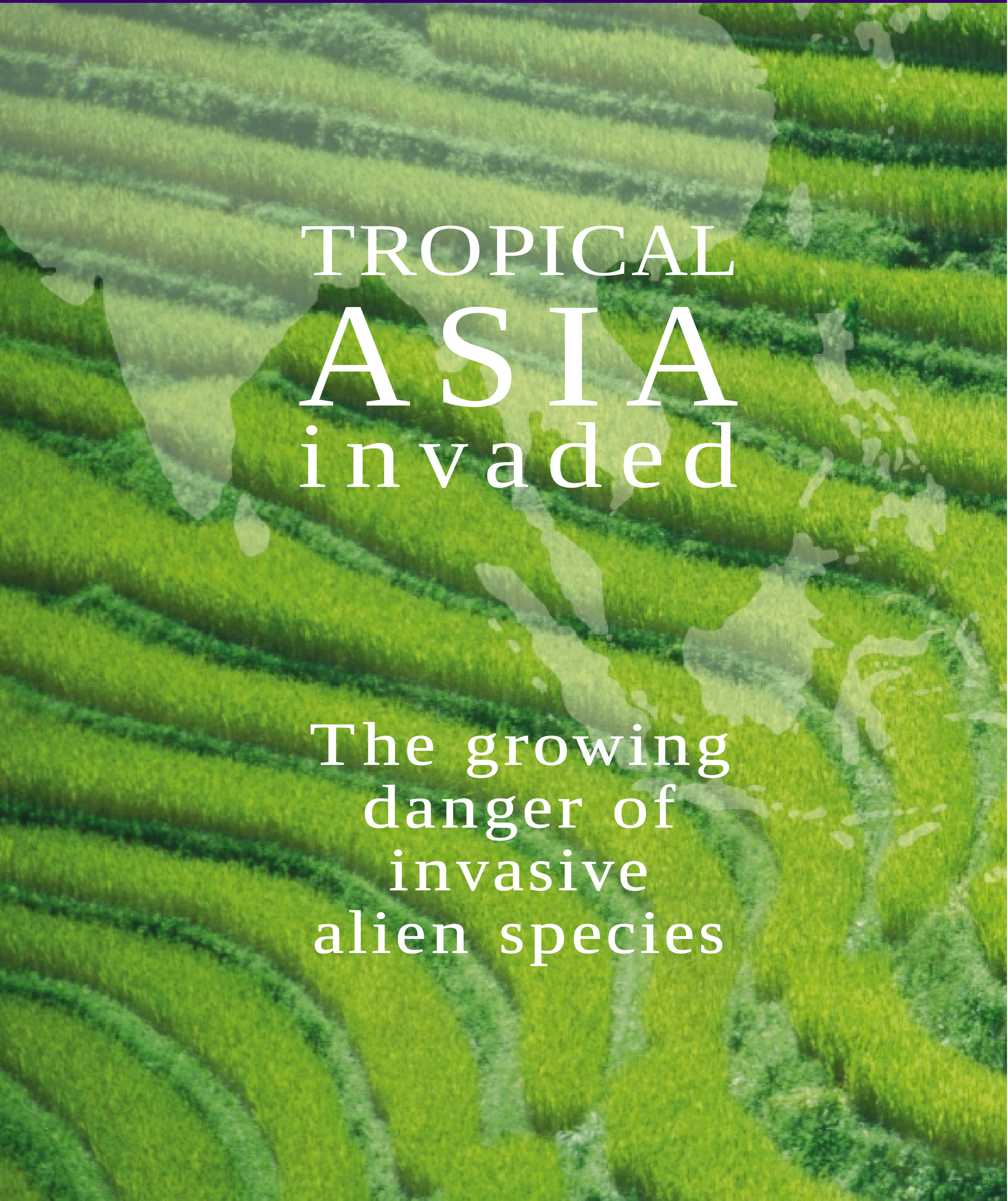
GISP

The Global Invasive Species Programme



TROPICAL ASIA invaded

The growing danger of invasive alien species

GISP

The Global Invasive Species Programme

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ACKNOWLEDGEMENTS

First published in 2004 by the GISP Secretariat

GISP wants to thank our partner organisations, the World Bank and the many individuals who helped make this publication a reality, giving their time and expertise freely despite busy work schedules and other commitments.

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Numerous people and organisations kindly made their photographs available. These include: Dr Xie Yan, Working for Water, The Ukuvuka Campaign, Photo Access, CSIRO, ISSG and the many websites that so kindly make their photographs available to non-profit organisations.

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Financial Support:
The World Bank through its Development Grant Facility and the Bank-Netherlands Partnership Programme

Special Thanks to:
Dr Xie Yan
Dr Wai Hong Loke and the rest of the CABI - SEARC team
Dr Sean Murphy from CABI
The GISP Board and Secretariat
The Globallast Programme in South Africa
Working for Water
The South African National Biodiversity Institute
Authors of previous GISP publications, notably the Global Strategy and GISP Toolkit and the South-Southeast Asia Proceedings of a workshop on forging cooperation throughout South and Southeast Asia and National Reports and Directory of Resources publications.

FOREWORD

'Invasive' and 'Alien' – these are indeed two highly dramatic and powerful words. Applying these powerful descriptors to species has certainly given them a lot of prominence. Thus, it is not surprising that Invasive Alien Species (IAS) are becoming more important on the global agenda, attracting greater attention and demanding more committed actions in dealing with them for the protection of biological diversity, economic endeavors, human health and the environment.

Invasive alien species impact on a multitude of sectors and know no political boundaries. They are not a new development but have existed for quite a while, for example, in the form of 'exotic pests' in agriculture. The modernization of travel, transportation and trade – coupled with climate change – has allowed these invaders to spread even faster and wider, often with alarming, devastating and irreversible consequences. Moreover, various international development and regional economic collaboration activities have also fueled the far-reaching dispersal of these organisms.

Tropical Asia is a region of mostly developing and emerging economies, many of which are dependent on agricultural, forestry, fishery and aquacultural resources as well as on ecotourism for growth, development and economic prosperity. Tropical Asia also boasts four of the twelve megadiversity centres of the world. Thus, the issue and threat of invasive alien species are very real and significant as exemplified by cases such as the golden apple snail, oriental fruitfly, shrimp whitespot virus, water hyacinth, avian influenza virus, severe acute respiratory syndrome (SARS) virus and many others. The publication of this book by the Global Invasive Species Program (GISP) is, therefore, very timely to further promote awareness, focus and action on this destructive scourge across a wide spectrum of communities in tropical Asia.

Since its inception, the GISP has forged an effective international partnership to coordinate and facilitate responses to the growing threat of invasive alien species. With the successful publication and dissemination of its book 'Africa Invaded', the GISP has continued to progress its mandate and responsibility of addressing the IAS issue regionally and globally. This edition on tropical Asia is testimony to the commitment of the GISP and its founding partners to raising awareness and offering their services to promote and facilitate the implementation of relevant provisions of the Convention on Biological Diversity. This book will also provide continued impetus in consonance with other activities for concerted actions to be taken in what will be a long-drawn war against invasive alien species.

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The Global Invasive Alien Species Issue

Those alien species that become established in a new environment, then proliferate and spread in ways that are destructive to human interests and natural systems are considered "invasive alien species" or IAS.

The spread of invasive alien species (IAS) is now recognised as one of the greatest threats to the ecological and economic well-being of the planet. These species are causing enormous damage to biodiversity and the valuable natural agricultural systems upon which we depend. Direct and indirect health effects are increasingly serious and the damage to nature is often irreversible. The effects are exacerbated by global change and chemical and physical disturbance to species and ecosystems.

Continuing globalisation, with increasing trade, travel, and transport of goods across borders, has brought tremendous benefits to many people. It has, however, also facilitated the spread of IAS with increasing negative impacts. The problem is global in scope and requires international cooperation to supplement the actions of governments, economic and public sectors and organisation at national and local levels.

Invasive species occur in all major taxonomic groups, including viruses, fungi, algae, mosses, ferns, higher plants, invertebrates, fish, amphibians, reptiles, birds and mammals. Even though perhaps only a small percentage of species that are moved across borders become invasive, these may have extensive and long-lasting impacts.

Environmental costs

Invasive alien species can transform the structure and species composition of ecosystems by repressing or excluding native species, either directly by out-competing them for resources or indirectly by changing the way nutrients are cycled through the system. IAS can affect entire systems; for example, when invasive insects threaten native species of insects, they can also have cascading effects on insect-eating birds and on plants that rely on insects for pollination or seed dispersal.

Increasing global domination by a relatively few invasive species threatens to create a relatively homogeneous world rather than one characterised by great biological diversity and local distinctiveness.

No criteria have yet been agreed upon for the minimum damage, spread or size of population needed for an alien species to be considered invasive. However, it is clear that a very small number of individuals, representing a small fraction of the genetic variation of the species in its native range, can be enough to generate, through its reproduction and spread, massive environmental damage in a new environment.

Economic costs

Invasive alien species have many negative impacts on human economic interests. Weeds reduce crop yields, increase control costs, and decrease water supply by degrading water catchment areas and freshwater ecosystems. Tourists unwittingly introduce alien plants into national parks, where they degrade protected ecosystems and drive up management costs. Pests and pathogens of crops, livestock and trees destroy plants outright, or reduce yields and increase pest control costs. The discharge of ballast water introduces harmful aquatic organisms, including diseases, bacteria and viruses, to both marine and freshwater ecosystems, thereby degrading commercially important fisheries. And recently spread disease organisms continue to kill or disable millions of people each year, with profound social and economic implications. GISP has not sought to estimate an aggregated economic cost of invasions globally, but one study for the USA estimates costs of US$137 billion per year from an array of invasive species.

Considerable uncertainty remains about the total economic costs of invasions. However, estimates of the economic impacts on particular sectors indicate the seriousness of the problem. The varroa mite, a serious pest in honeybee hives, has recently invaded New Zealand and is expected to have **an economic cost of US$267-602 million**, forcing beekeepers to alter the way they manage hives. Beekeepers argue that had border rules been followed or had surveillance detected the mite earlier, the problem could have been avoided entirely. It now appears too late to eradicate the mite, requiring a mitigation plan that is expected to cost US$1.3 million in its first stage.

A 1992 report by the Weed Science Society of America estimated that the total **cost of invasive weeds was between US$4.5 billion and $6.3 billion**. While the range of these figures indicates their uncertainty, they also indicate the order of magnitude of impact and argue for significant investments to prevent the spread and proliferation of these species.

In addition to the **direct costs** of management of invasives, the economic costs also include their **indirect environmental consequences and other non-market values**. For example, invasives may cause changes in ecological services by disturbing the operation of the hydrological cycle, including flood control and water supply, waste assimilation, recycling of nutrients, conservation and regeneration of soils, pollination of crops, and seed dispersal. Such services have both current use value and option value (the potential value of such services in the future). In the **South African Cape Floral Kingdom**, the establishment of invasive tree species decreases water supplies for nearby communities, increases fire hazards, and threatens native biodiversity justifying government expenditures of **US$40 million per year for manual and chemical control**.

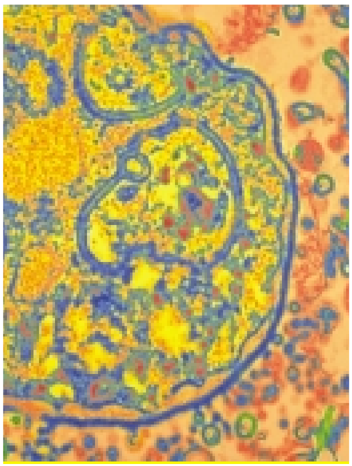
Although the loss of crops due to weeds or other alien pests may be reflected in the market prices of agricultural commodities, such costs are seldom paid by the source of the introductions. Rather, these costs are negative "externalities", i.e., costs that an activity unintentionally imposes on another activity, without the latter being able to extract compensation for the damage received. One special feature of biological invasions, as externalities, is that the costs of invasions are largely self-perpetuating, once they are set in motion. Even if introduction ceases, damage from the invasives already established, continues and may increase.

Most evidence of economic impact of IAS comes from the developed world. However, there are strong indications that the developing world is experiencing similar, if not proportionally greater, losses.

Invasive alien insect pests, such as the **white cassava mealybug and larger grain borer in Africa, pose direct threats to food security**. Invasive weeds constrain efforts to restore degraded land, regenerate forests and improve utilisation of water for irrigation and fisheries. Water hyacinth and other alien water weeds affecting water use currently **cost developing countries over US$100 million annually**.

Further, many introductions are unintentional, including most invertebrates and pathogens. Prices or markets cannot readily reflect the costs of these introductions. But

even in the case of introductions involving deliberate imports to support agriculture, horticulture, forestry, and fisheries, market prices for seeds, plants, or foods, do not generally reflect the environmental risks associated with their use. Thus producers have little financial incentive to take account of the potential cost of the loss of native species or disturbance to ecosystem functions. The policies developed to deal with conventional externalities involved in the general problem of biodiversity loss – such economic tools as taxes, subsidies, permits, and so forth – may not always be well suited to deal with the problem caused by invasions. This point highlights the urgent need for new economic approaches to deal with IAS.



AIDS virus

Human health costs

The dynamism among invasive pathogens, human behaviour, and economic development are complex and depend on interactions between the virulence of the disease, infected and susceptible populations, the pattern of human settlements, and their level of development. **Large development projects**, such as dams, irrigation schemes, land reclamation, road construction and population resettlement programmes, have contributed to the invasion of **diseases such as malaria, dengue, schistosomiasis and trypanosomiasis**.

The clearing of forests in tropical regions to extend agricultural land has opened up new possibilities for wider transmission of viruses that carry haemorrhagic fevers that previously circulated benignly in wild animal hosts. Examples include Argentine haemorrhage fever, "Guaranito" virus, Machupo virus, and Basia virus. Some pathways for the biotic invasion are complicated. For example, the prevalence of **lymphatic filariasis in the southern Nile Delta** has increased 20-fold since the building of the Aswan dam in the 1960s. This increase has been due primarily to the increase in breeding sites for the mosquito vector of the disease following the rise in the water table **caused by the extension of irrigation**. The problem has been exacerbated by increased pesticide resistance in the mosquitoes, due to heavy agricultural pesticide use and by rural-to-urban commuting among farm workers. Thus invasive species combined with variations in inter-annual rainfall, temperature, human population density, population mobility and pesticide use all contribute to one of the most profound challenges of invasive species: the threat to human health.

Infectious disease agents often, and perhaps typically, are invasive alien species. Unfamiliar types of infectious agents, either acquired by humans from domesticated or other animals, or imported inadvertently by travellers, can have devastating impacts on human populations. Pests and pathogens can also undermine local food and

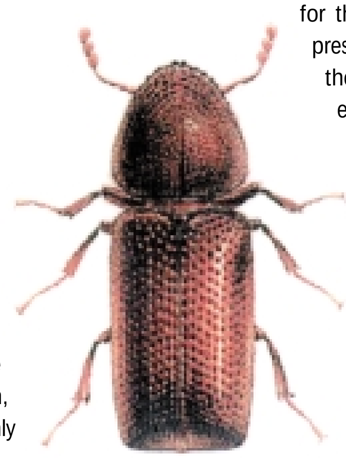
European green crab

livestock production, thereby causing hunger and famine.

Indirect health affects associated with IAS include the use of broad spectrum pesticides against invasive pests and weeds. Free from their natural controlling factors, these organisms often reach sustained outbreak levels that encourage widespread and chronic pesticide use.

Addressing the IAS issue

The spread of invasive alien species is creating complex and far-reaching challenges that threaten both the natural biological riches of the earth and the well-being of our people. While the problem is global, the nature and severity of the impacts on society, economic life, health, and natural heritage are distributed unevenly across nations and regions.



Larger grain borer

Some aspects of the global IAS problem require solutions tailored to the specific values, needs, and priorities of nations while others call for consolidated action by the larger world community. Preventing the international movement of invasive alien species and coordinating a timely and effective response to invasions **requires cooperation and collaboration among governments, economic sectors, non-governmental organisations, and international treaty organisations.**

At the national level, consolidated and coordinated action is required. This could be part of a national **biodiversity strategy and action plan**, with close involvement of the economic sectors and identifying people responsible for operative actions involving potential IAS as a key prerequisite. Clear responsibilities for each relevant sector would need to be identified.

Insurance mechanisms and liability regulations for the spread of IAS are almost non-existent, presenting a major deficiency for controlling the problem. Governments should therefore be encouraged to cooperate with the insurance sector to find solutions, beginning with feasibility studies.

Capacity and expertise to deal with IAS are not yet sufficient in many countries. Further **research on and capacity building** around the biology and control of IAS and biosecurity issues therefore need to be given attention and priority. This also relates to financial institutions and other organisations responsible for environment and development co-operation, at national and international levels.

A global information system regarding the biology and control of IAS is also required. Tools, mechanisms, best management practices, control techniques and resources need to be provided and exchanged. Such a proposed system is currently linked to the **Clearing House Mechanism of the Convention on Biological Diversity**.

Awareness raising and education regarding IAS should be given high priority in action plans, and development of economic tools and incentives for prevention are urgently needed.

The Convention On Biological Diversity

Numerous international instruments, binding and non-binding, have been developed to deal with aspects related to the IAS issue. The most comprehensive is the Convention on Biological Diversity (CBD), which calls on its parties – 188 governments as of 2004 – TO PREVENT THE INTRODUCTION OF, CONTROL OR ERADICATE THOSE ALIEN SPECIES WHICH THREATEN ECOSYSTEMS, HABITATS, OR SPECIES (Article 8h).

The CBD was one of the main results of the UN Conference on Environment and Development, held in Rio de Janeiro in 1992, and it entered into force in 1993.

The CBD commits governments to:

- take appropriate measures to conserve biological diversity
- ensure the sustainable use of biological resources, and
- promote the fair and equitable sharing of benefits arising from the use of genetic resources.

Under the CBD, governments agree to:

- prepare national biodiversity strategies and action plans
- identify genomes, species, and ecosystems crucial for conservation and sustainable use
- monitor biodiversity and factors that are affecting biological systems
- establish effectively managed systems of protected areas
- rehabilitate degraded ecosystems
- exchange information
- conduct public information programmes, and
- implement various other activities to meet the objectives of the CBD.

A set of guidelines entitled 'Guiding principles for the prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species' has been developed to assist countries with the implementation of Article 8(h). These guidelines can be found as an Annex to Decision VI/23 of the 6th meeting of Contracting Parties.

The Global Invasive Species Programme – GISP

The GISP mission is to conserve biodiversity and sustain human livelihoods by minimising the spread and impact of invasive alien species (IAS).

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.**

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 tools for quantifying the impact of invasive species.**

The goal of GISP is to enable governments and other organisations to use the best practices available to control IAS and to promote the development of additional tools and strategies needed to improve global management of IAS. GISP recognises that it is dealing with dynamic ecosystems; it does not advocate attempts to "freeze" any particular ecosystem in an imagined pristine state. Rather, it realises that active management of human effects on ecosystems is required in a time of increasing human impact.

Key GISP activities:

- GISP is in essence a facilitating and enabling body supporting a variety of global players in the IAS field. To this end, the GISP Secretariat works closely with various partner organisations all over the world, including the IUCN, CABI, TNC, SCOPE, the CBD, UNEP, IMO, SPREP, ISSG and many others.
- The newly established GISP Secretariat is based in Kirstenbosch Gardens in Cape Town, South Africa, where it is hosted locally by the South African National Biodiversity Institute. Apart from facilitating IAS work, the Secretariat supports work in the areas of communications, education and training, information management, IAS management, evaluation and assessment, economics and law and policy. Within South Africa, GISP has a special partnership with Working for Water – a highly successful local IAS and capacity building programme.
- A key focus for GISP is to support the implementation of relevant international legal instruments such as the Convention on Biological Diversity, in particular by acting as the focal point on IAS for its Clearing House Mechanism.
- A variety of multi-lingual publications and tools are developed and disseminated by GISP, including procedural best practice manuals, toolkits, educational material and regional / thematic specific information packages.

www.gisp.org

TROPICAL ASIA invaded

A GISP Publication

This publication is a product of the GISP Secretariat in cooperation with the GISP Board and Partnership Network. It is designed to be part of a series of similar publications, focusing on various regions, continents and / or specific ecosystems around the world, with a strong focus on the developing world. Further, it should be seen as part of a wider awareness raising and information programme within GISP, complementing other GISP projects and documents like the GISP Global Strategy and the GISP Toolkit, both available in various languages from the GISP website (www.gisp.org).

The publication aims to raise general awareness in tropical Asia and elsewhere about some of the more prominent IAS issues facing the continent today. It is not a technical document, but rather aims to demonstrate the diversity of the IAS issue to a broad audience, including decision and policy makers, government departments and the general public. Focusing not on a list of top invaders, but rather showcasing diverse species, affecting different ecosystems and regions within tropical Asia, it only highlights a small percentage of the IAS invading this region today. What becomes evident is that the IAS issue in tropical Asia is enormous both in terms of the number and diverse range of species invading the region, and of their impact on the health and livelihoods of its people.

Addressing the IAS issue in tropical Asia clearly requires both national and international action, and it is the goal of GISP to assist the region in raising awareness of this pressing need.

WATER HYACINTH

The water hyacinth *Eichhornia crassipes* is considered the world's worst invasive aquatic weed. Indigenous to the Amazon Basin of South America, it was introduced to many parts of the world as an ornamental plant, and today occurs in more than fifty countries on five continents.

The plant thrives in still and slow-moving waterbodies that have become nutrient-enriched through eutrophication. Dense mats of water hyacinth now blanket many of tropical Asia's natural and man-made waterbodies.

A watery existence

Water hyacinth is a perennial aquatic weed that is usually free-floating, although its long, feathery hanging roots may anchor it in shallow water. Individual plants are typically 100-200 mm high, but can reach a height of 1 m when growing in dense mats. The showy flowers are lilac-blue with yellow markings, and each produces about 300 seeds.

The seeds sink after being released from the seed capsule and can remain viable for up to 20 years, contributing to the plant's success as an invader. Once a seed germinates on moist sediments or in warm shallow water, the plant grows quickly and can flower within 10 to 15 weeks. Vegetative reproduction allows the population to increase rapidly, the plants budding to form daughter plants that break off and become entangled in dense mats. Individual plants or small clumps of water hyacinth may disperse downstream and can easily spread to new areas during floods.

Devastating impact

Water hyacinth infestations are associated with a variety of socio-economic and environmental impacts. Dense mats that block waterways inhibit boat traffic, with the result that they disrupt trade, fishing and recreational activities. Agricultural production can also be affected as the plant is a weed of wetland crops such as rice and jute, and often clogs irrigation canals and pumps.

The mats threaten hydro-electric power schemes, and increase siltation of rivers and dams by impeding water flow and trapping particles in suspension. They adversely affect the quality of drinking water, and pose a health risk by creating conditions suitable for mosquitoes and other vectors of disease.

The thick mats reduce light penetration into the water, which causes a decline in phytoplankton concentrations

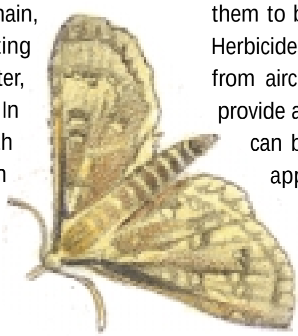
that support the zooplankton-fish food chain, resulting in ecosystem changes. Rotting material depletes oxygen levels in the water, further impacting aquatic biodiversity. In addition, vast quantities of water hyacinth can damage road and rail bridges when swept downriver during floods.

Physical and chemical control

As a readily available resource, water hyacinth has been used in paper, rope, basket and biogas production, as fodder for livestock, as mulch and compost for crop cultivation, and as a biological filter in water treatment schemes. Although some of these uses are successful as cottage industries, they are rarely commercially viable on a large scale. This is because water hyacinth is more than 90% water, so it is not cost-effective to remove and transport.

Manual removal of water hyacinth, although very labour-intensive, can be useful in controlling small infestations. Yet even mechanical harvesters are impractical in infestations larger than a hectare, due to the rapid rate of increase of the weed. These machines are also very expensive to purchase and operate – approximately US$600-1200 per hectare, which is six times more expensive than chemical control using glyphosate. Nevertheless, mechanical harvesters are successful in some areas, particularly near ports and hydroelectric power plants. The harvested material must be removed for utilisation or proper disposal to prevent plants and seeds returning to the water.

Booms or cables spanned across the river can also be used to accumulate plants moving downstream, allowing them to be more easily removed or chemically controlled. Herbicides such as glyphosate, diquat and 2,4-D, sprayed from aircraft, boat-mounted units or knapsack sprayers, provide a relatively cheap control option, and rapid results can be obtained. However, although relatively safe if applied by skilled operators, these herbicides are non-selective, and require ongoing follow-up spraying to control reinfestation.



The water hyacinth moth *Niphograpta albiguttalis*

The *Neochetina* weevil

Biological control – a sustainable option

Biological control is the only control option that is sustainable in the long term. The most effective biocontrol agents are the weevils *Neochetina eichhorniae* and *N. bruchi.* The adult weevils feed on the leaves of water hyacinth, while the larvae eat their way down the petioles (leaf stems) and into the crown, the growth point of the plant. This feeding damage stunts growth, impedes reproduction of the plants, and at high intensities causes them to rot, die and sink. Wind and wave action helps to break up water hyacinth mats already weakened by the weevils.

Another biocontrol agent widely introduced in Asia is the moth *Niphograpta albiguttalis (= Sameodes albiguttalis).* The adult moth does not feed during its short lifespan (4-9 days), but the larvae feed initially on the leaf surfaces and then bore through the petioles and buds, down into the crown, having much the same effect as the weevils.

Under ideal conditions, the weevils and the moth can bring water hyacinth under complete control within a few years. Unfortunately, the two weevils have different tolerances to climatic and eutrophic environments, while the moth prefers feeding on young or actively growing plants that are not always found in mature infestations. In order to supplement the effectiveness of these biocontrol agents,

Damage by *Niphograpta albiguttalis* larvae

Mechanical control of water hyacinth

a number of other natural enemies of water hyacinth – both arthropods and fungal pathogens – have therefore been introduced or are being considered for release.

However, in many instances the failure of biological control can be attributed to inappropriate integration with chemical and mechanical control, which may negatively impact the population of biocontrol agents. It is imperative, therefore, that integrated management plans for water hyacinth control are implemented on a site-specific basis. Furthermore, since eutrophication and reduction in water flow creates a stable and nutrient-rich environment in which the weed flourishes, these plans should include nutrient and hydrological control where possible.

The infestation of water hyacinth is a growing problem world-wide. An African example shown below.

Before infestation by water hyacinth

After infestation by water hyacinth

The power of the people

Nowadays, manual removal of water hyacinth is only recommended for small, isolated infestations, as this is a prohibitively labour-intensive means of control. But one uplifting success story is testimony to the results that can be achieved with many helping hands.

Water hyacinth was introduced to Bengal – today part of Bangladesh and India – towards the end of the 19th century, and by the 1920s had invaded all the region's waterbodies. The weed blocked rivers and interfered with agricultural activities, with the result that the economy showed signs of stagnation. It soon became clear that drastic measures were called for, and in 1936 the government promulgated the Water Hyacinth Act. This legislation not only prohibited householders from keeping or tolerating the weed on their property, but made cooperation with government-sponsored clearing drives a public duty. The people responded enthusiastically, and thousands turned out to volunteer. In the run-up to the elections a year later, all the major political parties pledged to eradicate water hyacinth. The elected politicians stuck to their promises, and the clearing drives were intensified. The removed material was valued as a fertiliser, which further encouraged people to harvest the weed.

By 1947 water hyacinth was brought under control, and over the next decade the rivers became navigable once more.

Giant salvinia *Salvinia molesta* is a free-floating water fern that is native to Brazil. It was widely introduced as an ornamental plant for ponds and aquaria, and has become a serious weed in many of the warmer regions of the world. In Asia it is classified as invasive in a number of countries, including India, Pakistan, Sri Lanka, the Philippines, Papua New Guinea, Indonesia and Malaysia.

A giant problem

Giant salvinia thrives in warm, nutrient-rich standing or slow-flowing waters. The plants grow rapidly, and in ideal conditions may double in size every two to five days. In the early stages of an infestation, the plants are small and have green leaves that lie almost flat on the water surface. Over time the leaves turn yellowish-green to brown and fold, causing them to interlink when pressed together in dense infestations. The resulting mats – sometimes up to a metre thick – tend to block waterways, obstructing boat traffic and disrupting fishing activity. They impede access to water by rural communities and their livestock, and clog intake pipes for water supply facilities, irrigation schemes and hydroelectric power plants. They also pose a health risk as they provide habitat for mosquitoes and other vectors of disease.

Apart from these socio-economic impacts, the dense mats have a variety of negative effects on the environment. They outcompete indigenous species by crowding out floating weeds and reducing the light available to submerged plants and phytoplankton. By blanketing the surface of waterbodies, they prevent atmospheric oxygen from entering the water. As the plants die and sink to the bottom, bacterial decomposition further depletes oxygen levels, creating conditions unsuitable for invertebrates and fish. The overall effect is a decline in water quality and a reduction in biodiversity.

Salvinia before and after treatment

Control

Giant salvinia reproduces vegetatively, and is able to regenerate from any fragment that includes a node. This facilitates its spread by water currents, by birds and mammals, and by boats and vehicles that enter infested waters. It also makes control very difficult, as a small piece left behind can cause a reinfestation. For this reason any removed material should be left to dry, and then burned or buried well away from the water. However, physical control is generally only feasible for small infestations, as the plant outgrows most efforts.

A number of herbicides have proved effective for chemical control of giant salvinia, but these may put other species at risk as they are non-selective. In addition, mass die-off of the weed can negatively impact on water quality.

Biological control using the host-specific weevil *Cyrtobagous salviniae* is the most sustainable option for controlling giant salvinia. The adult weevils, which are only about 2 mm long, feed on leaf buds and young terminal leaves, while the larvae tunnel in the rhizome and also feed externally. The resulting feeding damage causes the plants to become waterlogged, and they eventually sink. Control is usually achieved within one to three years in warm environments. However, the weevils and their eggs cannot survive extremes of temperature.

A Biological Control Success Story

The Sepik River in Papua New Guinea is one of the world's major river systems, with more than 1500 lakes and dozens of tributaries. Its catchment extends over 77 000 km^2, and the river is navigable for some 500 km upstream of its mouth on the northern coast of the island of New Guinea.

Cyrtobagous salviniae

The people of the region are heavily dependent on the river for their livelihood, using it as a source of food and a means of travel. But during the past few decades this relationship has been threatened by the invasion of two different aquatic weeds.

First came giant salvinia, believed to have been introduced by a missionary who threw the contents of a fish tank into the river. By 1977, 32 km^2 of the river was covered with the weed, and by 1979 this had increased to 79 km^2, resulting in severe food shortages in local communities. The dense mats of salvinia not only restricted fishing activity, but also limited access to subsistence gardens, hunting areas and food markets. There were even cases of sick people dying because they were unable to reach medical assistance in time. Some villages had to be abandoned altogether and the inhabitants integrated into neighbouring communities, creating a ripple-effect of social disruption.

In 1982 a biological control programme was initiated, using the weevil *Cyrtobagous salviniae*. The biocontrol agent soon became established in the areas surrounding the programme's headquarters in the lower reaches of the river, but the challenge was then to distribute it to the rest of the river system. Local communities came to the rescue, responding to a radio-transmitted call to collect bags of weevil-infested salvinia to take back to their home waters. A small plane was also used to ferry such material to mission airstrips further afield, from where it could be distributed by canoe. Before long the weevil was well established in all areas invaded by salvinia, and ultimately achieved spectacular results in control of the weed.

Unfortunately, the communities' revived relationship with the river was short-lived, because a second alien aquatic weed launched an invasion. Water hyacinth was first recorded in Papua New Guinea in 1962, and in 1984 was detected in the lower reaches of the Sepik River. By 1991 the weed was blocking large areas of the middle and lower floodplains, with devastating socio-economic and environmental consequences.

Once again, biological control saved the day. During the first five years of the programme, which started in 1993, 450 000 *Neochetina eichhorniae* and *N. bruchi* weevils were released. Water hyacinth infestations were reduced from approximately 27 km^2 to about 7 km^2, and even the worst-affected lagoons were left with only a narrow fringe of the weed.

ALLIGATOR WEED

The Alligator weed *Alternanthera philoxeroides* is a fast-growing perennial herb that is capable of growing on land and in water. Indigenous to the Parana River region of South America, it has become invasive in a number of Asian countries – including China, Burma, India, Thailand, Indonesia and Malaysia – as well as parts of the United States, New Zealand and Australia.

Aquatic infestations

The aquatic form of alligator weed has hollow, floating stems, which interweave to form dense mats on the water surface. These clog waterways and restrict flow in irrigation and drainage systems, with the result that they increase sedimentation and the risk of flooding. The mats frequently damage pumping equipment and sometimes affect hydro-electric power production. They impede fishing activity and recreational use of water bodies, provide habitat for mosquitoes, and are aesthetically unappealing – in China they have degraded some famous scenic sites. They also have a variety of ecological impacts, as they outcompete and displace indigenous plants, reduce water quality, prevent light penetration into the water and inhibit gaseous exchange at the air-water interface.

Alligator weed grows prolifically in nutrient-rich environments, and in flowing systems can tolerate brackish water with salinities as high as seawater. It colonises new areas when the mats break apart and float downstream, and can spread onto land when its horizontal stems grow up banks and into moist soil.

Terrestrial infestations

The terrestrial form of alligator weed produces solid, rather than hollow, stems, as well as underground rhizomes that can reach a metre in length. In unfavourable conditions the aboveground parts of the plant may die off, but the underground rhizomes and stems can remain viable and resprout at a later stage.

On land, alligator weed is a serious threat to agriculture. It is a major weed in rice paddies, reducing production by 20-63% in China. It also causes significant losses in other crops, including sweet potato, lettuce, wheat, corn, cotton, soybean and peanuts. It infests orchards, tea plantations, mulberry fields, and medicinal and herbal crops, while dense growth along banks can restrict access to water by livestock. In addition, the weed is toxic and can cause blindness of livestock, as well as skin photosensitisation in light-pigmented cattle, resulting in cancerous lesions.

Control

Alligator weed is extremely difficult to control, because the plant is able to regrow from small fragments. In aquatic environments, attempts at physical removal generally only contribute to the spread of the weed, as fragments break off and float downstream. On land, up to two metres of soil beneath the plant must be excavated to ensure that all root material is removed. Chemical control also tends to be unsatisfactory, as the weed is resistant to most herbicides. Glyphosate can be used for aquatic infestations, but does

Alligator weed

Infected river

not kill terrestrial plants, while metsulfuron methyl can be used on land but not in areas where it might result in water contamination. Generally, therefore, physical and chemical control are only viable for small, isolated infestations.

Biological control is the most promising method of controlling alligator weed. Although biological control often makes use of seed-feeding insects, the alligator weed rarely produces seed, and those that are produced are usually not viable. The most widely used biocontrol agent for this species is therefore an insect that feeds on the leaves of the plant, reducing photosynthesis and hence weakening the plant.

The flea beetle *Agasicles hygrophila* is a small beetle (5.5 - 7 mm long) with bold black and yellow coloration. The female lays on average 400 eggs, which usually hatch within a week, and the black caterpillar-like larvae disperse to feed on the surrounding plants. After about two weeks the larvae move down the plant to just above the waterline, where they burrow into the stems, plug the hole behind them, and pupate. The adult beetles emerge a week later and chew their way out of the stem, to begin feeding on the leaves.

Apart from the feeding damage to the leaves caused by both the larvae and adults, the stems become water-logged and begin rotting as a result of water entering the holes made by the emerging beetles.

The beetles serve as an effective biocontrol agent in lakes, ponds and slow-moving water, but often get washed away in flowing systems that are regularly flooded, while cold conditions either kill the beetles or reduce their ability to lay viable eggs. In ideal conditions, however, up to four generations may be produced per year.

The flea beetle *Agasicles hygrophila*

The giant mimosa *Mimosa pigra* is also called the catclaw mimosa or giant sensitive plant, because it has sensitive leaflets that fold up when touched or injured, and at night. It is due to this feature that the species has been widely introduced as an ornamental plant, although it is also used as a cover crop. The plant is indigenous to Central and South America, but has invaded many parts of the world, including large areas of south-east Asia.

An amphibious weed

Once introduced, giant mimosa spreads aggressively, as it grows rapidly, produces prolific quantities of seeds, and can thrive in both aquatic and terrestrial environments, allowing it to invade watercourses, floodplains and wetlands. The seeds are borne in bristly pods that break up into segments when mature, to facilitate their dispersal by floating downstream or by adhering to animal fur, clothing, equipment or vehicles.

The plant can grow as tall as 6 metres in moist sites and infestations can nearly double in just over a year under optimal conditions, replacing biodiversity-rich natural ecosystems with monospecific stands of mimosa. The dense, prickly thickets hamper the movements of livestock, reduce their grazing area and restrict their access to water. Aquatic infestations also tend to disrupt recreational activities, block irrigation channels and increase siltation in dams.

Control

Giant mimosa is difficult to control, because seeds can remain dormant in the soil for more than 15 years. Burning the thickets often results in mass germination of the seedbank. Furthermore, since the plants generally infest damp environments and there is no grassy understory to spread the fire, aerial application of a fuel such as gelled gasoline is usually necessary, which is costly and has secondary environmental impacts. Other methods of physical control include bulldozing and chaining to uproot the plants, but simply felling them at the base of the stem will result in regrowth unless the stump is treated with an appropriate herbicide.

Apart from cut-stump treatment, foliar-sprayed, stem-injected and soil-applied herbicides have been used in chemical control of the species. Fluroxypyr and metsulfuron methyl are often aerially applied as foliar sprays, while soil-applied tebuthiuron is sometimes recommended for use during the dry season, although it is ineffective in controlling seedlings.

A number of insect biocontrol agents and fungal pathogens have been introduced to the region for biological control of giant mimosa. The most effective are the seed-feeding beetles *Acanthoscelides quadrildentatus* and *A. puniceus*, which were released in Thailand in 1983, and subsequently spread unaided to neighbouring countries. The adult beetles feed on pollen, but the female lays her eggs on the plant's seedpods. After hatching each larvae tunnels into a seed, which it hollows out as it feeds. As much as 50% seed destruction has been observed at some sites, although 5-15% is more common.

An integrated approach to control is most successful, using biocontrol agents together with mechanical, fire and chemical techniques. For example, bulldozing can be used to break up dense stands of giant mimosa, increasing the area of stand edge for the seed beetles to colonise.

MILE-A-MINUTE WEED

The mile-a-minute weed, *Mikania micrantha*, is so named because of its incredible growth rate. Shoots have been reported to lengthen by as much as 27 mm per day, and within a few months an individual plant can cover more than 25 square metres. The plant is a climber, also known as Chinese creeper, American rope and bitter-vine. Indigenous to South and Central America, it is closely related to *Mikania scandens*, which originated in North America, and *Mikania cordata*, from south-east Asia and Africa. Mile-a-minute is the most invasive of the three species, and is a problem weed throughout the warm, humid region of south-east Asia, as well as West Africa.

Smothering habits

Mile-a-minute weed has been recorded as invasive in Bangladesh, India, Sri Lanka, Nepal, China, Malaysia, Thailand, the Philippines, Indonesia, Papua New Guinea, Borneo, and many of the surrounding Pacific Islands. It was widely introduced as a cover crop and garden ornamental, and was able to spread rapidly because of its efficient reproduction – a single plant can produce up to 40 000 seeds per year. The small, black seeds have a tuft of white bristles at one end to facilitate their dispersal by wind, or by adhering to clothing and animal fur. The plant also reproduces vegetatively, each node of the stem being able to produce roots on contact with the soil. This allows the plant to regenerate from small fragments.

The mile-a-minute weed thrives in open, disturbed areas, so it rapidly overgrows abandoned areas and is frequently found growing rampantly along roadsides. More serious, however, is its presence in plantations and forests, where it is a major pest. The weed climbs up other plants to reach the sunlit tree canopy, smothering the host plants in the process and depriving them of light needed for photosynthesis, as well as competing with them for nutrients and water. The weed also has allelopathic properties, releasing substances that inhibit the growth of other plants. As a result, it negatively impacts biodiversity in natural areas and production in agricultural and forestry areas.

The weed is especially problematic in tea crops in India and Indonesia, and rubber plantations in Sri Lanka and Malaysia. However, it also increases the cultivation costs of oil palm, pineapple, banana and cocoa, as it necessitates ongoing labour-intensive control efforts. Subsistence farmers are most seriously affected in this regard, as time-consuming hand-weeding of crops causes a decline in productivity. Timber and pulp production in teak and other commercial forestry operations are also negatively impacted by the weed.

Control

The ability of mile-a-minute to regenerate from small stem fragments makes control of the weed extremely difficult. Although infestations can be physically cleared with hand tools or mechanical brushcutters, the plant rapidly regrows. Chemical control – using herbicides such as glyphosate and 2,4-D – is complicated by the risk of killing the host plants or contaminating crops. A number of insect natural enemies have been released for biological control of the weed, and more recently the rust fungus *Puccinia spegazzinii* has shown promise as a biocontrol agent. Attack by the fungus causes leaf, petiole and stem cankering, and ultimately death of the plant.

DID YOU KNOW?

Mile-a-minute weed was deliberately introduced to India during the Second World War to camouflage airfields.

***Chromolaena odorata* – commonly called chromolaena, triffid weed or Siam weed – is one of the worst invasive plant species in the humid tropics and subtropics of the world. Its native range extends from Florida in the United States to northern Argentina, but it has invaded large parts of Africa, Oceania and Asia, where it continues to spread southward and eastward.**

Menace to agriculture

Chromolaena occurs as both a shrub standing at least 3 m tall in the open, and as a scrambler reaching a height of 10 m among trees. It grows rapidly and produces massive quantities of light, hairy seeds – more than a million per plant – which are dispersed by wind and water and by adhering to animals, humans, vehicles and machinery. The plant thrives on disturbed land and forms dense thickets that smother indigenous vegetation, reducing biodiversity. The thickets also represent a fire hazard, as the plant's leaves contain highly flammable oils and alkaloids that increase the intensity of fire.

Chromolaena decreases Asia's agricultural productivity by invading subsistence food gardens, cultivated crops, and young or neglected plantations of tobacco, cocoa, coconut, rubber and oil palm. In some areas it impacts commercial forestry operations, both by suppressing the growth of young trees through competition and by allowing fire to penetrate deeper into plantations. It also reduces grazing for livestock by invading pastures. In addition, the leaves cause acute diarrhoea of cattle when browsed, and skin rashes and irritation in some people after contact.

Control

Chromolaena control requires an integrated approach, the methods used being dependent on the size of plant and the type of vegetation infested. Repeated follow-up work is necessary, as the plant is capable of vigorous growth from stem coppice, root suckers and seed.

Seedlings and young plants can be removed by handpulling, while herbicides are available for cut-stump treatment and for foliar application to seedlings and coppice growth. An annual burning regime effectively controls chromolaena invasions in grassland by killing mature plants and preventing new seedlings from establishing.

Biological control of chromolaena in Asia initially focussed on the leaf-feeding moth *Pareuchaetes pseudoinsulata*, which proved extremely effective in some areas. The moth does not feed during its week-long lifespan and is only active at night, when it searches for a mate. The female lays large quantities of eggs, depositing them in batches of about 80 on the underside of chromolaena leaves. After hatching, the caterpillars feed on the leaves, sometimes completely defoliating plants. The resulting reduction in height and density of chromolaena allows other plant species to compete for the newly created space.

More recently the stem-galling fly *Cecidochares connexa* has been widely introduced, and appears to be

Pareuchaetes moths

Fire in triffid weed burning into a plantation

Pareuchaetes caterpillars

achieving some success in the biological control of chromoloaena. The female fly lays her eggs in the stem tips of chromolaena, and as the larvae develop the plant forms galls around them. Mature larvae pupate in the galls, and the adult fly later emerges through a thinner epidermal 'window'. The galls distort the stems and cause reduced plant growth, with heavy infestations resulting in die-back of chromolaena.

A number of other biocontrol agents have been released or are being investigated, including some fungal pathogens.

DID YOU KNOW?

Triffid weeds were walking, man-eating plants in the science-fiction book *The Day of the Triffids*, written by British author John Wyndham in the 1950s. The name was adopted for chromolaena because of the plant's monstrous, alien-invading characteristics!

Chromolaena is also called Siam weed because Thailand – formerly known as Siam – was one of the first countries in Asia to be invaded by the weed.

Exploiting military conflict

Chromolaena's insidious spread through Asia can be largely attributed to human activity during military conflict. During World War II, the initial point of invasion in coastal and island nations was typically ports used as bases by Japanese or Allied forces. In the same way, troop movements probably carried the weed into East Timor after the colony was invaded by Indonesia in 1975. By the time an Australian peace-keeping force arrived in East Timor in September 1999 to provide interim assistance during the transition to independence, dense infestations of chromolaena covered the hill-sides. A comprehensive quarantine programme was set up to minimise the risk of returning troops re-introducing the weed to Australia – an eradication campaign launched in 1994 had successfully controlled the primary invasion in northern Queensland. All clothing, personal effects, vehicles and machinery were inspected for seeds at more than 20 wash stations. Vehicles were found to be harbouring up to half a kilogramme of seeds each, mostly stuck to the radiators and undercarriage.

PARTHENIUM

***Parthenium hysterophorus*, commonly called parthenium, congress weed, carrot weed or white top, is native to Mexico. The weed was accidentally introduced to Asia, Australia and Africa – usually as seed contaminating grain shipments – and has proved to be an extremely aggressive invader. In Asia it was first detected in the 1950s, in the Indian town of Poona. It spread rapidly throughout the country, and has since invaded Bangladesh, Bhutan, Nepal, Pakistan and Sri Lanka, as well as parts of China.**

Hazardous herb

Parthenium is an herbaceous annual with an erect stem that becomes woody with age, allowing it to reach a height of two metres. It produces thousands of seeds that are readily dispersed in mud adhering to vehicles, machinery and animals, as well as by water and wind. The seeds can remain viable on the soil surface for up to two years, while buried seeds can stay dormant for as long as 20 years before germinating.

Parthenium colonises disturbed land, including overgrazed and recently ploughed or cleared areas, and because it has an allelopathic effect – the chemical inhibition of growth and seed germination of other plants – it can quickly dominate pastures and crop fields. The weed is unpalatable to livestock, so its invasion results in grazing shortages. If it is mixed in with fodder, it may taint the meat and milk, and cause severe skin and gastrointestinal irritations in cattle, buffalo and sheep.

Parthenium is also a health hazard for humans, because contact with the plant or pollen can cause allergic reactions such as dermatitis, asthma and hayfever. In the Indian city of Bangalore, for example, air samples taken over a six-year period revealed that parthenium pollen comprised 40-60% of the total pollen count, and was a major cause of allergenic rhinitis. Another study in New Delhi found that 62 out of 63 patients diagnosed with airborne contact dermatitis showed a positive reaction to parthenium.

Control

Physical control of parthenium is impractical for all but isolated plants and very small infestations, as the plant must be uprooted, which is not only labour-intensive but is hampered by the risk of allergic reactions. Furthermore, removal and disposal of plants that have already flowered may disperse the seeds, leading to new infestations.

Individual plants can be killed with foliar application of herbicides, but rapid regeneration from seed soon follows. The only successful chemical control method is to use residual soil-applied herbicides to kill pre-emergent plants, but these are non-selective and environmentally undesirable. The most favourable method of control is to maximise competition against the weed by maintaining good grass growth. In India, replacement of parthenium has been achieved by manual removal of the weed, followed by seeding with marigolds or Cassia plants.

The leaf beetle *Zygogramma bicolorata* – a chyrsomelid from Mexico – was released in India as a biocontrol agent in 1984. The adult beetles feed on the flowers and foliage, while the larvae feed inside the stem, stunting the plant's growth and reducing its competitiveness and seed production. The beetle is proving to be effective in the biological control of parthenium in certain regions and within particular climatic parameters. A number of fungal pathogens also show promise as potential biocontrol agents.

LANTANA

***Lantana camera* is indigenous to South and Central America, but was widely introduced as an ornamental plant and is now considered a weed in more than 50 countries worldwide. It has invaded most of the southern region of Asia, forming dense thickets that displace natural communities and compromise agricultural productivity.**

Weed of many colours

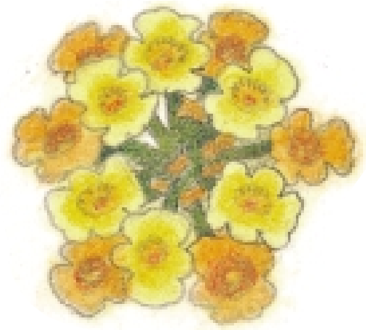
Lantana is a highly variable species, with hundreds of different cultivars that differ in appearance and in their tolerance to environmental conditions. The plant may occur as a compact shrub or a scrambler more than 5 m high, and is often used as a hedge plant because it forms impenetrable barriers. However, it is this quality that makes it such a menace when it invades agricultural land and forestry plantations. The thickets disrupt access of livestock to grazing and water, interfere with farming and forestry activities, and increase the intensity of fire. By encroaching onto pastures, they reduce the carrying capacity and productivity of agricultural land. Lantana is also a weed in a variety of crop fields and plantations, including coffee, coconuts, oil palms, rubber, bananas and sugarcane.

Furthermore, the entire plant is toxic, and ingestion of the leaves and fruit can poison cattle and sheep, exhibiting as increased sensitivity to sunlight. The soft skin of the nose, eyes, ears and lips become covered in sores that make eating and breathing painful, causing the animals to lose condition or even die.

In some areas, lantana thickets provide a breeding ground for malarial mosquitoes and other vectors of disease.

Unfriendly neighbour

Little else can grow in lantana thickets because the plant is allelopathic, releasing chemicals into the soil to prevent other species from germinating. As a result, the thickets reduce plant biodiversity and change the composition of associated animal communities. In addition, the absence of



groundcover results in increased erosion, particularly on steep slopes.

Lantana is able to spread rapidly once introduced to an area as the seeds are widely dispersed by birds, which eat the fruit, and are sometimes also washed from infested areas during floods, causing sudden invasions downstream.

Control

Lantana is difficult to control, as it will coppice and form denser thickets if it is simply slashed and left. Physical control is labour-intensive, and should only be used on its own for seedlings and small, individual plants. These can be uprooted by handpulling when the soil is moist or first loosened with a hoe, pick or fork. Uprooting of large plants or dense thickets is not recommended as it results in soil disturbance, increasing the risk of soil erosion and reinfestation by lantana seedlings and opportunistic weeds.

A combination of physical and chemical control is best used for larger plants and dense thickets. Top growth should be cut away and the plant felled close to the ground, after which the stump should be treated with a registered herbicide. Foliar application of herbicides is suitable for small lantana plants and regrowth, but for large, dense bushes it is expensive and not very successful, since the maximum height that can be reached using a knapsack sprayer is about 2 metres.

All forms of control should be followed by revegetation, ideally with indigenous groundcovers, to prevent seedlings from forming new thickets. It is also essential

LEFT: Pupa of the herringbone leafminer MIDDLE: Adult *Falconia* on lantana leaf RIGHT: Young *Falconia* nymphs on lantana leaf

that ongoing follow-up work, involving handpulling of seedlings and spot-spraying of regrowth, is conducted at least annually.

Biological control pioneer

Lantana was the first weed to be targeted for biological control, starting in 1902. Since then, at least 40 biocontrol agents have been released in some 50 countries, but lantana remains one of the world's most vigorous invasive weed species. The most widely established biocontrol agents in Asia are the leaf-sucking bug *Teleonema scrupulosa* and the leaf-mining beetle *Uroplata girardi*. However, more insects and fungal pathogens are being trialled as potential biocontrol agents on an ongoing basis. By suppressing growth and reproduction of lantana, biological control will not only reduce the cost of conventional control, but also help decrease the invasive potential of the weed.

DID YOU KNOW?

Lantana was originally introduced to Sri Lanka in 1826 for horticultural purposes, but later it was deliberately established in the southern parts of the island nation to protect sugarcane plants from elephant damage. Today it significantly reduces the grazing area for elephants in the nearby Uda Walawe National Park – a major elephant sanctuary – and is a problem weed throughout the country.

Damage to lantana bush (foreground) caused by *Falconia*

PROSOPIS

The genus *Prosopis*, commonly known as mesquite, includes more than 40 species, most of which are indigenous to an area ranging from Argentina to the southern USA. Several species have become invasive in other parts of the world, particularly the sub-tropical *Prosopis glandulosa* and *P. velutina* and the tropical *P. juliflora* and *P. pallida*. These species have been widely introduced as a source of fuelwood, fodder and shade, and are also used for sand stabilisation, soil improvement, or for hedges to contain livestock.

Fuelwood and fodder

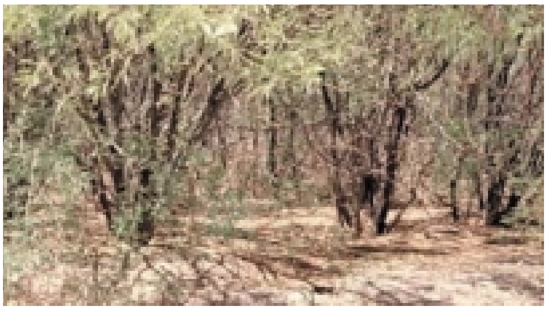
Prosopis are fast-growing, nitrogen-fixing trees that are tolerant of arid conditions and saline soils. They are valued as a source of fodder because the seed pods are a nutritious food for livestock when ripe. However, green pods are bitter and can poison livestock in large quantities, while the foliage is unpalatable due to the high tannin content.

Although individual prosopis occur as small trees, invading populations tend to form dense, impenetrable thickets made up of shrubby, multi-stemmed plants that provide minimal shade and produce fewer pods. The thickets reduce grass cover, so they limit natural grazing and hence stocking density. They also restrict the movement of livestock and obstruct their access to water, since they frequently invade watercourses. Long tap roots allow the plants to reach deep water tables, so invasive prosopis may deplete vital groundwater reserves in water-scarce environments. Furthermore, the thickets impact biodiversity by excluding indigenous vegetation and associated animal life.

The success of prosopis species as invaders is largely attributable to the massive number of seeds produced – about 60 million per hectare per year – and their efficient dispersal. Some seeds are carried far from their source by flowing water, especially during floods, but on a more local scale livestock and wild animals disperse the seeds after feeding on the pods. The hard-coated seeds are softened during their passage through the digestive tract, which enhances their germination, while the animals' droppings provide a ready supply of nutrients for the developing seedling. If the seeds fail to germinate immediately they may lie dormant in the soil for up to 10 years. Destruction of surrounding vegetation and exposure of the soil often stimulates mass germination of the soil seedbank, resulting in a sudden infestation.

A win-win solution

Prosopis is considered a valuable asset in many arid regions of Asia, where few other trees could survive, so eradication of this alien invader is generally not an option. A possible solution to the conflict of interests surrounding prosopis is



to control invasive populations and manage them as agroforestry plantations. Apart from providing fodder and fuelwood, prosopis trees may yield hard and durable timber that can be used to make furniture and parquet flooring, while the protein-rich pods can be used in the manufacture of various food products. Unfortunately, the shrubby, multi-stemmed plants typical of invasive thickets generally only yield small pieces of lower-quality wood, with a large amount of wastage. Nevertheless, the wood may be suitable for making handles for appliances, brushes and tools, as well as charcoal and wood chip products.

Control of prosopis is especially difficult because the plants can regrow from vegetative buds just below ground level. These buds sprout new shoots if the above-ground parts of the plant are damaged, with the result that a small shrub may become a dense bush if attempts at control are inefficient. The plants are therefore usually felled close to the ground, preferably below the point of branching, after which an appropriate registered herbicide is sprayed on the cut surface. Prosopis is sometimes controlled with herbicides alone, using basal bark treatment for mature plants and foliar spray for seedlings.

Two biocontrol agents – *Algarobius prosopis* and *Neltumius arizonensis* – have been introduced in some parts of the world for prosopis control. Both are seed-feeding beetles that reduce the invasiveness of prosopis plants, without affecting their useful attributes. A number of fungi that infect prosopis are also being investigated, to assess their potential for development as mycoherbicides.

Algarobius prosopis

Neltumius arizonensis

DID YOU KNOW?

In the Indian region of Rajasthan, *Prosopis juliflora* is often referred to as 'vilayati', which means 'foreign'. The region has suffered massive deforestation, and although local people are grateful that the tree has averted a serious fuel shortage, they are well aware of its negative side-effects.

'Miracle tree' or menace?

Leucaena leucocephala **– known as Ipil Ipil in parts of tropical Asia – is another tree species that is useful as a fodder and firewood resource, but is widely denigrated as a weed. It is a fast-growing, nitrogen-fixing and drought-tolerant tree that is native to Mexico and central America. Sub-species *leucocephala* arrived in Asia two centuries ago – it was reportedly introduced to the Philippines before 1815 – and is now pan-tropically naturalised. Sub-species *glabrata* was widely promoted by international agroforestry organisations in the 1970s and 1980s, and now occurs in most sub-tropical and tropical parts of the world. The plant was called the 'miracle tree' in the early years of its global cultivation, as it provides a nutritional food source for livestock. However, both the foliage and seeds contain the toxic amino acid mimosine, and can be toxic in large quantities. Leucaena tends to invade forest margins, roadsides, wasteland, riverbanks and sometimes also cultivated land, forming dense thickets that are difficult to eradicate because the plant resprouts vigorously after cutting.**

In Taiwan, populations of leucaena – introduced by the Portuguese or Dutch in the 17th century – increased rapidly during the 1980s, due to a change in land use patterns. Many pastures and fields were abandoned, so livestock were no longer feeding on leucaena leaves, while local people did not need as much fuelwood because they had electricity. Leucaena has now formed pure stands in large areas of Taiwan, and has invaded the tropical coastal forests in the extreme south of the island.

NUTRIA

The nutria *Myocastor coypus*, also called the coypu, is a large, semi-aquatic rodent with webbed hind feet. It is indigenous to South America, but was introduced to North America, East Africa, Europe and Asia for its thick, soft fur. It has established large feral populations in some areas, and is considered a pest because of its burrowing and feeding habits.

Crop losses and structural damage

After being introduced to countries outside the species' natural range, nutria were either released into the wild for subsequent recapture, or raised at fur farms, from where some probably escaped. Many were also deliberately released from fur farms after the demand for fur declined. Being able to adapt to a wide variety of environmental conditions, they soon made themselves at home in local ponds, rivers, swamps and drainage canals.

Nutria live in burrows that they dig in vegetated banks next to water, although sometimes they use those abandoned by other animals. They are herbivores with a huge appetite for plants, eating approximately 25 per cent of their body weight per day. At high densities their feeding can significantly impact natural plant communities. In some places they have even converted dense stands of reed to open water, destroying the habitat of wetland birds. They also increase erosion by digging up roots and underground tumours, which help to bind the soil together.

Furthermore, nutria cause considerable damage to crops such as rice, sugarcane, corn, soybean and vegetables, as well as some fruit trees. Their burrowing also weakens the banks of rivers, dams and irrigation canals, and may undermine building foundations and road beds. In the United States, nutria are most abundant along the Gulf Coast of Louisiana and Texas, where they frequently damage water-retaining levees in fields flooded for rice and crawfish production, as well as flood-prevention levees that protect low-lying areas. The animals also tend to gnaw on wooden structures with their large incisors, damaging buildings and jetties.

Control

The most practical method of control is to encourage people to harvest nutria. During the 1970s, when nutria pelts fetched $4 to $8 each, trappers in the United States killed about 1.8 million of the animals annually, which helped to control the population. Once demand for the fur had fallen and many hunters turned to alternative livelihoods, nutria numbers increased dramatically and their negative impacts became evident. In 2002 the Louisiana authorities introduced a bounty on nutria, offering trappers US$4 for every nutria tail produced, in the hope of culling some 400 000 nutria per year.

Although nutria fur has little value today, the meat is lean in fat and high in protein, and could form an important supplementary food source. Apart from trapping, it is possible to shoot the animal at night, in areas where nocturnal hunting is permitted.

Baiting is sometimes used to concentrate nutria in specific locations where they can be more easily trapped, shot, or poisoned. Poisoned bait should be placed on a floating raft in standing water where nutria are known to occur, in order to reduce the risk of affecting non-target species, and a period of pre-baiting should first take place. Once the nutria are habituated to a particular feeding site and food type, such as carrots, sweet potatoes or apples, an appropriate pesticide such as zinc phosphide can be applied to the bait. The nutria carcasses must be collected and properly disposed of, to prevent poisoning scavengers that might eat any undigested stomach material.

DID YOU KNOW?

Nutria were intentionally introduced to China, Thailand and Vietnam for fur-farming. In China they were introduced in the early 1960s, and by the mid-1980s the animals were being raised in large numbers, especially in the south. However, the quality of the fur was found to be inferior and a market failed to establish, so in the mid-1990s many of the nutria were set free. In the meantime, other Asian countries had introduced nutria from China, including Thailand, which imported a breeding population in 1993. Today, the nutria is considered an agricultural pest in both countries.

RATS

Rats are undoubtedly the world's most wide-spread invasive alien mammals, with the greatest economic impact. The costs associated with the approximately 250 million rats in the United States, for example, have been estimated at US$19 billion per year. However, rats also cause significant environmental impacts, and have contributed to the extinction of many species of wildlife.

Three main culprits

The three most common invasive alien rats worldwide are the black rat *Rattus rattus*, the brown rat *Rattus norvegicus* and the Polynesian rat *Rattus exulans*. The black rat is the most widely distributed of the three. Thought to be indigenous to the Indian subcontinent, it now occurs throughout Asia and the rest of the world. It achieved its global distribution by stowing away on sailing ships, and for this reason it is also known as the ships rat.

The brown rat, also called the Norwegian rat, is the largest of the three rats. It is believed to have originated in northern China but had spread to Europe by the early 1700s, after which it was probably transported on ships to the rest of the world. It is a good swimmer and thrives in sewers, as well as buildings, where it tends to inhabit basements and cellars. In contrast, the black rat prefers the upper stories and ceilings of buildings, and is therefore known as the roof rat in many regions.

The Polynesian rat is the smallest of the 56 species of the genus *Rattus* worldwide. Although its original range is uncertain, it is probably indigenous to south-east Asia. However, it has spread throughout the Malaysian peninsula, Java, the Philippines, Sulawesi and the Oceania region. Its natural habitat is forest, where it sometimes nests and feeds in trees, but it commonly takes up residence in houses, granaries and cultivated fields.

Island extinctions

Living in close association with people, rats cause a variety of socio-economic impacts by eating crops and stored grain, contaminating food stocks with their waste, chewing through power cables and spreading diseases. They also have a destructive effect on biodiversity. All three species are omnivorous and eat a wide range of foodstuffs, including seeds and seedlings, fruits and berries, eggs and small animals. By preying on other species or competing with them for food, they have caused the decline of many small mammals, birds, reptiles and invertebrates. Their effect has been particularly severe on islands – they are responsible for more island extinctions of birds, snakes and lizards than any other predators. In the past, cats were sometimes released on islands to control rat populations, with devastating consequences for birds and other small animals.

Most successful control programmes have made use of poisoned bait. For example, after the Polynesian rat was discovered in Jian Township in eastern Taiwan in 1999, an intensive control programme was initiated. Between 5 and 10 poison stations were set up per hectare, each resupplied on a weekly basis with poison baits (0.005% Flucoumafen, 1 kg/ha). Over 4 000 poison stations have been established since 2002, resulting in a significant reduction in the rodent population.

Rats and 'Black Death'

Rat-borne diseases have claimed more human lives than all the wars in history combined! As a reservoir for the bubonic plague bacterium *Yersinia pestis*, the black rat is held accountable for 200 million deaths in medieval times alone.

Bubonic plague is transmitted by fleas from rats to people, but then spreads rapidly as it is highly infectious. An outbreak occurred in China in the early 1330s, but the disease was not introduced to Europe until 1374, when several Italian merchant vessels returned from a trip to the Black Sea – a key trade link with China. Many of those onboard were already dying when the ships docked in Siciliy, and the disease quickly spread throughout the surrounding countryside. The following year it reached England, where it was known as the Black Death because its symptoms included black spots on the skin. The disease ultimately killed almost a third of Europe's people.

Outbreaks of bubonic plague continue to occur – mostly in rural areas – with the World Health Organisation reporting 1000 to 3000 cases globally every year. Fortunately, the disease can now be treated with antibiotics.

INDIAN HOUSE CROW

As its name suggests, the Indian house crow *Corvus splendens* is indigenous to the Indian subcontinent. However, the bird has spread widely along the coasts of Asia and Africa, hitching rides on ships to colonise new areas. It mainly occurs in urban and suburban environments, living in close association with humans.

Bully bird

As an avian invader, the Indian house crow is undesirable for a host of reasons. It is an aggressive and opportunistic feeder, and has a devastating impact on indigenous bird populations by eating eggs and chicks, and mobbing other birds that might compete with it. It threatens the local wildlife by preying heavily on frogs, lizards, small mammals, fish, crabs and insects. It affects agricultural productivity by stripping fruit trees in orchards and decimating grain crops, eating chicks of domestic poultry, and has even been known to peck out the eyes of sheep and pigs. It is unafraid of humans, and may enter houses to steal food, dive-bomb people walking past the nest, and frighten children by snatching food from their hands.

Indian house crows have also been blamed for causing power cuts in some areas, as they often construct nests out of wire in electric pylons. Furthermore, their droppings at roosts and feeding areas have been known to strip paint off walls and deface statues.

More seriously, however, the birds pose a threat to human health, because they are a vector for pathogens that cause cholera, typhoid, dysentery and salmonella poisoning. They scavenge for food in rubbish dumps, informal settlements, open-air abattoirs and markets, and may contaminate food and drinking water with their faeces. It is primarily because they represent a health hazard that efforts are made to control their populations.

Control

To date, the most effective control has been achieved using a poison called Starlicide (3-chloro-p-toluidine hydrochloride). The poison is mixed with meat bait, ideally beef, which should be cut into small chunks and fed to the birds at a feeding site near their roost. However, before any poisoning takes place the birds should be accustomed to being fed by conducting pre-baiting for at least two weeks. A regular feeding routine should be established until the birds recognise the baiter and a large group gathers at the feeding site well before feeding. Pre-baiting also lessens the risk of ingestion by non-target species, as the crows will chase off any other birds approaching the feeding site.

Once the crows are habituated, they should be fed poisoned bait. Starlicide takes about 20 hours to take effect, but since it is metabolised during that period, the corpse will be free of poison and will not affect other animals that might scavenge on it. Dead crows around the roost site should be collected by somebody other than the baiter to avoid arousing the birds' suspicion.

DID YOU KNOW?

The Indian House crow was introduced to Malaysia as a biocontrol agent of rhino beetles in oil palm estates.

It was first introduced to Africa in the 1890s, when it was taken to Zanzibar to help keep the island free of rubbish. It then used passing ships to spread along the continent's east coast. The bird is now found in Cape Town at the southern tip of Africa, and in some parts of the North African coast bordering the Suez Canal and Mediterranean Sea.

Ships passing through the Suez Canal – possibly warships returning from the Gulf War – provided an opportunity for the Indian house crow to reach Europe. The first European record was from Gibraltar in March 1991, and a small breeding colony has since become established in Holland.

DID YOU KNOW?

Two bird species – the sulphur-crested cockatoo *Cacatua galerita* and the rainbow lorikeet *Trichoglossus haemotodus* – have invaded Hong Kong, where they are significant pests of ornamental trees and fruit groves. Their loud calling means that they are noisy neighbours too! The native range of both species includes Australia, New Guinea and Indonesia.

The red-eared slider *Trachemys scripta elegans* is a freshwater turtle native to the Mississippi River valley in the United States. It gets its name from the red stripes on the sides of the head and its habit of quickly sliding into the water if disturbed, leaving barely a ripple. The turtle has been introduced around the world, mainly through the pet and aquarium trade but also for the Asian food market. There are concerns that it may compete with indigenous turtles for food and space.

Popular pet

The red-eared slider is a popular pet that is relatively easy to care for, as it eats a wide variety of foodstuffs. The brightly coloured young turtles are especially sought after, but they darken with age and may become too large for home aquaria. Many people probably release unwanted pets into local waterbodies, and the animals sometimes wander away from garden ponds. In Asia, the turtles are also often released during Buddhist merit-making ceremonies.

The turtles are able to adapt to a wide variety of habitats, and easily become established in slow-flowing rivers, shallow lakes, ponds, swamps, drainage ditches and reservoirs. They prefer quiet waters with a muddy bottom and plentiful vegetation, and have an omnivorous, generalist diet. Juveniles tend to be mainly carnivorous, while adults are more herbivorous, but both will feed opportunistically on aquatic insects, snails, small amphibians and crustaceans, and aquatic plants and algae. The turtles feed at night and spend most of the day sunning themselves, basking on rocks, logs, vegetation or banks. In fact, they sometimes flood floating birds' nests by climbing onto them, and have been reported to prey on young chicks.

Salmonella spreaders

In 1975, the sale of red-eared sliders under four inches in size was banned in the United States by the Food and Drug Administration. This was because the animals were being raised in crowded, unsanitary conditions, surrounded by rotting food that became contaminated with *Salmonella* bacteria. The turtles were unaffected by the bacteria, but served as carriers of salmonellosis, causing thousands of cases of the disease in children who bought the animals as pets.

However, the turtles were still allowed to be raised for sale in other countries, and between 1988 and 1994 approximately 26 million were exported to international markets. The hatcheries now rely heavily on antibiotics to control bacterial infections, which has given rise to antibiotic-resistant strains of *Salmonella*. Apart from the resulting threat to humans, there is a risk that released or escaped turtles will spread diseases and parasites into the environment.

Some countries, including all member nations of the European Union, have banned turtle imports, mostly because of concerns about the species' impact on indigenous ecosystems. However, 3 to 4 million hatchlings are still exported from the United States every year. In some Asian countries, notably China, Malaysia and the Philippines, the turtles are farmed for food.

BLACK-STRIPED MUSSEL

The black-striped mussel *Mytilopsis sallei* is indigenous to the Gulf of Mexico and the Caribbean Sea, but has been introduced to the coastal waters of Asia, probably as a hull-fouling organism on ships. It is now found in parts of India, Japan, Taiwan, Hong Kong, Indonesia, the Philippines and possibly also Fiji. It is a serious pest at some sites, causing massive fouling problems, as well as reducing biodiversity by displacing indigenous species.

Foul play

The black-striped mussel is an effective invader because it can tolerate a wide range of temperatures and salinities. It also grows very rapidly and is capable of spawning only a month after settlement. A single female can release tens of thousands of eggs during monthly spawnings, so populations quickly reach high densities. In sheltered inshore and estuarine waters – the species' preferred habitat – it can form dense monocultures up to 15 cm thick. This allows the mussel to outcompete other organisms for food and space, which not only reduces local biodiversity but also impacts fishery and aquaculture operations based on oysters and other mussels.

The invasive mussels soon overgrow any intertidal and sublitoral structures on which they can settle, including marine intake and outlet pipes, jetty pylons and breakwaters, and boat hulls and anchors. The consequences of this fouling, and the ongoing remedial actions required, may have a significant economic impact. For example, fouling on boat hulls increases drag – which reduces speed and increases fuel costs – and may damage the hull surface, while clogging of the cooling water intakes may cause the engine to overheat, with costly results.

Most control measures involve painting structures with anti-fouling products and regularly scraping off mussel growth. However, Australian authorities took a more extreme approach when the black-striped mussel was discovered in Darwin harbour in 1999. Large-scale chemical treatment of the harbour waters, using copper sulphate and chlorine, successfully eradicated the invading population, at a cost of some US$2.2 million.

The natural range of the cane toad *Bufo marinus* extends from southern Texas in the United States to the tropical parts of South America. The toad was widely introduced as a biocontrol agent of insect pests in sugar cane and other crops, and was able to spread rapidly because it has a wide environmental tolerance, eats almost anything, and has few natural enemies. In Asia the species is well established in Japan, Papua New Guinea and the Philippines.

Noisy neighbour

The cane toad is one of the world's largest toads, with an average length of 10-15 cm, although individuals as big as 24 cm have been recorded. It feeds mainly on insects, but also eats worms, snails, smaller amphibians, reptiles and mammals, carrion, and even household scraps and pet food. It lives on dry land but needs shallow, still or slow-flowing water to reproduce. In fact, it is able to breed in highly saline water, which accounts for the species name '*marinus*' and the alternative common name, 'marine toad'.

The toad also tolerates a wide temperature range and can survive the loss of up to half its body water. It is only active at night; during the day and in cold or dry weather it shelters in moist areas under leaves, stones or debris, or burrows into loose soil. Although its natural habitat is tropical forest, in its introduced range it prefers living in close association with people. In rural areas it is commonly found in villages and cleared areas, while in urban environments it readily takes up residence in gardens, ponds, drainpipes and piles of rubble. It is generally an unwelcome visitor, partly because its loud calls keep people awake at night!

Poisonous pest

More importantly, however, the toad can poison pets – in Hawaii up to 50 dogs die every year after mouthing cane toads. If the toad is threatened, paratoid glands behind the eardrums ooze a venomous secretion that may cause cardiac arrest if ingested. The toad can also squirt a fine spray of the secretion at attackers up to a metre away. The venom is absorbed through the mucous membranes of the eyes, nose and mouth, causing painful inflammation and even temporary blindness. The eggs and tadpoles of the toad are also poisonous, and people have apparently died after eating soup made with the gelatinous eggs.

Apart from the threat to humans and their pets, the cane toad may poison and injure other animals that prey on the adults, tadpoles or eggs, such as snakes, iguanas and crocodiles, although most seem to be able to tolerate low levels of the toxin. Some birds are known to rip open the toad's soft belly and eat only the mildly poisonous internal organs.

With its enormous appetite for insects, the cane toad probably also impacts indigenous wildlife by competing with other insectivorous animals for food. Indeed, in Australia it eats such large quantities of honey bees that it presents a management problem for beekeepers! It also preys on and competes with indigenous frogs and toads for food and breeding habitat.

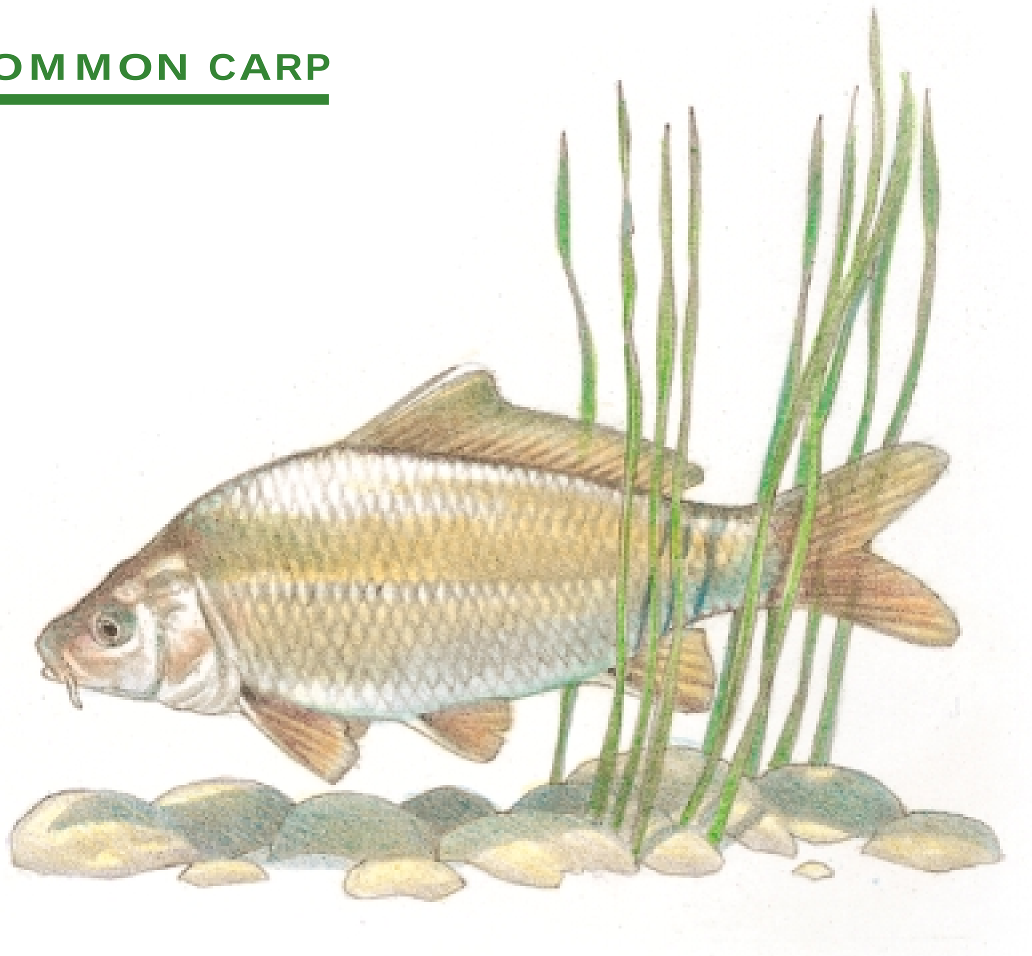
Scientists in Australia are investigating various means of controlling the cane toad, such as using gene technology to interfere with metamorphosis of the toad and thus prevent it from maturing and reproducing, or isolating a pheromone that could be used to disrupt the breeding cycle.

American bullfrog

The American bullfrog *Rana catesbeiana* is another alien amphibian that has invaded parts of Asia. It hails from the eastern parts of North America, but has been widely introduced to other parts of the world as a food crop, either for aquaculture or for harvesting from the wild. In some areas it was introduced as a biological control agent of agricultural pests, or as a pet for home aquaria and garden ponds. Once established, it may have a significant effect on local biodiversity by preying on indigenous frogs and toads as well as other aquatic herpetofauna, such as snakes and turtles.

Some of the many variations of the bullfrog

COMMON CARP



The common carp *Cyprinus carpio* is native to Europe, but was one of the first species to be introduced outside its natural range, and now has a global distribution. Many varieties of common carp exist – among the most popular are the scale carp *C. carpio communis*, mirror carp *C. carpio specularis* and leather carp *C. carpio nudus.*

The common carp was deliberately introduced for food in most cases, as it provides a cheap source of protein. In some regions of the world it was introduced for sport-fishing, but although it is considered a premier sport-fish in Europe, it is among the least favoured targets of anglers elsewhere, and is often regarded as a pest because of the damage it causes to freshwater habitats. Furthermore, its widespread introduction has resulted in the spread of a number of fish parasites.

Bottom feeder

The common carp is a member of the minnow family, and is closely related to the goldfish. However, it can grow to enormous sizes – exceeding a metre in length and reaching a weight of over 35 kg – and in exceptional cases may live for up to 50 years.

The carp is a bottom-dwelling fish, which prefers living in large, slow-flowing or standing water bodies with soft benthic sediments. It can tolerate low-oxygen conditions, as it is able to gulp air at the surface, and can withstand temperature fluctuations and extremes. It thrives in muddy rivers and dams.

The carp is omnivorous, preferring water weeds and filamentous algae but also eating aquatic insects, snails, crustaceans, worms, snails and the spawn of other fish. It forages in bottom sediments, taking mud into the sucker-like mouth and then ejecting it after the food has been extracted.

Muddy waters

It is because of its feeding activity that the carp is such an unwelcome invader. By uprooting plants and disturbing bottom sediments it causes severe habitat damage, to the detriment of indigenous fish and other animals. Its grubbing behaviour muddies the water, reducing light penetration and thus inhibiting the productivity of submerged plants. It releases phosphorus normally locked up within the bottom sediments, which may result in phytoplankton blooms. The increased turbidity reduces visibility, so it affects feeding by sight-dependent fish, and limits their food availability because benthic organisms are smothered by resettled sediment. Stirred-up sediment also clogs the gills and filter-feeding apparatus of aquatic organisms. All of these impacts render the habitat unsuitable for the survival of other species.

The carp's success as an invader can be attributed to its wide physiological tolerance, omnivorous diet, fast growth rate and high fecundity – a single female can lay well over 100 000 eggs per season. It also reduces the numbers of other fish predators that might prey on its young, both by eating the spawn of other fish and making the habitat unsuitable for them. As a result, carp generally monopolise water bodies to which they are introduced.

Control

Carp are an important source of food, and support subsistence and commercial fisheries in many parts of the world. Yet, due to their destructive effects, efforts have been made to control carp in some regions, with varying success. The most basic method of physical control is to encourage people to harvest the fish, either by angling or seine-netting. Control through water level manipulation, traps and electrofishing has also been attempted, but has generally proved to be too labour-intensive or not cost-effective.

The most common method of preventing carp infestation is the use of barriers, such as metal grates, electrical barriers and culverts that channel outgoing water to produce high velocities, blocking the entry of carp. However, the initial cost is high, and the structures may obstruct the spawning runs of other fish, as well as boat traffic. The effectiveness of metal grates is also limited, as they exclude adult carp but not their fry.

Chemical control usually involves the use of rotenone, a natural chemical extracted from the stems and roots of several tropical plants. It acts by being absorbed through the gills and inhibiting oxygen transfer at the cellular level, resulting in suffocation. It can be effective for controlling small, isolated populations of carp, and is environmentally non-persistent, so restocking of indigenous fish can occur in the same season of treatment. However, rotenone is non-selective, so it also kills non-target fish and many invertebrates.

In an effort to ensure more selective action, rotenone-impregnated baits have also been tested in recent years. Pre-baiting with non-toxic bait was conducted to attract carp to a feeding station, and hence maximise the number of fish poisoned. However, as soon as rotenone was added to the food supply, the carp detected it and stopped feeding.

Australian scientists are now experimenting with a method to achieve biological control of carp by limiting their reproduction. The ‘daughterless gene method’ aims to genetically modify carp so that they stop producing female offspring. It is hoped that the population will become biased towards males over time, and eventually decline.

Carp Cousins

A number of other carp species have been introduced to south and south-east Asia, where many have established invasive populations. All are indigenous to parts of China and the former Soviet Union.

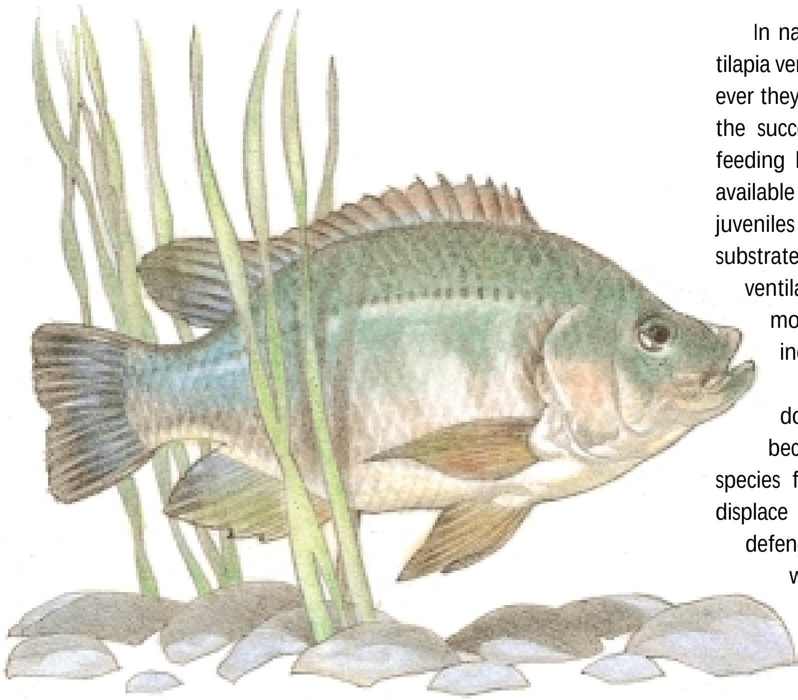
The grass carp *Ctenopharyngodon idella* – sometimes called the white amur – has been widely introduced for aquaculture purposes, and also as a biocontrol agent of aquatic weeds. It not only competes with indigenous fish for food, but at high densities can decimate aquatic vegetation, destroying natural habitat and resulting in dramatic ecosystem changes.

The black carp *Mylopharyngodon piceus* is sometimes called the snail carp, as it feeds almost exclusively on snails and mussels. It is also known as the black amur and Chinese roach. Freshwater snails play an important role in maintaining the health of aquatic ecosystems, so their depletion may have serious impacts. There are also concerns that black carp may compete for food with indigenous birds, fish and small vertebrates.

The silver carp *Hypophthalmichthys molitrix* is a filter-feeder that thrives in the plankton-rich mid and upper layers of lakes and reservoirs. It has generally been stocked as a food fish, but also introduced for phytoplankton control in some areas. However, it competes with indigenous planktivorous fish and filter-feeding mussels.

The bighead carp *Hypophthalmichthys nobilis* is a filter-feeder that seems to prefer zooplankton, although it will opportunistically consume phytoplankton and detritus too. It is sometimes introduced for water quality management in sewage lagoons and aquaculture ponds. Invasive populations have the potential to deplete zooplankton populations, and hence impact species that rely on plankton for food, including all larval fishes, some adult fishes, and mussels.

Grass carp



In natural habitats, such prolific breeding means that tilapia very quickly become the most abundant fishes where ever they are introduced. Other features that contribute to the success of tilapia as invaders are their omnivorous feeding habits, which allow them to take advantage of available food sources, and the low mortality rate of juveniles due to parental care. All tilapia are either substrate-brooders – guarding the nest from predators and ventilating the developing eggs with their fins – or mouth-brooders, in which the eggs and fry are incubated in the mouth of one or both parents.

Tilapia impact local biodiversity because they dominate the fish biomass of waters in which they become established, and compete with indigenous species for food, habitat and breeding sites. They also displace other fish through their aggressive behaviour in defending their nests. In addition, tilapia hybridise readily with other cichlids, resulting in genetic contamination of indigenous fish populations. The introduction of tilapia around the world has probably also facilitated the spread of fish parasites.

Tilapia are freshwater fishes belonging to the cichlid family. The various species are indigenous to different parts of Africa and the Middle East, but a number of them have been introduced to other parts of the world, where they have established invasive populations in the wild. In some instances they were introduced as sportfish, aquarium fish, or even as biocontrol agents to control waterweed or filamentous algae, but in most cases they were intended for aquaculture.

Early maturity

Tilapia are second only to carp as the most widely farmed freshwater fishes on a global scale, and by 2000 the world harvest of farm-raised tilapia had exceeded 1 200 000 tons. They are ideal species for aquaculture because they are hardy fishes, with a wide environmental tolerance, and they reach sexual maturity at a relatively young age, which allows for rapid population growth. However, in unfavourable conditions, such as limited food and space, they mature and breed at much smaller sizes than usual. This is known as stunting, and is undesirable in aquaculture as it results in large numbers of fish that are of sub-optimal size for the seafood market. Efforts to overcome the problem have included hybridisation between tilapia species to produce all-male or sterile offspring. These hybrid fish are commonly marketed as ‘red tilapia’.

Nile tilapia

As its name suggests, the native range of the Nile tilapia *Oreochromus niloticus* includes the Nile river basin, but the species also occurs naturally in the Rift Valley lakes, some West African rivers, and Israel. The present-day distribution is much broader, however, as the Nile tilapia has been widely introduced to south-east Asia, other areas of Africa, parts of Europe, and the Americas, with negative consequences for indigenous fish populations.

Nile tilapia is the species most commonly used for fish-farming. Taiwan is the largest exporter of tilapia worldwide, sending about 70% of its domestic production to Japan as high-quality fillets for the sashimi market and to the United States as frozen fish. China, Indonesia and Thailand are also major producers, with Vietnam having only recently entered the world tilapia market.

Mozambique tilapia

The Mozambique tilapia *Oreochromus mossambicus* is indigenous to southern Africa. However, it has been widely dispersed beyond this range, having been introduced to tropical and warm temperate localities throughout the world for aquaculture, subsistence fishing and sport-fishing.

Mozambique tilapia can grow to more than 36 cm, so in the natural environment there are few predators that can target adult fish. They do, however, prey opportunistically on other fish, although they are omnivorous feeders that eat whatever is available, and seem to prefer detritus and plant matter. They have a wide salinity tolerance, being able to live and even breed in seawater, and can withstand low-oxygen conditions.

Mozambique tilapia are prolific breeders, capable of reproducing several times per year when conditions are favourable. The female incubates the eggs and fry in her mouth, which ensures a high survival rate. This efficient reproductive strategy, together with the species' flexible habitat requirements, have allowed Mozambique tilapia to invade a variety of habitats, including dams, ornamental ponds, irrigation and stormwater channels, lakes, rivers and the upper reaches of estuaries. Since they inevitably dominate these habitats and increase water turbidity through their bottom feeding – to the detriment of indigenous fish populations – they are generally regarded as pests.

However, in some areas they provide an important source of food. In Papua New Guinea, for example, the fish was originally introduced in 1954 for aquaculture, but escaped from fish farms and rapidly became established in the Sepik River system. In 1977 more tilapia were introduced by the East Sepik Rural Development Project, and the species now provides the primary source of protein for communities living along the river.

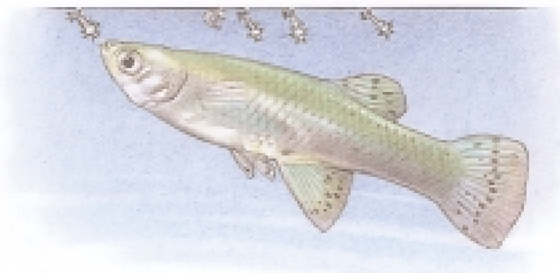
Mosquito Fish

The mosquito fish *Gambusia affinis* is indigenous to the south-eastern parts of the United States and northern Mexico. Starting in about 1900, however, it was distributed around the world for the biological control of mosquito larvae. It is now well established in approximately 70 countries, including most of those in south and south-east Asia.

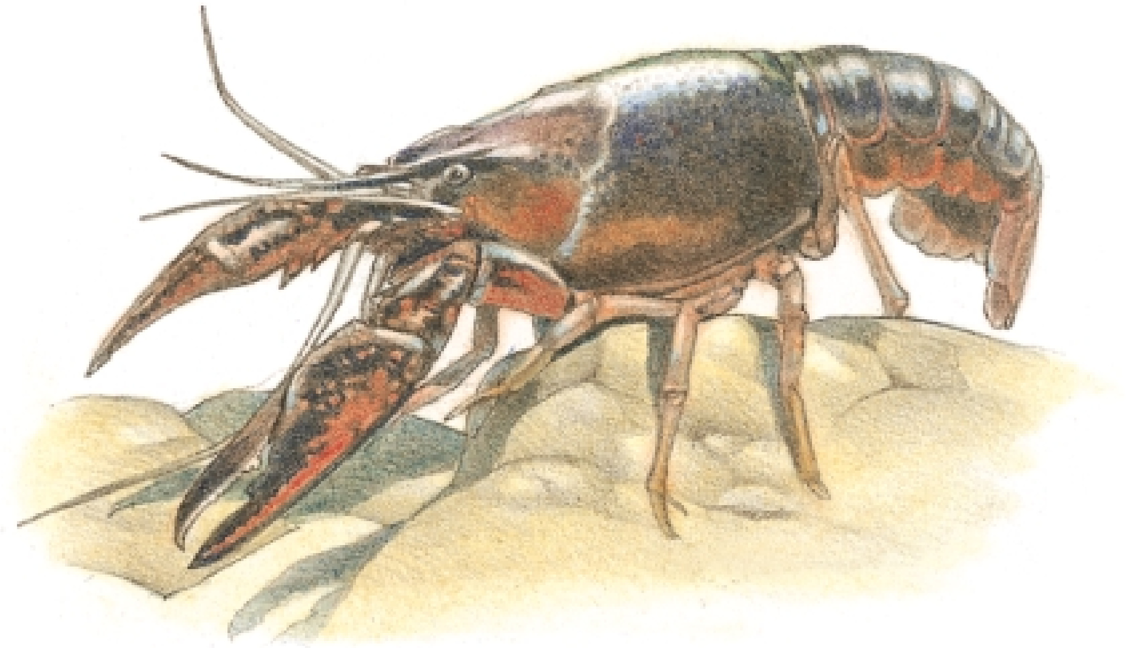
EFFICIENT REPRODUCTION

The mosquito fish is a small but hardy fish, able to survive in waters with low oxygen levels, high salinities and high temperatures. Its wide tolerance range, together with its efficient reproductive strategy, allows it to multiply rapidly and dominate habitats into which it has been introduced. Indeed, individual populations have been recorded to increase from 7 000 to 120 000 in just five months! The female incubates the eggs internally and gives birth to live young – ensuring a better survival rate – and several broods can be produced per year, each made up of 50 to 100 young. This high breeding rate makes it difficult to eradicate the fish once established.

The mosquito fish is regarded as a pest in many countries, as it not only competes with indigenous fish species for zooplankton food, but also preys on their eggs and larvae. Owing to these tendencies, it is held responsible for the decline of various species of indigenous fish. Furthermore, there is evidence that it prefers feeding on macro-invertebrates rather than mosquito larvae. By reducing populations of indigenous fish and macro-invertebrates that help control mosquito larvae naturally, the mosquito fish may actually exacerbate the mosquito problem.



LOUISIANA CRAYFISH



The Louisiana crayfish *Procambarus clarkii*, also known as the red swamp crayfish, supports a lucrative aquaculture industry in its native range, and is a popular component of the region's Cajun cuisine. It has been introduced to Africa, Europe and Asia, in most cases with negative consequences.

Highly adaptable

The Louisiana crayfish is indigenous to the southern parts of the United States and northern Mexico. It has been introduced to other regions primarily to diversify local fisheries or for aquaculture purposes. In China it is frequently raised in combination with crops, especially rice. In Japan it became a popular family pet, and was also traded by aquarium and garden pond hobbyists in parts of Europe. In a few cases in Africa it was released as a biological control agent against the snail hosts of bilharzia (schistosomiasis). In the United States it was stocked outside its natural range as a food source for gamefish such as largemouth bass and bluegill, and spread by anglers using it as bait.

Once introduced, the species quickly became established in the wild after animals escaped or were deliberately released. Louisiana crayfish can survive in a variety of natural and manmade habitats, such as rivers, wetlands, dams and irrigation canals, where they burrow into soil banks along the shoreline. They are able to tolerate a wide range of salinities as well as oxygen-poor conditions, high pollution levels and fluctuating water levels, and adults can travel long distances over land to colonise new areas. More importantly, the Louisiana crayfish is a prolific breeder and a generalist feeder, able to exploit most available food sources.

Variety of impacts

Apart from aquatic plants, the Louisiana crayfish eats insects, worms, snails, amphibians, crustaceans and small fish, as well as their eggs and fry. Its huge appetite has been blamed for the disappearance of some species of snails in African wetlands, and for the decline of certain amphibians in parts of the United States. In addition, the crayfish is aggressively territorial, so it frequently outcompetes and excludes indigenous predators, further reducing local biodiversity.

A number of other impacts are associated with invasion by Louisiana crayfish. Their burrowing weakens dam walls, creates leaks in levees and aquaculture ponds, and increases erosion along watercourses. When farmed in combination with rice crops, they inevitably raise the cost of rice culture by burrowing into dykes and eating the rice plants.

The Louisiana crayfish is a vector of the 'crayfish plague' *Aphanomyces astaci*, which caused a collapse of the crayfish industry in Europe after it was introduced with the American red signal crayfish in the 1860s. In some parts of the world it is also a vector for harmful human parasites, including the lung fluke Paragonimus westermani and the rat lungworm *Angiostrongylus cantonensis*, which are passed on to humans who eat undercooked crayfish.

Control

Once established in an area, Louisiana crayfish are extremely difficult to eradicate. Limited success has been achieved with traps baited with fresh fish or meat and left overnight. Research is now being conducted using sex hormones – or pheromones – as bait, in the hope that crayfish looking for a mate will be more readily lured into traps. For small ponds and dams, drainage and physical removal of crayfish has sometimes been effective, but the animals can escape capture by burrowing deeper into the mud or moving over land to nearby pools.

Natural enemies have kept crayfish numbers in check in some areas. For example, where there are large heron colonies in wetlands in southern Europe, the birds exact a heavy toll on the crayfish population. In the United States, the species is not normally a problem in sport-fishing dams stocked with trout, bass, catfish and bluegills, but introducing these predatory fish to control crayfish in other areas has generally not been successful and causes secondary impacts.

Chemical control is not recommended for crayfish. Toxic pesticides are likely to kill non-target species, threaten water quality and contaminate water supplies. Recently, research has been conducted on the potential of a biodegradable surfactant – Genapol OXD-080, a fatty alcohol polyglycol ether – to control crayfish in rice paddies. However, the non-selective action of the product means that it is a threat to biodiversity. Trials showed that it risked contaminating irrigation canals, and killed mosquito fish at concentrations well below those needed to achieve control of crayfish.

AFRICAN CATFISH

The African catfish *Clarias gariepinus* is also known as the African magur or sharptooth catfish. It is probably the most widely distributed fish in Africa, as its native range extends from South Africa through central, west and north Africa, into the Middle East and eastern Europe. In the 1950s it was introduced to Indo-China by the French, and was subsequently widely distributed in south and south-east Asia for fish-farming. In many cases, however, the introduced fish is a hybrid between the African catfish and an indigenous species *C. macrocephalus*.

Breathes air and walks on land

The African catfish is an ideal species for aquaculture because it is a very hardy fish and has an extremely high growth rate. Under intensive pond management systems, fish could be reared to 'table size' every 3 to 4 months.

Clarias gariepinus

Full-grown fish can grow to more than a metre long, but smaller fish are normally preferred for eating.

The catfish can easily become established in the wild, as it has such a wide environmental tolerance range. It can survive in waters with high turbidity, low oxygen levels and extremes of temperature, salinity and pH, and during dry periods can burrow into moist sand. It occurs in almost any habitat but favours floodplains, large sluggish rivers, and lakes and dams. It can even move overland by crawling on its pectoral fins, and breathe air using a specialised breeding organ.

The catfish is a threat to biodiversity as it eats almost anything, including indigenous fish, birds (even domestic ducklings), frogs, snails, crabs and insects, as well as plant material and plankton. It is a voracious predator, and my hunt in packs, herding fish prey towards shallower water where they can be easily caught.

DID YOU KNOW?

A related species, *Clarias batrachus*, which is indigenous to south and south-east Asia, was introduced to Florida in the United States during the 1960s, and has since spread throughout the state. Known as the walking or Thai catfish, it is considered a menace because of its predatory habits. It has even been known to invade aquaculture ponds to prey on fish stocks!

The golden apple snail *Pomacea canaliculata* – so named because its large round shell resembles a golden delicious apple – is a freshwater snail that is indigenous to South America. It was introduced to Taiwan in 1980, and has since become an invasive pest throughout south-east Asia, where it is widely known as the golden kuhol.

Ravages rice

The golden apple snail is thought to have initially been introduced to Taiwan through the aquarium trade, but it was subsequently promoted as a high-protein food for both humans and farm animals. In 1982 it was introduced to the Philippines for snail-farming, and spread rapidly after escaping into waterways. In addition, many snail farms were abandoned after a market failed to develop because consumers did not like the taste of the snail. Within a few years the snail had become a major pest of rice; indeed, by the early 1990s, rice farmers considered it to be their greatest pest problem. Today approximately half of the country's 3 million hectares of rice lands are infested, causing huge production losses.

The species has since spread throughout south-east Asia and is now on the verge of entering India, posing a threat to that country's extensive rice-growing areas. The snail feeds on young rice seedlings, with large adults being able to consume up to 25 per day. This necessitates replanting of seedlings two to four times per crop season, which is not only costly and labour-intensive but also significantly reduces yield.

Habitat modification

The golden apple snail also eats a wide variety of other plants – preferring the young, soft parts – as well as decomposing organic matter. By feeding heavily on aquatic vegetation it probably impacts indigenous fauna through habitat modification and competition. It has already been implicated in the decline of south-east Asia's native species of Pila apple snails.

The snail is a hardy species, being able to tolerate polluted water and low oxygen levels. It can also aestivate during the dry season, remaining buried in moist soil with its operculum closed. The bright pink eggs are laid just above the water surface; people often collect them and take them home as a delicacy, which facilitates the species' spread.

The golden apple snail has also invaded the southern parts of the United States as well as Hawaii, where it is a major pest of taro cultivation. There are concerns that it will soon enter Australia – even though strict quarantine measures are enforced for cargo from infested countries – and threaten the country's natural wetlands and rice-growing areas.

Eggs of the golden apple snail

Control

Integrated pest management of the golden apple snail incorporates physical, chemical and biological control methods, together with management methods such as manipulating water levels in rice fields and transplanting older seedlings. Physical control by hand-picking can be effective, but is extremely labour-intensive. Attractants such as banana, papaya and old newspaper can help to concentrate snails, facilitating their collection.

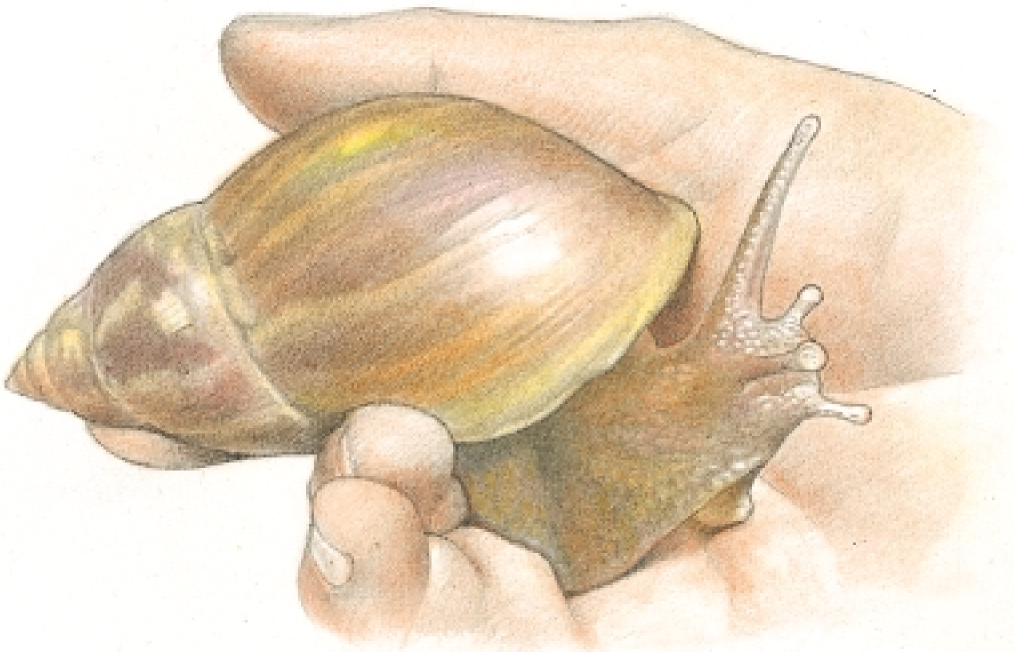
Many farmers resort to chemical control, using broad-spectrum pesticides that not only impact non-target organisms but also endanger the health of people working in the rice fields. A safer approach is to place plant parts containing substances that are toxic to the snails – such as tobacco leaves and red peppers – amongst the rice plants. To date, biological control methods have focussed on using predators such as ducks or fish to minimise the snail population.

Case study : Vietnam

The golden apple snail was introduced to Vietnam in 1988, and people were encouraged to culture it in their gardens as a high-protein duck and fish food. Subsequently, two snail farms were established as a joint venture between Vietnamese and Taiwanese companies for large-scale culture and export to Taiwan. Some snails escaped and spread to nearby ponds, trenches and rice fields, where they quickly reached pest status. The Vietnamese government banned snail farming in 1992, and spent vast sums of money on control programmes and public awareness campaigns.

In 1996, seasonal flooding allowed the snail to spread rapidly throughout the delta region of the Mekong River. Before long, the species had become established in 57 of the country's 61 provinces, with devastating consequences for rice production. The government appealed for assistance from the Food and Agricultural Organisation, which set up a nationwide integrated snail management programme. An important achievement of the programme was the training of scores of Plant Protection Officers, who in turn organised Farmers' Field Schools attended by thousands of farmers. These helped raise awareness about the impact of the snail and various control techniques, including rice-fish farming, which entails raising fish in rice fields. The common carp, for example, was found to reduce populations of the snail in rice fields by up to 90% over a period of three months, while also enhancing the food security of farmers and generating income.

GIANT AFRICAN SNAIL



The giant African snail *Achatina fulica* is typically about 7 centimetres tall, but can grow as large as 20 centimetres and weigh as much as a kilogramme. Native to East Africa, it was first introduced to Asia in 1847, when live specimens were taken from Mauritius to Calcutta, India. Today the snail is widely distributed in southern and eastern Asia, and has also invaded many of the Indo-Pacific islands, as well as the West Indies and West Africa.

Public nuisance

Away from its natural enemies, the giant African snail is able to increase rapidly in numbers, and has become a destructive pest of crops and garden plants. It also feeds on indigenous vegetation, and often poses a conservation problem by altering habitat and outcompeting other snails for food. At times it may experience population explosions and become a public nuisance, hampering human movement by covering roads and paths. In addition, the snail is a vector for disease such as eosinophilic meningitis, caused by the parasite rat lungworm that is passed to humans through eating raw or improperly cooked snails.

Although the giant African snail is a tropical species, it is capable of surviving adverse conditions – even snow – by aestivating, so it is a potential threat to countries in cooler and drier climates. While the snail has in cases been deliberately introduced for food, medicinal use or as an ornamental species, it may also be accidentally imported by the nursery and agricultural trade when soil, plants or packaging material are contaminated with the snail or its eggs. Once introduced, the eggs are typically dispersed in garden waste and in soil adhering to construction and landscaping machinery.

Control

The snails are hermaphrodite – having both male and female sex organs – and after a single mating can lay up to 1200 eggs in a year. The effectiveness of this reproductive strategy is highlighted by a case study of the snail's introduction and subsequent eradication from Florida in the United States. In 1966 a boy returning from Hawaii smuggled three giant African snails into Miami, and his grandmother released them into her garden. Three years later state authorities launched an eradication campaign – which ultimately cost over US$1 million – and by 1973 more than 18 000 snails had been found!

The success of the campaign can be attributed to the invader's early detection; the giant African snail is extremely difficult to eradicate once established. Control methods include hand-collecting, poisoning with molluscicides, and even using flame-throwers! The rosy wolf snail *Euglandina rosea* was widely introduced as a biocontrol agent for the giant African snail, with disastrous consequences.

DID YOU KNOW?

The giant African snail is extensively farmed in Thailand and China. The canned product is exported to European markets, to meet the demand for 'escargots'.

ROSY WOLF SNAIL

The rosy wolf snail *Euglandina rosea* is a predatory terrestrial snail that is native to Latin America and the south-eastern United States. Starting in 1955 – when it was released in Hawaii – the species has been introduced to more than 20 oceanic islands and a number of Asian countries as a biocontrol agent against the giant African snail, Achatina fulica, and other snail pests. While there are no indications that it has been successful in controlling the giant African snail anywhere, it has caused the extinction or decline of indigenous snail species wherever it has been introduced.

For example, it was released in Mauritius in 1960 to control the giant African snail, which had been introduced as a potential food resource but had negatively impacted crops. Since then, 24 of the 106 snail species endemic to Mauritius have become extinct, and the rosy wolf snail is largely to blame.

The snail gets its common name from its rose-pink shell and its wolf-like habit of tracking and running down its prey. When it locates the slime trail of another snail, it quickens its pace, following the trail until it catches up with its victim. Small snails are swallowed whole, while larger ones are manoeuvred to expose their soft parts so that chunks can be torn off with the radula teeth.

YELLOW CRAZY ANT

The yellow crazy ant *Anoplolepis gracilipes* is thought to be indigenous to West Africa, but has invaded most of south and south-east Asia, as well as East Africa and the Indo-Pacific islands. It is also known as the long-legged ant, and often referred to as A. longipes. Its names reflect its yellowish colour, its habit of running around frantically in different directions – especially when disturbed – its slender (gracile) body, and long legs and antennae.

Promotes scale insects and sooty mould

The yellow crazy ant was primarily spread in cargo transported around the world, but in some cases it was deliberately introduced as a biocontrol agent of insect pests in coconut, cocoa and coffee plantations. It soon became an agricultural pest itself, however, because of its mutualistic relationship with Homoptera. In exchange for their sugary honeydew secretions, the ant protects scale insects from predators such as wasps and spiders, and also distributes the young to new host plants, so that they can form new populations. At high densities the sap-sucking bugs weaken plants, and this is compounded by sooty mould that colonises the honeydew, causing canopy dieback or even the death of the tree.

The ant may also undermine crops such as sugarcane and coffee by nesting at the base of plants. Furthermore, although it does not bite or sting, it defends itself by spraying formic acid, which causes skin burns and irritates the eyes of farm workers. The ant also subdues and kills prey in this way, aggressively attacking anything from small insects, spiders, crustaceans and molluscs to large land crabs, birds, mammals, and reptiles. By decimating endemic keystone species it can drastically alter community structure and species composition, and affect important ecosystem processes.

For example, on Christmas Island, an Australian territory bordering the Indonesian archipelago, yellow crazy ants have drastically reduced the population of the red land crab, killing an estimated three million crabs over an 18 month period. The crab is the dominant endemic consumer on the rainforest floor, foraging on seedlings and fallen leaves. Its decline is causing a fundamental shift in the structure of the forest ecosystem, due to increased seedling recruitment, enhanced species richness and slower breakdown of leaf litter. Furthermore, in parts of the island where the ants occur, more than 90% of trees and shrubs are infested with sooty mould, resulting in extensive canopy dieback. The ants also disrupt the reproduction of a variety of reptiles, birds and mammals on the forest floor and canopy.

Control

The yellow crazy ant forms huge super-colonies, extending over several hectares and comprising as many as 300 queens and up to 36 000 workers. Control is best achieved by scattering protein bait pellets – made of fishmeal and laced with an appropriate insecticide – in the vicinity of the nest. Foraging ants take the bait back to the nest, where it is shared amongst the workers, larvae and queens. Since the queens are the only ants able to reproduce, killing them accelerates the eradication of the colony.

FIRE ANT

The native range of the fire ant *Solenopsis geminata* extends from Central America to the southern parts of the United States. Human commerce has facilitated its spread, however, and it is now widely distributed in the tropical and subtropical regions of the world, including most of south-east Asia and the surrounding Indo-Pacific islands.

Painful sting

The fire ant is so-named because its sting causes an intense burning pain. Each ant can exact multiple stings, but more serious injuries to humans and animals occur when they disturb a colony, resulting in attack by numerous ants. Owing to its aggressive behaviour, the ant tends to displace other animals in infested areas, with negative consequences for biodiversity.

The ant is considered an agricultural pest not only because it stings farm workers, but also because it promotes the outbreak of homopteran pests and diseases for which they are a vector, and damages plastic irrigation tubing. However, it is being considered as an agent for the biological control of the golden apple snail *Pomacea canaliculata*, as it is one of the few animals known to eat the snail's eggs. Grass seeds and arthropods are major components of the diet, but in domestic situations it will feed on any sweets, meats and fats.

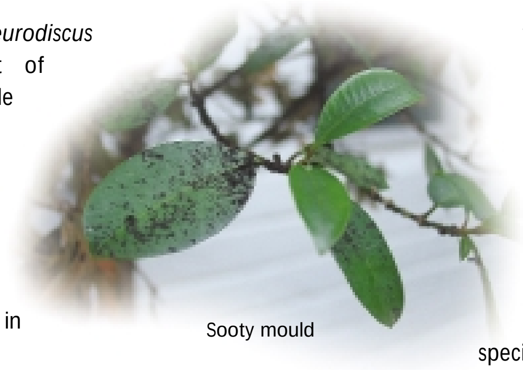
Big-headed ant

The big-headed ant *Pheidole megacephala* is indigenous to southern Africa, but is now widespread throughout the temperate and tropical zones of the world. In Asia it is invasive in the Philippines, and has recently become established in Hong Kong.

The ant is omnivorous, harvesting seeds but also preying on other invertebrates. It will even kill small vertebrates, such as bird hatchlings. It threatens biodiversity by displacing indigenous ant species and other invertebrates through its aggressive behaviour. It impacts agriculture by tending homoptera such as mealybugs, which reduce crop productivity, and making holes in plastic irrigation tubing. It is also a domestic nuisance because it chews through telephone cabling and electrical wires.

Some of the most important invasive alien species in Asia are insect pests of agriculture. Their destructive feeding habits can cause massive crop failure, with crippling socio-economic consequences.

Spiralling whitefly



Sooty mould

The spiralling whitefly *Aleurodiscus dispersus* is a serious pest of commercial fruit and vegetable crops, as well as many ornamental trees and shrubs. It is indigenous to Central America and the Caribbean region, but is spreading throughout the world's tropical and sub-tropical areas. It is widely distributed in south and south-east Asia.

The spiralling whitefly is in fact not a fly but a homopteran bug, related to the aphids and scales. It resembles a tiny white moth no more than 2-3 mm long, and lays its eggs on the leaves of plants in a characteristic spiral pattern. Both the immature and adult stages cause feeding damage by piercing the leaves and sucking the sap, which may lead to premature leaf fall. Furthermore, they produce copious quantities of sugary honeydew, as well as a white, waxy flocculent material. The honeydew provides a substrate for the growth of sooty mould, which blackens the leaf and inhibits photosynthesis. Severe infestations result in defoliation and death of the plant. Both the black mould and the white wax disfigure the plant, reducing its value or making it unmarketable.

In India the spiralling whitefly was first detected as recently as 1993. It has now become a major pest of guava, and has been recorded on more than 250 host plant species. Among the many other plants that the spiralling whitefly affects worldwide are mango, pawpaw, banana, coconut, avocado, tapioca, citrus, chilli, lettuce, tomato, aubergine, poinsettia, hibiscus and rose bushes. International trade of these plants has facilitated the pest's spread.

A number of biocontrol agents, including three coccinellid beetles and two parasitic wasps, are successful in controlling spiralling whitefly in some regions. For garden and household plants, contact and systemic insecticides are useful, but these are impractical on a large scale. Tobacco extract, neem oil, fish oil, rosin soap and detergent solutions have been found effective in India.

Khapra beetle

The khapra beetle *Trogoderma granarium* is one of the world's worst pests of grain products and seeds. It is believed to have originated from the Indian subcontinent, but has spread throughout south-east Asia, the Middle East, parts of Europe, and much of Africa.

The beetle is only a few millimetres long and cannot fly, but commerce and trade has facilitated its spread. It hides away in cracks, crevices and even behind paint scales and rust flakes, allowing it to infest food stored or transported in warehouses, containers or packaging materials that were previously exposed to the pest.

The adult beetles live for only 5-10 days, and in favourable conditions the entire lifecycle – from eggs to larvae, to pupae to beetles – can be completed within a month or two. However, in adverse conditions, such as food shortage, little moisture and low temperatures, the larvae enter a state of dormancy in which they can remain for as long as eight years.

It is the larvae that cause the damage to stored food, particularly wheat, barley, rice and seeds, but also spices, beans, lentils, nuts, pasta and powdered milk. They not only eat the food, but contaminate it with their excreta and shed skins, causing gastrointestinal irritation in human consumers. The larvae have five to nine stages, so large numbers of shed skins soon accumulate, and these are usually the first sign of infestation, although pheromone-baited traps can be used to detect the adult insects. The khapra beetle is particularly difficult to control with insecticides, and fumigation of the entire building with methyl bromide is usually necessary.

Diamond-back moth

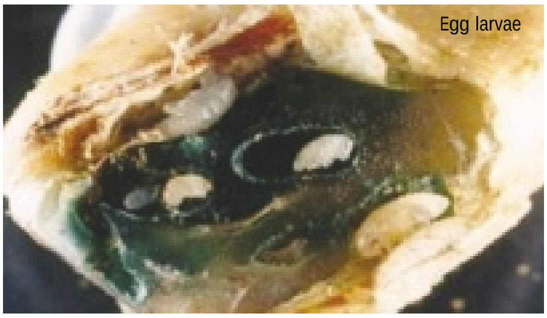
The diamond-back moth *Plutella xylostella* is named for the zig-zag markings on its wings, which when folded over the back create a diamond pattern. The species probably originated in the Mediterranean region, but has spread to many parts of the world, including the Indian subcontinent and south-east Asia. It is able to disperse over long distances, remaining in continuous flight for several days and covering distances of 1000 km per day.

Worldwide, the species is the most important pest of crucifer plants, including cabbages, cauliflower, broccoli, brussel sprouts, radishes, turnips and watercress. The moth lays its eggs on the leaves, and after hatching the larvae cause extensive feeding damage. In attempting to control the pest, farmers in Asia used insecticides at ever-increasing frequency and dosage. This not only resulted in the elimination of natural enemies of the moth, but also in it developing resistance to all major groups of insecticide. In fact, the moth was the first crop pest in the world to develop resistance to DDT, and later to the bacterial insecticide, *Bacillus thuringiensis*. The heavy use of insecticides also left toxic residues on crops, impacted non-target organisms and caused environmental pollution.

Today, the moth is controlled through an integrated pest management approach, using a combination of biological, chemical and cultural control. The most effective biocontrol agents in Asia are the larval parasitoid wasps *Diadegma semiclausum* and *Cotesia plutellae* in the highlands and lowlands respectively, while egg parasitoid wasps belonging to the genus *Trichogramma* are less successful and require frequent mass releases. Chemical control relies mainly on the bacterial insecticide B. thuringiensis and neem kernel extract sprays, but pheromone traps are used in some areas. One effective cultural control method is to grow mustard as a trap crop, sown at least 10 days before the crucifer crop to provide an alternative host for the diamond-back moth.

Much research has been devoted to developing integrated pest management programmes to control this pest. The most effective biocontrol agents in Asia are the larval parasitoid wasps *Diadegma semiclausum* and *Cotesia plutellae* in the highlands and lowlands respectively, while egg parasitoid wasps belonging to the genus *Trichogramma* are less successful and require frequent mass releases. Chemical control relies mainly on the bacterial insecticide *B. thuringiensis* and neem kernel extract sprays, but pheromone traps are used in some areas. One effective cultural control method is to grow mustard as a trap crop, sown at least 10 days before the crucifer crop to provide an alternative host for the diamond-back moth. There are some success stories. Unfortunately the most common farm practice is still to calendar spray the crop with insecticide or a cocktail of insecticides.

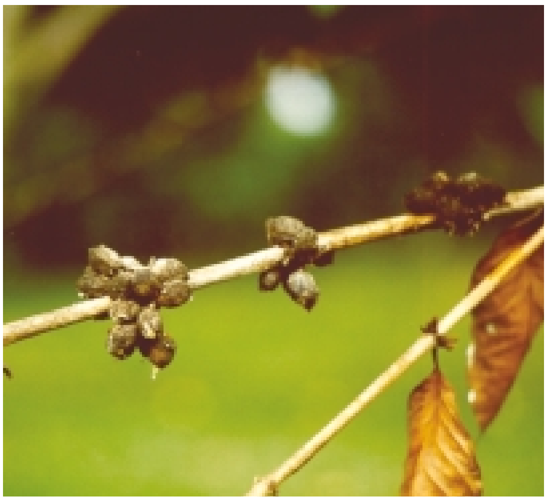
Coffee berry borer



The coffee berry borer *Hypothenemus hampei* is a tiny black beetle, thought to originate from Central Africa. Its distribution now includes most of the major coffee producing nations of Africa, Central and South America, and Asia. The first infestation in India was detected in 1990, and before long the pest was causing losses estimated at US$ 300 million per annum.

The female beetle bores into immature coffee berries to lay eggs, and after hatching the larvae feed on the bean contents. The damaged berries turn brown and some fall to the ground, while others are retained on the tree until harvesting. Both scenarios result in a drop in yield, while those that are harvested and inadvertently ground up with the rest of the crop degrade coffee quality.

Chemical control using insecticide sprays such as endosulfuran is not cost-effective, because the pest is protected deep inside the berry for much of its lifecycle. The best results are achieved with an Integrated Pest Management approach, using biological control agents such as the parasitic wasp *Phymasticus coffea* and fungal pathogens, together with appropriate cultural practices and the judicious use of agrochemicals where necessary.



Beans attacked by beetle

Leafminers

The leafminers *Liriomyza sativae*, *L. trifolii* and *L. huidobrensis* are small flies that are pests of a wide variety of vegetables and ornamentals in Asia and Oceania. All three species are native to the Americas, but the global trade in horticultural products and large-scale production of ornamental flowers, particularly chrysanthemums, have allowed the species to expand their range worldwide.

The increase in their pest status in south-east Asia may be attributable to the indiscriminate use of insecticides in the past, which decimated natural enemies of the leafminers, precipitating destructive outbreaks. The adult flies lay their eggs on the host plants and the larvae feed within the leaves. Although a single larva causes minimal damage, large populations destroy the leaves and affect the growth of plants. At high densities the pests significantly reduce crop yields; for example, in some areas of Indonesia, L. huidobrensis has been reported to have caused 100% yield loss in potato crops and up to 70% losses in other crops.

The leafminers have developed resistant to most insecticides, so Integrated Pest Management techniques are now being promoted in south-east Asia. These include biological control, cultivating resistant or tolerant cultivars of plants, using sticky yellow traps to capture the flies, and implementing management options and cultivation techniques that will discourage infestation by the pests. Selective insecticides should be used only as a last resort.

Pea leafminer

Celery leafminer

Pea leafminer larvae

The smallest of invasive alien species – disease-causing micro-organisms such as bacteria, viruses and fungi – pack a giant-size punch in terms of their impact on human health, agricultural productivity and the global economy.

SARS

Severe acute respiratory syndrome (SARS) is a respiratory illness caused by a coronavirus. The illness first appeared in southern China in November 2002, and is widely believed to have originated in animals traded in the region's markets. By March 2003, SARS was recognised as an international threat. It spread rapidly to more than two dozen countries in North and South America, Europe and Asia, resulting in more than 8000 cases and over 750 deaths. It caused massive disruption of travel and tourism, and had a significant impact on the global economy. The virus is thought to be transmitted primarily through respiratory droplets emitted when an infected person coughs or sneezes.

SARS in Singapore

In August 2003, amidst the SARS outbreak, most companies in the services industry in Singapore – one of the many affected economies in the region – recorded the largest-ever drop in operating income between April in June of that year. These losses were the direct result of local citizens staying at home and visitors canceling travel arrangements to the region out of fear of the contagious killer virus. Among the businesses, the air transport industry was worst hit wit a 42, 2% contraction in business receipts while transport-related services recorded income losses of 27,7% for the period. Ironically, medical receipts fell by as much as 34,8% because citizens put off all non-emergency treatment for fear of contracting the SARS virus.

Drastic measures taken by Singaporean schools

On 26 March 2003 Singapore announced a closure of all schools for more than two weeks as a precautionary measure against the new SARS virus. Aimed at prevention, the move had another spin-off – it added to the intense fear many citizens had towards this killer disease. The Singapore Prime Minister even referred to this fear when he said in his 2003 National Day Rally Speech that SARS stood for "Singaporeans Are Really Scared"!

When the schools reopened, the returning students had to, under strict supervisions, disinfect their desks each day with detergent while they were handed thermometers to take their temperatures twice daily. Special logbooks were kept for each student to record the readings and those with readings of 37,5ºC or higher were sent for immediate medical observation.

Mr Kim Hak-Su – Executive Secretary of the United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP) as part of the Opening Statement of the September 2003 meeting of the Committee on Emerging Social Issues, held in Bangkok:

"Infectious diseases such as SARS are more than just a health problem. They have a profound impact on the social and economic development in the Asian and Pacific region. Unless this is recognised, our ability to respond effectively to new and re-emerging infectious diseases will be limited."

Avian Influenza

Avian influenza is a viral infection caused by a Type A influenza virus. Wild waterbirds are believed to act as natural hosts of such viruses, and their contaminated saliva, nasal secretions and faeces may infect domestic birds such as poultry and pets, causing widespread disease and mass mortalities. Between December 2003 and February 2004, for example, outbreaks of the H5N1 virus strain occurred amongst chicken and ducks in South Korea, Japan, Vietnam, Thailand, Indonesia, Cambodia, Laos and China. Although avian influenza viruses do not usually infect humans, several instances have been reported since 1997, and in this epidemic there were 34 confirmed cases in Vietnam and Thailand, with 23 fatalities. Most of those infected were children and young adults who had been in close contact with poultry. At present there is no indication of human-to-human transmission, but all influenza viruses are capable of changing. It is feared that a new sub-type of the virus might emerge that could rapidly spread around the world, causing an influenza pandemic.

Devastating effects of avian influenza

HIV/AIDS

The Human Immunodeficiency Virus – HIV – was first isolated in 1983, but it is thought to have originated from cross-species transfer of a simian immunodeficiency virus from chimpanzees in central Africa, probably centuries ago. By the end of 2003, an estimated 40 million people worldwide had been infected with HIV, with 4.6-8.2 million cases in south and south-east Asia.

The virus is primarily spread by sexual transmission, but also through contact with contaminated blood, tissue, or needles, and from mother to child during birth or breast-feeding. The virus damages the immune system over time, weakening the body's resistance to other infections. This eventually results in the onset of AIDS – Acquired Immune Deficiency Syndrome – a clinical, ultimately fatal, disease accompanied by dramatic weight loss. Pneumonia is the leading cause of death, but the incidence of certain types of cancers is also increased.

State of the AIDS epidemic in South Asia

According to UNAIDS, more than 5 million people in South Asia are living with HIV/AIDS, with over 90% of those infected, living in India. And, the numbers are increasing! Both high-risk behaviors and infection rates are growing across the region. Countries across tropical Asia are running the risk of experiencing the devastating social and economic impacts of the kind of full-blown AIDS epidemics seen in Africa and elsewhere.

In India alone, around 5.1 million people are infected with HIV. This rate is still low in terms of total population figures, but this still makes India a nation with one of the largest HIV-positive populations in the world, second only to South Africa. However, the epidemic has already advanced into the generalised state (prevalence rate of higher than 1 percent among women attending ante-natal clinics in 1993) in seven of India's 28 states.

Although other countries in the region, such as Bangladesh, Pakistan, and Nepal, are characterized by a low prevalence among the general population, sizable sub-population groups in these countries have significantly higher rates. These groups characteristically engage in high-risk activities such as injecting drugs with contaminated needles and engaging in the selling and buying of sex.

The World Bank lists a number of significant structural and socio-economic factors that add to the risk of a full-blown AIDS epidemic in South Asia. These are:
• More than 35 % of the population lives below the poverty line • Low levels of literacy • Porous borders • Rural to urban and intrastate migration of male populations • Trafficking of women and girls into prostitution • High stigma related to sex and sexuality • Structured commercial sex and casual sex with non-regular partners • Male resistance to condom use • High prevalence of sexually transmitted diseases (STDs), and • Low status of women, leading to an inability to negotiate safe sex.

Cholera

Cholera is an infectious disease caused by the bacterium *Vibrio cholerae*. It is spread in food and water contaminated by bacteria from the faeces of infected people. Symptoms include severe and painful diarrhoea, resulting in dehydration and even death if left untreated. Indeed, more than half of all patients die without treatment, which mainly involves intravenous or oral replacement of fluids and salts, while antibiotics can shorten the duration of the disease.




Foot and mouth disease

Foot and mouth disease is caused by a virus from the family Picornaviridae. It affects cloven-hoofed animals such as cattle, pigs, sheep, goats and deer. The name of the disease refers to the painful blisters and inflamed skin on the mouth and feet of infected animals. There is no treatment for the disease, so it can only be eradicated from an area by slaughtering all infected animals, as well as any that may have been in contact with them. For example, during the February-September 2001 outbreak in Britain, just over 2 000 cases were reported, but more than 4 million cattle had to be slaughtered. Since the virus can be spread in meat, diary food, soil, bones, untreated hide and farm equipment, restrictions are imposed on movements within the affected area, and exports are banned.

Rabies

All warm-blooded animals, including humans, are susceptible to rabies, which is caused by a virus that enters the body through the bite of an infected animal. The virus attacks the central nervous system, and is almost always fatal unless a vaccine is administered soon after the bite occurs. Suspect animals must be killed for a diagnosis to be confirmed, as this necessitates examining brain tissue. Symptoms usually appear within four to six weeks in humans, and include spasmodic contractions of the diaphragm and larynx. Patients experience extreme thirst, but develop a fear of water, known as hydrophobia, that prevents them from drinking. Death is usually the result of a convulsive seizure, or cardiac or respiratory failure.

The rabies virus

Newcastle disease

Newcastle disease, caused by a virus belonging to the family Paramyxoviridae, is a disease of birds, including domestic poultry, cage and aviary birds, and wild birds. There is no known cure for the disease, which is characterised by digestive, respiratory and nervous distress, although many birds die without showing any symptoms. The virus is shed in the droppings, as well as secretions from the nose, mouth and eyes, so it spreads rapidly within a bird colony or poultry farm. Humans unwittingly facilitate the spread the disease when infected material contaminates their clothes, shoes or equipment.

Epizootic ulcerative syndrome

Epizootic ulcerative syndrome, commonly referred to as EUS, is a disease of freshwater and estuarine fish that has spread throughout south and south-east Asia in the last two decades. It is indistinguishable from red spot disease – first observed in eastern Australia in 1972 – and mycotic granulomatosis – reported from Japan in 1971 – but in Asia the responsible organism has been identified as the fungus *Aphanomyces invaderis*. Infected fish develop ulcerative lesions that may erode so deeply that they expose the skeleton and internal organs. The disease affects both wild and cultivated fish, causing episodic mass mortalities, but snakeheads and catfish are particularly vulnerable. In the decade up to 1993, EUS resulted in losses worth an estimated US$100 million in Thailand.

White spot syndrome virus

White spot syndrome virus – generally referred to as WSSV – is the leading cause of disease-related production losses in the shrimp culture industry. Since its first appearance in cultured penaeid prawns in Taiwan in 1992-1993, it has spread rapidly through the shrimp-growing regions of Asia and the Indo-Pacific. In 1995 the first case of WSSV in the Western Hemisphere was reported from Texas.

The disease is associated with a group of viruses that appear to be similar in genetic composition and are widely dispersed geographically. It can induce 100% mortality in infected shrimps within 2 to 7 days from the onset of clinical signs, which comprise white spots on the exo-skeleton, a reddish discoloration, lethargy and reduction in food consumption. The virus targets ectodermal and mesodermal cells, including the cuticular epithelium, connective tissues of some organs, nervous tissue and muscle. As a result, it damages – and may ultimately destroy – organs such as the stomach, gills, heart and eyes.

Cultured penaeid prawns

Citrus canker

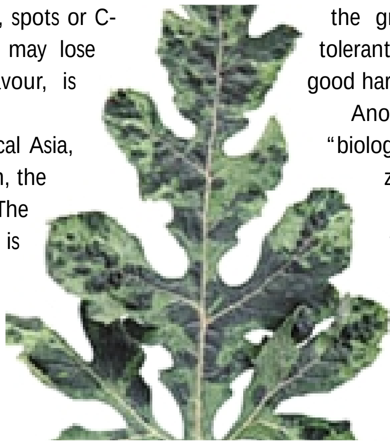
Citrus canker is a bacterial disease of citrus plants, such as oranges, lemons, limes and grapefruit, which causes premature leaf and fruit drop. It is characterised by brown, raised lesions – each with a greasy-looking margin and a yellow ring or halo – on the fruit, leaves and twigs. It is highly contagious, and is readily spread by windborne rain, birds and insects, and humans.

Citrus canker probably originated in Southeast Asia, which is the ancestral home of citrus. In spite of the heightened regulations imposed by many countries to prevent introduction, the disease continues to increase its geographic range. Citrus canker presently occurs in over thirty countries in Asia, the Pacific and Indian Ocean islands, South America, and the United States.

Papaya ring spot virus (PRSV)

The papaya ring spot virus (PRSV) originates in South America, and was first detected in Asia in 1975, in Taiwan. It has since spread to most papaya-growing areas in south and south-east Asia, probably through the importation of infected papaya plants. Once introduced, it is transmitted from plant to plant by aphids, which carry the virus in their piercing mouthparts. Symptoms of the disease include mottling and distortion of the leaves, streaks on the leafstalks and stem, and characteristic rings, spots or C-shaped markings on the fruit. The plant may lose vigour, and fruit quality, particularly flavour, is compromised.

PRSV is a severe problem all over tropical Asia, including Thailand, Malaysia (Johore), Taiwan, the Philip-pines, and the southern region of The People's Republic of China. Globally it is widespread and can be found from the Middle East to the Caribbean and South America. In Europe it is a known invader in France, Germany and Italy as well as in India and parts of the United States such as Florida, Hawaii, and Texas.



Although there is no cure for this viral disease, there are various proven ways of managing this global pest. Preventing new introductions of PRSV in major growing areas is at present the best option available. This is mostly done by controlling the transportation of papaya plants and other host plants. In addition, early detection and rapid response can be effective but only in areas where the virus is not yet established. Another strategy is to promote the growing of plants that are more tolerant to the virus while still producing good harvests even when infected.

Another control method is through "biological barriers" consisting of barrier zones of non-susceptible plants to protect healthy papaya plantations from the PRSV-carrying aphids. The virus is non-persistent, and one can therefore easily get rid of it whilst it feeds on these "barrier" plants before feeding on the papaya, thus preventing virus transmissions.

Potato blight

The most important disease of potatos worldwide is late blight, caused by the fungus *Phytophthora infestans*. It was largely responsible for the Great Irish Famine of 1845-1847, in which a million people died. The disease is widespread in most Asian potato-growing countries – ranging from the tropics to temperate regions – and causes rotting of the leaves, stems and tubers. It is especially prevalent in wet seasons and cool mountain areas, and in extreme cases can result in yield losses of up to 80%. The disease is mainly spread through exposure to infected plant material, but also through wind-dispersal of fungal spores.

TROPICAL ASIA invading

Invasive Alien Species originating from tropical Asia

While numerous invasive alien species occur in tropical Asia, many of the region's own plants and animals have invaded other parts of the world. The following pages highlight a small selection of these 'exports'.

Kudzu

Kudzu *Pueraria montana* is a semi-woody vine, indigenous to southern and eastern Asia, from India to China and Japan. It was first introduced to the United States as an ornamental vine to shade the Japanese pavilion at the 1876 Centennial Exposition in Philadelphia. Later, during the 1930s, farmers were encouraged to plant the vine to control soil erosion. Its rapid growth rate – up to 20 metres per year – allowed it to spread rapidly, creeping overland and climbing whatever lay in its path. It formed dense infestations, invading valuable crop land, infesting forests, climbing utility poles and damaging telephone and power lines, and over-running houses where it was planted to shade porches. It now affects up to 7 million acres of land in the south-eastern parts of the United States, causing an estimated US$100 million in damages to crops, forests and property.

Mysore thorn

The Mysore thorn *Caesalpinia decapetala* – also known as Mauritius thorn, cat's claw and wait-a-bit – is indigenous to tropical Asia, but has invaded Africa, Australia, subtropical parts of New Zealand, as well as the islands of Hawaii, Fiji, French Polynesia and New Caledonia. It was typically introduced as a hedge plant, as it forms dense, thorny thickets that act as an impenetrable barrier. However, this makes it a problem plant when it blocks access of livestock to water, pastures and shade, or hampers the movements of humans. In forestry plantations, the thickets increase exploitation costs by obstructing access to trees and interfering with the activities of workers. Along watercourses, they restrict water flow and block the movement of debris during flooding, which may exacerbate flood damage.

The Mysore thorn is also a threat to biodiversity. It is an aggressive climber, capable of smothering indigenous vegetation, and little else can grow in the shade beneath the dense leaf canopy.

Although the native range of the two species below does not fall within the tropical Asian region, they do occur in the waters off China and are known marine invasives the world over.

North Pacific seastar

The North Pacific seastar *Asterias amurensis* is a large, yellow and purple starfish that is native to China, Korea, Russia and Japan. It has been introduced to Tasmania and Victoria in Australia, presumably either as larvae in ballast water or as hull-fouling juveniles and adults. Although it prefers temperatures of 7-10 °C in its native range, it can invade much warmer waters, thriving in temperatures of up to 22 °C in Australia. It is usually found in shallow subtidal zones, but has been reported from waters as deep as 200 metres.

The starfish is highly predatory, preferring mussels, scallops and clams, but feeding opportunistically on a wide range of food, including other starfish. It can quickly establish large populations – in Port Phillip Bay, near Melbourne, for example, the population reached an estimated 12 million within two years of being detected. It is therefore a threat to indigenous marine invertebrates, as well as shellfish fisheries and mariculture operations. Ironically, the mariculture industry may inadvertently spread the species, on equipment such as oyster seed trays, salmon cages and mussel ropes. In addition, the starfish has a very long planktonic stage – remaining as free-swimming larvae for up to 90 days – which also facilitates its dispersal.

Chinese mitten crab

The Chinese mitten crab *Eriocheir sinensis* is native to rivers of China and Korea that drain into the Yellow Sea. In 1912 a specimen was recorded in the River Aller in Germany, and today invasive populations can be found throughout northern Europe. In North America, the crab was first detected in San Francisco Bay in 1992, and is now well established throughout the estuary, as well as in rivers of the surrounding catchment.

The crab lives in freshwater, taking between one and five years to develop, depending on environmental conditions. Then, in late summer, the adults migrate to the coast to breed in brackish or salt water, and die shortly afterwards. After a planktonic larval development stage, the juvenile crabs move upstream in spring to complete their lifecycle. The juveniles mainly eat vegetation, but as they mature the crabs increasingly prey upon animals, especially small invertebrates such as worms and clams. At high densities, therefore, they have the potential to impact indigenous communities through predation and competition.

Also of concern is their burrowing habit, which may increase erosion and cause slumping of river banks and canal walls. This not only alters freshwater habitats, but may threaten engineering works such as drainage and irrigation systems. The crabs have also been known to clog pumps, screens and intakes in water schemes.

In San Francisco Bay, the crabs disrupt some fishing and shrimping operations by stealing bait and – when caught in large numbers – by damaging nets and the fish catch within them.

Common mynah

The common mynah *Acridotheres tristris* is sometimes called the Indian mynah because it is native to India and surrounding countries in south and south-east Asia. However, the bird has become established in Australia, New Zealand, South Africa, Hawaii, New Caledonia, Fiji, Western Samoa, the Solomon Islands, Cook Islands, and some other oceanic islands. In many cases it was introduced deliberately to control insect pests on crops, but sometimes accidentally when cagebirds escaped. The bird is an opportunistic feeder that eats almost anything, contributing to its success as an invader.

In areas where it has invaded, the mynah reduces the biodiversity of local birdlife, as it competes aggressively with indigenous birds for food and nest sites, and eats their eggs and chicks. It damages fruit and grain crops in agricultural areas, and may cause a decline in populations of beneficial insects. It probably also facilitates the spread of invasive plants, by eating their fruit and dispersing the seeds in their droppings. In Hawaii, for example, the mynah was introduced to control insects in sugarcane fields, but was later implicated in the spread of invasive *Lantana camera.*

Mynahs often roost communally, and may nest in hollows in trees or walls and under roof eaves. They are considered a nuisance by people living in urban areas, being noisy birds that call loudly as they enter and leave the roost. They are also unwelcome houseguests because they attack other garden birds, eat the fruit on garden trees, make a mess with their droppings, and may bring itch-causing mites into the home when nesting in the eaves.

Small Indian mongoose

The native range of the small Indian, or Javan, mongoose *Herpestes javanicus* extends from Pakistan to the south coast of China, and throughout the Malaysian Peninsula and Java. Starting in the 1870s, it was widely introduced to the West Indies, Mauritius, Hawaii and several other islands to control rats and snakes in sugarcane fields or other crops. It was only partly successful in this regard, but it spread rapidly and soon became a pest.

Apart from killing domestic poultry, the mongoose began preying on indigenous animals. Ground-nesting birds and their eggs were particularly easy targets, but small mammals and reptiles were also threatened. The mongoose has already been held responsible for the extinction of two birds in Jamaica and seven amphibian and reptile species in Puerto Rica. Furthermore, the species is a vector and reservoir of rabies and leptospirosis. Based on the public health risk, poultry losses, and impact on biodiversity, it is estimated that the mongoose is causing US$50 million in damages each year in Puerto Rico and the Hawaiian Islands alone.

Macaque monkey

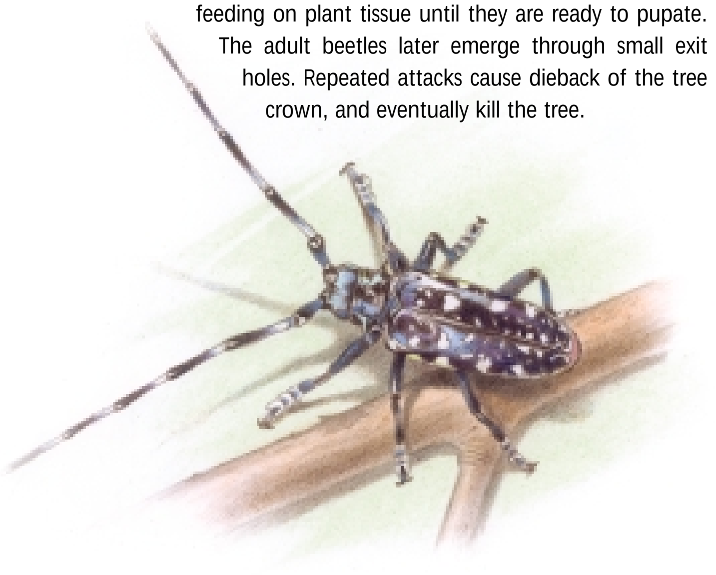
The crab-eating macaque *Macaca fascicularis* – native to south-east Asia – is thought to have been introduced to Mauritius by the Portuguese in the early 16th century. The population has since grown to between 40 000 and 60 000, and the monkeys are regarded as agricultural pests because they steal sugarcane and other crops on the island. They also facilitate the dispersal of invasive plant species by feeding on fruits and seeds, which make up about 70% of the diet. They threaten indigenous forest birds by competing with them for these food resources, and more importantly, by preying on their eggs and chicks.

Indeed, nest predation by the monkeys, as well as by feral cats and rats, is compromising the recovery of the endangered pink pigeon, which is being brought back from extinction by a captive-breeding programme. The monkeys cannot be killed for socio-religious reasons, but many are trapped and exported for biomedical research purposes. A levy is paid to the National Parks and Conservation Fund for each monkey exported.

Asian long-horned beetle

The Asian long-horned beetle *Anoplophora glabripennis* is indigenous to China and Korea. It was probably introduced to the United States during the 1980s, on wooden packing material. In 1996 the first infestation was discovered in New York, and two years later a second infestation was found in Chicago. In 2001 the first European infestation was discovered, in Braunau in Austria.

The beetle attacks hardwood trees, such as maple, poplar, birch, horsechestnut, willow, elm and mulberry. The adults feed on the leaves, petioles and twigs, then bore into the trunk of the tree to lay their eggs. After hatching, the developing larvae tunnel beneath the bark, feeding on plant tissue until they are ready to pupate. The adult beetles later emerge through small exit holes. Repeated attacks cause dieback of the tree crown, and eventually kill the tree.



Since larvae live deep inside the tree for much of the year, conventional insecticides are ineffective in controlling the pest. Previously the only solution was to destroy all infested trees, and by May 2001 more than 6 000 trees had been felled in New York and Chicago. More recently, the insecticide imidacloprid has shown promising results in controlling the beetle. The insecticide is injected into the tree and then disperses through the vascular system, allowing it to poison the tunnelling larvae as well as adult beetles feeding externally. An eradication programme initiated in May 2004 aims to treat approximately 69 000 trees in New York, to prevent further infestation. Biological control agents are also under investigation.