight the further into the future they accrue. It accounts for the fact that people generally prefer to enjoy benefits now and costs later, and that any funds tied up in a particular action or project could be used productively to generate returns or profits elsewhere. In most cases, the discount rate is therefore based on the opportunity cost of capital – the prevailing rate of return on investments elsewhere in the economy. It thus follows that a high discount rate reflects a strong preference for present consumption, and a low discount rate reflects longer-term considerations and preferences. As illustrated below in Figure 9, the higher the discount rate applied, the less weight is given to future costs and benefits expressed as present values.

Figure 9: the effects of applying a discount rate



The question of discounting generally, and specifically of which discount rate to use, has been the subject of some debate in relation to environmental costs and benefits. Generally speaking, the higher the discount rate used, the less weight is given to future costs and benefits. As many of the costs of invasive species are long-term, while many of their benefits are immediate, it has been argued that applying any discount rate (and especially high ones) inherently prejudices against taking actions to address invasives, and that a lower (or zero) discount rate should be applied.

Detailed guidance on how to apply a discount rate can be found in Irvin 1978.

6E Dealing with risk and uncertainty

Estimating probabilities and expected values

The economic analysis of invasives involves dealing with both risk (for example the risk that a particular species will become invasive and cause certain impacts) and uncertainty (for example uncertainty about the future trajectory or impacts of a particular invasive species under given conditions). Risks are involved when probabilities can be assigned to the likelihood of an event occurring (and thus the value of possible outcomes can be known). In contrast, uncertainty describes a situation where little is known about future impacts and where no possibilities can be assigned to certain outcomes, or where even the outcomes are so novel that they cannot be anticipated (and thus the range of possible values can be estimated but no probabilities can be attached).

While risk can be dealt with, at least in principle, through treating it as a cost and incorporating numerical probabilities into economic analysis, uncertainty is a much more difficult issue to cope with, and requires a general policy of caution and precaution (see above 5C predicting and measuring impacts: the limits of science). Although under both risk and uncertainty the optimal strategy for addressing invasives is to equate the marginal costs and marginal benefits of measures, uncertainty changes the manner in which these costs and benefits are valued (Horan *et al* 2002, Anderson and Quiggin 1990).

Standard economic analysis depends on estimates of the expected value for the costs and benefits of different courses of action or decision-making options. Technically, the expected value of a variable is the sum of its possible values at any point in time, each weighted by the probability of it occurring. Invasives involve high levels of uncertainty and unpredictability. The probabilities that are used to calculate expected values are thus difficult to estimate in the case of invasives. Although many invasive problems involve very low probabilities and low risks, their costs and potentially damaging effects tend to be extremely high (Horan *et al* 2002, Perrings 2002): these low probability/high damage characteristics need to be weighed up.

At the same time, the probability of establishment of intentionally introduced species is usually higher than that of unintentionally introduced species, because the they have been selected for their ability to survive in the environment where they are introduced and may be introduced repeatedly (Perrings 2002). The probability that invasives will both become established and spread depends in turn on the resilience of the environment they are being introduced into, and they ways in which it has been used, managed and altered (and will continue to be in the future). There is a need to also consider a complex range of additional ecological variables which determine both the probability of invasions as well as the costs of their management, including the continuing dispersal of invasive species into adjacent ecosystems, the degradation of ecosystem functions and further impacts or re-invasion after eradication or control (Born *et al* 2004).

Factoring risk and uncertainty into economic decision-support tools

Box 20: decision analysis to evaluate alternative management strategies for controlling invasive weeds in Australia

When a weed invasion is first discovered a decision has to be made on whether to attempt to eradicate it, contain it or do nothing. Ideally, these decisions should be based on a complete benefit-cost analysis, but this is often not possible. A partial analysis, combining knowledge of the rate of spread, seedbank longevity, costs of control and techniques of economic analysis, can assist in making a good decision.

In this example, a decision model was used to determine when immediate eradication of a weed should be attempted, or more generally whether weed control should be attempted at all. The model was designed as a first step in developing rapid-assessment tools to evaluate alternative management strategies when invasions are first discovered. The control measure considered consisted of establishing a barrier zone along the perimeter of the invasion and, if appropriate, eliminating the established weed population. For any given invasion size the most desirable course of action is determined by selecting the strategy that maximizes net benefits, measured in present value terms. Net benefits are measured relative to the do-nothing option. The technique is based on identifying two 'switching points': the invasion size at which it is no longer optimal to attempt eradication but where containment may be an option; and the invasion size at which it becomes optimal to apply no form of control at all. The model is applied to a woody perennial weed in a natural environment.

The results show that seedbank longevity is the main constraint on the maximum eradicable area and spread rate is the main constraint on the maximum containment area. Stochastic simulations were undertaken to derive probability distributions of costs which were than used to evaluate the effect of budget constraints on areas that can be eradicated. The study found that, in the absence of a budget constraint, it may be desirable to eradicate invasions from areas as large as 8,000 ha, but when budget constraints typical of those faced by agencies in Australia are introduced, feasible eradicable areas are less than 1,000 ha.

From Cacho *et al* 2008

In practice, a number of tools are available which allow risk and uncertainty to be included in economic analysis. Three of the most widely-applied tools are:

- **Sensitivity analysis.** This is the quantitative process of testing the effects of changing certain key variables in economic analysis – for example the discount rate, prices, levels of impact, exchange rates, cost of control and management measures, and so on. Most commonly it involves considering the impact of changes in these variables on NPV. As well as providing a range of possible values for the net benefits attached to a particular course of action, depending on the future conditions that pertain, sensitivity analysis helps to highlight which variables the NPV is particularly sensitive to changes in. Detailed guidance on how to apply sensitivity analysis can be found in Irvin 1978, ODA 1988 and Winpenny 1991.

- **Risk-benefit analysis.** This decision-support tool focuses on the prevention of events carrying serious risks, and is thus particularly applicable to invasives. It can be viewed as the inversion of normal cost-benefit analysis, because it starts by presuming no action and then assesses the costs of inaction as the likelihood of the specified risk occurring. The benefit of inaction is the saving in the cost of preventive measures. Detailed guidance on how to apply risk-benefit analysis can be found in Irvin 1978, ODA 1988 and Winpenny 1991.

- **Decision analysis.** This decision-support tool weights the expected values of a given course of action (in other words, the sum of possible values weighted by their probability of occurring) by attitudes to risk, to give expected utilities. It draws up and assesses decision makers' preferences, judgements and trade-offs in order to obtain weights that are attached to outcomes carrying different levels of risk. Detailed guidance on how to apply decision analysis can be found in Irvin 1978, ODA 1988 and Winpenny 1991.

6F Distinguishing between financial and economic values

As described earlier in this toolkit, invasives involve both private and social costs and benefits, and a key part of economic analysis is to provide the information which will allow these to be calculated and weighed up. It is important to distinguish between financial and economic values, and to recognise that the analysis of invasives invariably involves aspects of both.

Financial analysis

Financial analysis looks only at the private returns accruing to a particular individual or group. It calculates costs and benefits at market prices, reflecting the actual cash profits and expenditures that people face – and thus does not compensate for the fact that these markets and prices may in practice be highly distorted as regards full "social" costs and benefits.

A financial analysis might for example measure and compare the relative profitability of different crop mixes (one of more of which involves a potentially invasive species), or the relative costs and benefits to a landholder of taking action to control or eradicate invasive species. In the majority of cases, financial analysis would include only the direct costs and benefits associated with invasives or with measures to address them, and would not incorporate broader effects on the economy.

Economic analysis

In contrast, economic analysis examines the effects of invasive species, or measures to address them, on society or the economy as a whole. It considers all costs and benefits, for all affected groups. Sometimes weights are assigned to prioritise particular groups, benefits or costs that are considered to be of particular importance in economic terms (see 4F recognising the complexity of invasive costs and benefits). As such, economic analysis is primarily applicable to the calculations made by government or donor agencies, who are concerned with broad societal and economy-wide impacts.

Because economic analysis assesses the desirability of a given course of action from the perspective of society as a whole, it usually adjusts financial costs and benefits to account for the various imperfections and distortions in the market. This involves calculating values measured at their "real" cost or benefit to the economy, usually omitting transfer payments and valuing all items at their opportunity cost to society. Economic analysis commonly involves the use of "shadow prices", when market prices are felt to be poor estimates of "real" economic value.

Detailed guidance on how to apply economic analysis can be found in Irvin 1978, ODA 1988 and Winpenny 1991.

6G Designing economic and financial instruments to address invasives

Internalising externalities and correcting market distortions

Most of the management interventions described so far in this module involve measures to regulate, mitigate or adapt to the presence of invasive species. Economic and financial instruments offer a key source of support to these interventions because they provide a suite of tools which affect people's behaviour by working on their economic and financial motivations, and which aim to correct for the economic policy, price and market failures that form an underlying cause of invasions (as discussed in module 2).

The use of economic and financial instruments to shape production, consumption, investment and trade behaviour is nothing new. A wide array of taxes, subsidies, prices, markets and policies form a core strategy for economic management in most countries, and are increasingly being applied also to key environmental problems across the globe (see for example Munasinghe and Cruz 1994, OECD 1999). Although as yet relatively undeveloped, there is a great deal of scope for addressing economic and financial instruments to the problems associated with invasive species. They frequently provide a cost-effective means of influencing the key causes of biological invasions, and reinforce more conventional regulatory and management measures.

Economic and financial instruments essentially aim to change the policies, prices and markets people face, so as to ensure that the broader social costs or externalities of invasives are internalised in private decisions. In some respects they therefore resemble closely the instruments that are used more generally for environmental management, and which correct for distortions and failures which encourage particular consumption, production and trade behaviour which is deemed to be not in the best interests of society. A notable difference between invasives and externalities as conventionally understood in economics is however that invasions, once set in motion, are largely self-perpetuating and often their impacts also increase over time. Usually, externalities continue only if the source activity is maintained. Another issue is that the effects of invasives are often felt as trans-boundary externalities, which further complicates the use of economic and financial instruments.

These unique characteristics mean that many of the economic and financial instruments that are commonly used to deal with environmental externalities only have limited applicability for the case of invasives (Jenkins 2002, Perrings 2002). The following section of this toolkit looks briefly at some of the economic and financial instruments which have application to invasives. A number of publications provide detailed guidance and case studies on the use of economic instruments to tackle environmental problems, including OECD 1999 and Rietbergen and Mc-Cracken 2000.

Types of economic and financial instruments that can be used to address invasives

A broad typology of economic and financial instruments can be proposed which have potential application to invasives, including charges and fees, fiscal instruments, bonds and deposits and trade measures (Figure 10). Most of these are based the "polluter pays principle", namely that the individual or company who is responsible for introducing or spreading invasive species should bear the costs of measures to prevent, eradicate, contain or manage that species and to mitigate and remediate the damage it gives rise to (Horan *et al* 2002, Jenkins 2002). In practical terms, this involves confronting producers, consumers and traders with the invasives-related cost of their actions (Perrings *et al* 2005a) via the prices and markets they face.

In many cases, economic instruments have the dual purpose of changing the incentive structure that economic actors face, at the same time as generating sufficient revenues to cover the costs of a third party (usually government) to undertake the actions that are necessary to respond to the invasive species and any damage it causes, such as direct management, ecosystem restoration, provision of alternative technologies and products, and compensation. This latter use is an important one: as several authors have pointed out, public funding to invasives management remains woefully inadequate in most parts of the world (Jenkins 2002). It should also be emphasised that a key step in the application of economic and financial instruments is also to identify, and dismantle, the policy, market and price distortions and perverse incentives that underlie invasions.

Figure 10: typology of economic and financial instruments to address invasives

Category	Description	Examples
Charges and fees	Measures which rationalise prices and improve markets for the goods and services which utilise or depend on invasive species or to alternative products and technologies, or develop markets in quotas or permits which relate to invasive species	Ballast water fees, tradable permits
Creation of markets	Measures which create markets or prices for the land areas or ecosystem services which are impacted by invasive species	Payments for ecosystem services, biodiversity offsets
Fiscal instruments	Budgetary measures which apply taxes and subsidies to the goods and activities which utilise or depend on invasive species or to alternative products and technologies	Investment taxes, product taxes, preferential credit
Bonds and deposits	Measures which require the provision of monetary security when economic activities are carried out which involve invasive species, refundable against any damage occurring as a result of that activity	Performance bonds, damage bonds, import deposits, restoration deposits
Trade measures	Measures whose justification is primarily to guard against invasives but which take the form of trade instruments	Import tariffs and quotas, import duties, export taxes, trade bans, eco-duties, border tax adjustment

From Emerton 2001

Figure 10 gives examples of the ways in which these categories of economic and financial instruments can be applied to invasive species. As yet, there is very little use of economic and financial instruments to address the problems associated with biological invasions – and it is therefore difficult to give specific examples of cases where particular instruments have worked well or have been less successful. In general it should however be noted that most of the instruments referred to will work best where there are relatively well-developed markets and trading networks for invasive species, and where the capacity exists to enforce and regulate particular restrictions, requirements and fees.

Box 21: economic and financial instruments that can be used to address invasives

- The use of payments for environmental services, made to landholders or others to restore invaded ecosystems which provide important services (such as water supply, carbon sequestration, and fire protection), by the beneficiaries of these services. An example is given of payments for hydrological services through the Working for Water programme in South Africa that contracts previously unemployed individuals to clear public or private mountain catchments and riparian zones of invasive alien plants in order to restore natural fire regimes, the productive potential of land, biodiversity, and hydrological functioning. Water utilities and municipalities have begun to contract Working for Water to restore catchments that affect their water supplies. (Turpie *et al* 2008).

- The use of invasion risk tariffs to confront exporters with the costs of their actions. It is suggested that these should be embedded in trade agreements (Perrings *et al* 2005a).

- The posting of bonds equal to the estimated cost of repairing any future damage that could occur in the worst-case scenario of intentional introductions (Thomas and Randall 2000).

- The use of environmental assurance bonds on importers of new species or those undertaking high risk activities, set at a rate equivalent to the conjectured damage if the species was to establish, naturalise, and become invasive (Perrings 2000).

- The levying of fees on activities which might cause invasions, which could in turn be used to create a fund to pay for preventive measures and rapid response to invasive problems. It is suggested that fees could be charged to those involved in global trade and travel, via levies on the import of any live animal or plant that is originally from another continent, on incoming passengers, cargo ships and airplanes (Jenkins 2001 and 2002).

- Using a package of insurance requirements and bonding requirements on activities which may potentially introduce or spread invasives, as well as applying civil and criminal fines and penalties (Jenkins 2001 and 2002). It should however be noted that many of these instruments suffer from a time lag problem, and that it is also often difficult to isolate the cause of an invasion (Jenkins 2002).

- Using tradable risk permits where permits are denominated in terms of the likelihood or probability of an invasive alien species introduction. The tradable permit market would work by providing each vessel with risk permits for potential invaders, and allow vessels to trade the permits among themselves. The only requirement is that the level of risk actually generated by each vessel must not exceed the vessel's permit holdings (Horan and Lupi 2005).

Obviously the applicability of particular instruments will vary across different situations and contexts, and typically the most effective approach is to design a package of mutually-reinforcing instruments which together provide both incentives (to controlling the use of invasives) and disincentives (to introducing and spreading them). These will obviously vary for the *ex ante* control of species introductions and the *ex post* control of introduced species that have become invasive (Perrings 2000). Box 21 describes some of the specific economic and financial instruments that have been proposed by various authors to tackle invasives.

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on the economics of invasives

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The Global Invasive Species Programme

Glossary

of key terms

as they apply to economics and invasion biology

Economic Analysis of Invasive Species

acclimatised species (= naturalised species)	an alien species that has been introduced and maintained within an ecosystem for so long that it is deemed to be a part of that ecosystem and in law and practice is given parity with native species.
alien invasive species	an alien species that has become invasive (see “invasive” below)
alien species	a species that is not native to the ecosystem in which it is introduced.
benefit cost ratio (BCR)	a measure of project desirability or profitability: the ratio between the discounted total benefits and costs of a project.
choice experiment valuation techniques	a *Stated Preference approach* technique for valuing ecosystems or environmental resources that presents a series of alternative resource or ecosystem use options, each of which is defined by various attributes including price, and uses the choices of respondents as an indication of the value of ecosystem attributes.
conjoint analysis valuation techniques	a *Stated Preference approach* technique for valuing ecosystems or environmental resources that asks individuals to consider the status quo and alternative states of the world. It describes a specific hypothetical scenario and various environmental goods and services between which respondents have to make a choice.
consolidation	the settling or establishment of an expanded distribution of an alien species that is becoming invasive
consumer surplus	the difference between the value of a good and its price, in other words the benefit over and above what is paid that is obtained by a consumer who is willing to pay more for a good or service than is actually charged.
containment	the restriction (by human hand) in area or range of a species that is spreading – possibly to become invasive – with intention to stop the spread to new areas
contingent valuation techniques (CVM)	a *Stated Preference approach* technique for valuing ecosystems or environmental resources that elicits expressions of value from respondents for specified increases or decreases in the quantity or quality of an environmental good or service, under the hypothetical situation that it would be available for purchase or sale. This yields their willing to pay (WTP) for the quality of quality of the good or service under question, or willingness to accept compensation (WTa) for its loss.
cost based approaches to valuation	a group of techniques for valuation that look at the market trade-offs or costs avoided of maintaining ecosystems for their goods and services, including *replacement costs, mitigative or avertive expenditures and damage costs avoided* methods.
cost-benefit analysis (CBA)	a decision tool which judges the desirability of projects by comparing their costs and benefits.
cost-effectiveness analysis (CEA)	a decision tool that judges the desirability of a project according to the minimum cost way of attaining a particular objective.
damage cost avoided valuation techniques	a *Cost Based approach* technique for valuing ecosystems or environmental resources that estimates the value of ecosystem goods and services by calculating the damage that is avoided to downstream infrastructure, productivity or populations by the presence of ecosystem services.
decision analysis	a decision tool that judges the desirability of projects by weighting the expected values of a given course of action (in other words, the sum of possible values weighted by their probability of occurring) by attitudes to risk, to give expected utilities.

Glossary of key terms

direct values	a component of *Total Economic Value*: environmental and natural resources that are used directly as raw materials and physical products for production, consumption and sale.
discount rate	the interest rate used to determine the present value of a future stream of costs and benefits.
economic analysis	examines the effects of projects, programmes and policies on costs and benefits to society as a whole, valued according to economic or shadow prices.
economic values	values measured at their "real" cost or benefit to the economy, usually omitting transfer payments and valuing all items at their opportunity cost to society.
ecosystem	a complex of organisms and their environment interacting as a distinct ecological unit irrespective of political boundaries. An ecosystem can be natural or modified by human activity and influence (e.g. forest and agro-ecosystems)
effect on production valuation techniques	a *Production Function approach* technique for valuing ecosystems or environmental resources that quantifies the relationship between changes in the quality or quantity of a particular ecosystem good or service with changes in market value of production.
eradication	the complete removal ***of all living representatives*** of a species that is becoming (or is likely to become) invasive in a specified area or country
establishment	a phase (between ***introduction*** and ***naturalisation***) in the (gradual) settling of a species in a new area such that it is able to reproduce without human assistance
existence values	a component of *Total Economic Value*: the intrinsic value of environmental or natural resources, regardless of their current or future use possibilities.
externality	the positive or negative consequence of an economic activity that is experienced by unrelated third parties, that is not reflected in the price of the goods or services being produced and for which no compensation is paid or received
financial analysis	examines the effects of projects, programmes and policies on costs and benefits to the private returns accruing to a particular individual or group, valued according to financial prices.
financial values	values measured at market prices, as outflows or inflows to a particular individual or group.
hedonic pricing valuation techniques	a *Surrogate Market approach* technique for valuing ecosystems or environmental resources that values ecosystem goods and services by relating their presence or quality to other prices, for instance housing property or wages.
'hitchhiker'	a biological specimen that is carried into a new ecosystem, without the knowledge of the person involved. 'Hitchhikers' usually are carried by or in another species, or in vessels, vehicles, shipping materials or otherwise
habitat	the environment of a species or population – usually within a larger system, the ecosystem
indirect values	a component of *Total Economic Value*: environmental services which maintain and protect natural and human systems.
internal rate of return (IRR)	a measure of project desirability or profitability: the *discount rate* at which a project's *Net Present Value* becomes zero.
introduction	the passage of a species into a new area/ecosystem/country in which it becomes alien or exotic
invasion	species invasion or biological invasion is the action of an invasive species as its population increases in size and spread and begins to have negative impacts on the ecosystem it has entered

invasive species	a species that causes harm in an ecosystem by entering or affecting the stability of other parts of the ecosystem, whether by uncontrolled reproduction or by other means. Invasive species are often alien to a country, but some native species may become invasive, where external factors alter the ecosystem so that they become "alien".
invasiveness	the characteristic(s) of a species that enable its ability to invade an area or ecosystem
management of an invasive species	actions to reduce the size, impacts and/or effects of a species invasion once that invasion has become established
marginal benefit	the change in benefit associated with consuming one additional unit of a good or service.
marginal cost	the change in cost associated with producing one additional unit of a good or service.
marginal value	the change in value resulting from one more unit of a good or service produced or consumed.
market price valuation techniques	a technique for valuing ecosystems or environmental resources by using its market price: how much it costs to buy, or what it is worth to sell.
mitigative or avertive expenditure valuation techniques	a *Cost Based approach* technique for valuing ecosystems or environmental resources that assesses the value of ecosystem goods and services by calculating the cost to mitigate or avert economic losses resulting from their loss.
multi-criteria analysis	a decision tool that integrates and weights different types of monetary and non-monetary information, based on ecological, social and economic criteria: economic valuation of ecosystem goods and services can be incorporated as one of these criteria.
native species (= indigenous species) (see "acclimatised species), above)	a species that is assumed be intrinsically part of the ecosystem, owing to having developed there, having arrived in the area long before record of such matters was kept, having arrived by natural means (unaided by human action), etc. = an indigenous species
naturalisation	the process by which an alien species becomes a (new) part of a local fauna or fauna, reproduces and spreads without human assistance: see "acclimatised species", above
net present value (NPV)	a measure of project desirability or profitability: the sum of *discounted* net benefits and costs of a project.
opportunity cost	the value to the economy of a good, service or resource in its next best alternative use.
option values	a component of *Total Economic Value*: the premium placed on maintaining environmental or natural resources for future possible uses some of which may not be known now, over and above the direct or indirect value of these uses.
pathways	kinds of human action that result in (and/or enable) the introduction (intentional or unintentional) of an alien species to a new ecosystem, area or country
pest	Any species (or other related taxon such as subspecies, strain, biotype) of plant, animal or micro-organism (including pathogens) that is injurious to plants, animals and human activities
polluter pays principle	the individual or company who is responsible for introducing or spreading invasive species should bear the costs of measures to prevent, eradicate, contain or manage that species and to mitigate and remediate the damage it gives rise to

precautionary approach	as contained in Principle 15 of the Rio Declaration on Environment and Development and reiterated in the Convention on Biological Diversity: "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".
prevention	the stoppage of an organism from entering a country, area or ecosystem because it has been deemed to be a potential pest, pathogen or invasive species
private good	a good which, if consumed by one person, cannot be consumed by another. the benefits of a private good are both divisible and excludable.
production function approaches to valuation	a group of techniques for valuation that attempt to relate changes in the output of a marketed good or service to a measurable change in the quality of quantity of ecosystem goods and services through establishing a biophysical or dose-response relationship between ecosystem quality, the provision of particular services, and related production, including *effect on production* methods.
public good	a good whose benefits can be provided to all people at no more cost than that required to provide it for one person. the benefits of a public good are indivisible, and people cannot be excluded from enjoying them.
replacement cost valuation techniques	a *Cost Based approach* technique for valuing ecosystems or environmental resources that assesses ecosystem values by determining the cost of man-made products, infrastructure or technologies that could replace ecosystem goods and services.
reproductive capacity	the relative ability of an organism to produce viable offspring (measured by numbers of offspring or their rate of survival to the stage of reproduction)
restoration of invaded ecosystems	return of an ecosystem impaired by biological invasion to a former state of health or preferred and agreed status
risk-benefit analysis	a decision tool that focuses on the prevention of events carrying serious risks and assesses the costs of inaction as the likelihood of the specified risk occurring.
shadow prices	prices used in economic analysis, when market price is felt to be a poor estimate of "real" economic value.
stated preference approaches to valuation	a group of techniques of valuation that ask consumers to state their valuation of or preference for specific ecosystem goods and services directly, including *contingent valuation*, *conjoint analysis* and *choice experiments* methods.
surrogate market approaches to valuation	a group of techniques of valuation that look at the ways in which the value of ecosystem goods and services are reflected indirectly in people's expenditures, or in the prices of other market goods and services, including *travel cost* and *hedonic pricing* methods.
taxon	the group in which an organism is classified (such as species, genus, family)
total economic value (TEV)	the sum of all marketed and non-marketed benefits associated with an ecosystem or environmental resource, including *direct, indirect, option and existence values*.
travel cost valuation techniques	A *Surrogate Market approach* technique for valuing ecosystems or environmental resources that takes the costs people pay to visit an ecosystem as an expression of its recreational value.
vectors	agents that transport or assist the movement of a species along a pathway towards introduction (to a new ecosystem)
weed	a plant that is growing where it is not "wanted"; a plant pest (see "pest", above)

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