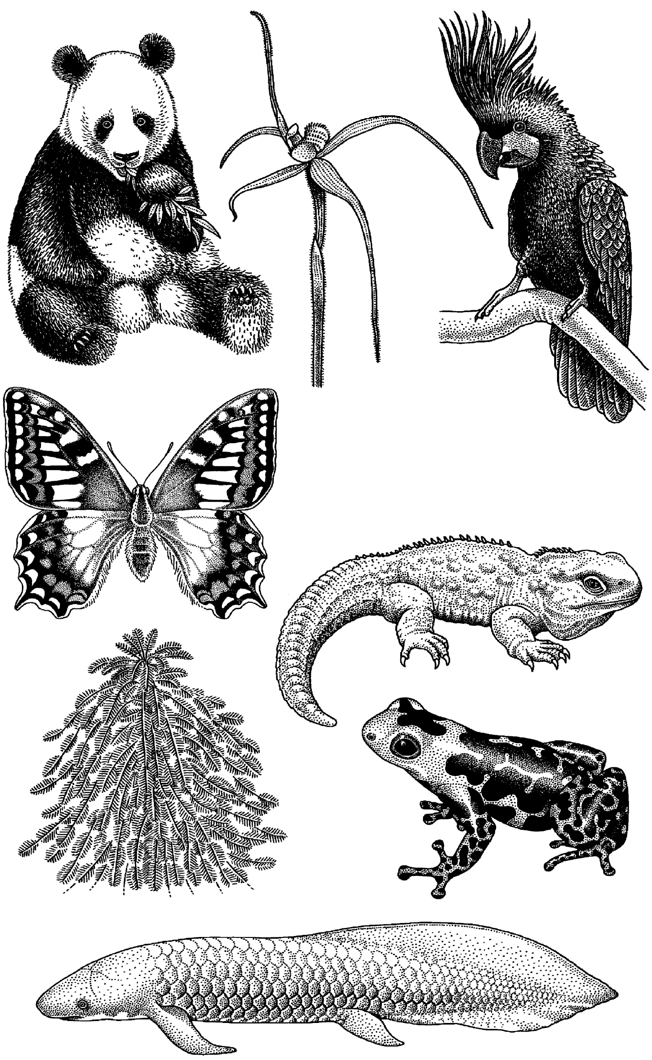
Chapter 1

Introduction

Many species are threatened with extinction. Populations of endangered species typically decline due to habitat loss, over-exploitation, introduced species, pollution and climate change. At small population sizes, additional factors (demographic and environmental variation, genetics and catastrophes) increase their risk of extinction. Conservation genetics applies genetic knowledge to reduce the risk of extinction in threatened species

Terms

Biodiversity, bioresources, catastrophes, critically endangered, demographic stochasticity, ecosystem services, endangered, environmental stochasticity, evolutionary potential, extinction vortex, forensics, genetic diversity, genetic drift, genetic stochasticity, inbreeding depression, introgression, meta-analysis, purging, reproductive fitness, speciation, stochastic, threatened, vulnerable



Selection of threatened species. Clockwise: panda (China), an Australian orchid, palm cockatoo (Australia), tuatara (New Zealand), poison arrow frog (South America), lungfish (Australia), Wollemi pine (Australia) and Corsican swallow-tail butterfly

The 'sixth extinction'

Biological diversity is rapidly being depleted as a consequence of human actions

The current extinction crisis has been called the 'sixth extinction', as its magnitude compares with that of the other five mass extinctions revealed in the geological record (Leakey & Lewin 1995). Extinction is a natural part of the evolutionary process, species typically persisting for ~5–10 million years. Biodiversity (the variety of ecosystems, species, populations within species, and genetic diversity within species) is maintained when extinctions are balanced by the origin of new species (**speciation**). However, mass extinctions, such as the cosmic cataclysm at the end of the Cretaceous, 65 million years ago, reduce biodiversity. It takes many millions of years for recovery. The sixth extinction is equally dramatic. Species are being lost at a rate that far exceeds the origin of new species but, unlike previous mass extinctions, this is mainly due to human activities (IUCN 2007).

Conservation genetics, like all components of conservation biology, is motivated by the need to preserve biodiversity and to reduce current rates of extinction.

Why conserve biodiversity?

Maintenance of biodiversity is justified for four reasons: the economic value of bioresources, ecosystem services, aesthetics and rights of living organisms to exist

Bioresources include all of our food, many pharmaceutical drugs, natural fibres, rubber, timber, etc. Their value is many billions of dollars annually. For example the world fish catch is valued at $US58 billion annually (UNEP 2007). Over half of the top 150 prescription drugs in the USA contain active ingredients derived directly or indirectly from living organisms (Millennium Ecosystem Assessment 2005a). Malaria, one of the world's most deadly diseases, has been treated with drugs derived from natural products, including quinine, chloroquine, mefloquine, doxycycline and artemisins. Further, the natural world contains many novel, potentially useful resources (Beattie & Ehrlich 2004). Ants synthesize novel antibiotics that are being investigated for use in human medicine, spider silk is stronger weight-for-weight than steel and may provide the basis for light high-tensile fibres, etc.

Ecosystem services are essential biological functions that are provided free of charge by living organisms (Millennium Ecosystem Assessment 2005a). Examples include oxygen production by plants, climate regulation, carbon sequestration, nutrient cycling, natural pest and disease control and pollination of crop plants. In 2000, these services were valued at $US38 trillion ($10^{12}$) per year, similar in size to the yearly global national product (Balmford *et al.* 2002). For example, honeybee pollination of crops has been valued at $US2 billion per annum (UNEP 2007). The benefit : cost ratio for wildlife conservation versus exploitation is 100 : 1, based on a review of 200 case studies (Balmford *et al.* 2002).

Humans derive pleasure (aesthetic value) from living organisms, expressed in cultivation of ornamental plants, keeping pets, visiting zoos and nature reserves, ecotourism and viewing wildlife documentaries. This translates into direct economic value. For example, the aggregate revenue generated by ecotourism in Southern Africa was estimated as $US3.66 billion in 2000, roughly 50% of all tourism revenue in the area (Millennium Ecosystem Assessment 2005a).

The ethical justification for biodiversity conservation is that one species on Earth does not have the right to drive others to extinction, parallel to abhorrence of genocide among human populations.

The primary international conservation body, IUCN (the World Conservation Union), recognizes the need to conserve the biological diversity at all three levels (McNeely *et al.* 1990). Genetics is a key consideration at all levels, being the sole issue in the first, having an important role in species viability, and a role in ecosystem viability (Bangert *et al.* 2005; Lankau & Strauss 2007). Its importance to ecosystem viability has only recently been documented. For example, a seagrass community with higher genetic diversity recovered better following a heatwave, and snails and isopods associated with seagrass also benefited (Reusch *et al.* 2005).

IUCN recognizes the need to conserve biodiversity at three levels: genetic diversity, species diversity and ecosystem diversity

Endangered and extinct species

Recorded extinctions

The proportions of species in different groups known to have gone extinct since records began in 1600 are small, being only 1–2% in mammals and birds (Table 1.1). However, the rate of extinction has generally increased with time (Primack 2006) and many species are now threatened. Further, many extinctions must have occurred unnoticed, especially those due to habitat loss (Millennium Ecosystem Assessment 2005a).

Over 900 extinctions have been documented since records began in 1600, the majority of these being island species

Table 1.1 Recorded extinctions, 1600 to present, for mainland and island species worldwide

	Number of extinctions on					
Taxa	Islands	Mainlands	Oceans	Total	% extinctions on islands	% of taxon extinct
Mammals[a]	51	30	4	85	60	2.1
Birds[a]	92	21	0	113	81	1.3
Reptiles[a]	20	1	0	21	95	0.3
Amphibians[a]	0	2	0	2	0	0.05
Fish[a]	1	22	0	23	4	0.1
Molluscs[b]	151	40	0	191	79	
Invertebrates[a]	48	49	1	98	49	0.01
Flowering plants[a]	139	245	0	384	36	0.2

[a] Primack (1998).
[b] WCMC (1992).

The majority of recorded extinctions, and a substantial proportion of currently threatened species, are on islands (Table 1.1). For example, 81% of all recorded bird extinctions are insular, four-fold greater than the proportion of bird species found on islands (Myers 1979). We will return to vulnerability and significance of insular populations later in the book.

Extent of endangerment

Many species are threatened with extinction, including 23% of vertebrate animals, 51% of invertebrates and 70% of plant species

IUCN (the World Conservation Union) defines as **threatened** species with a high risk of extinction within a short time frame. These species fall into the categories of critically endangered, endangered and vulnerable, as defined below. In mammals, reptiles, birds, amphibians, fish and plants IUCN (2007) classified 22%, 31%, 13%, 30%, 38% and 70% of assessed species as threatened (Fig. 1.1). Of mammal species, 1.4% are extinct, 0.1% extinct in the wild, 3.4% critically endangered, 7.2% endangered and 12.0% vulnerable.

There are considerable uncertainties about the data for all except mammals, birds, amphibians and gymnosperms, as the status of many species has not been assessed in the other groups. Estimates for microbes are not available as the number of extant species in these groups is unknown.

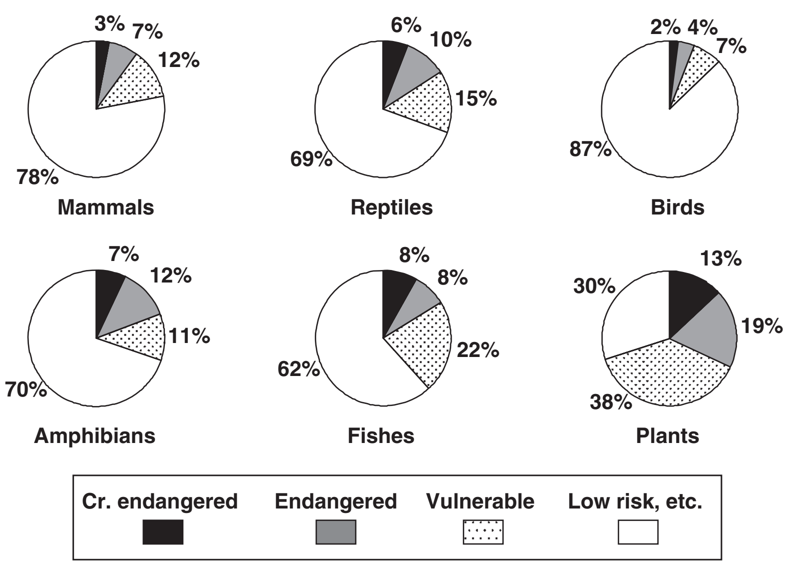


Fig. 1.1 Percentages of mammals, birds, reptiles, amphibians, fishes and plants categorized as critically endangered, endangered, vulnerable and at lower risk (after IUCN 2007).

Projected extinction rates

Projections indicate greatly elevated extinction rates in the near future

There is a consensus that extinction rates are destined to accelerate markedly, typically by 100–1000-fold or more above the 'normal' background extinction rates deduced from the fossil record (Millennium Ecosystem Assessment 2005a). This is primarily due to the continuing escalation of the human population, and its anticipated impact on the rest of the global biota.

Current extinction rates are 10 times those in the fossil record (UNEP 2007). In line with these projections, the overall threat status of the planet's birds has worsened since 1988 (Butchart *et al.* 2004). Further, there has been an alarming recent decline in amphibians, probably exacerbated by a pathogenic fungus in association with global warming. Up to 122 amphibian species have disappeared since 1980 (Pounds *et al.* 2006, 2007). Global climate change is projected to commit 15–37% of species to extinction by 2050 (Thomas, C. D. *et al.* 2004). In Britain 28% of native plant species have declined over the last 40 years, 54% of native bird species have declined over the last 20 years and 71% of native butterflies have declined over ~20 years (Thomas, J. A. *et al.* 2004).

What is an endangered species?

The IUCN (2007) has defined criteria to classify threatened species into **critically endangered**, **endangered**, **vulnerable** and **lower risk**, based on population biology principles developed largely by Mace & Lande (1991). These categories are defined in terms of the rate of decline in population size, restriction in habitat area, the current population size and/or the probability of extinction (Table 1.2).

Endangered species are those with a high risk of immediate extinction

Table 1.2 Defining endangerment (IUCN 2007 criteria)

Category	Probability of extinction	Time
Critically endangered	50%	10 yrs or 3 generations
Endangered	20%	20 yrs or 5 generations
Vulnerable	10%	100 yrs

A critically endangered species exhibits at least one of the characteristics described in the second column under A–E in Table 1.3. These characteristics include: an 80% or greater decline in population size over the last 10 years (or three generations); an extent of occupancy of less than 100 square kilometres; a population size of less than 250 mature adults; a probability of extinction of 50% or more over 10 years (or three generations). For example, there are only about 65 Javan rhinoceroses surviving in Southeast Asia and their numbers are continuing to decline, so this species falls into the category of critically endangered. Other examples are given in the Problems at the end of the chapter.

There are similar, but less extreme characteristics required to categorize species as endangered, or vulnerable. Species falling outside these criteria are designated as lower risk. IUCN has also defined categories of extinct, extinct in the wild, conservation dependent, near threatened and data deficient (IUCN 2007).

Table 1.3 Information used to decide whether species fall into the critically endangered, endangered or vulnerable IUCN categories (simplified from IUCN 2007). *A species falling within any of the categories A–E in the critically endangered column is defined as critically endangered. Similar rules apply to endangered and vulnerable*

Criteria (any one of A–E)		Critically endangered	Endangered	Vulnerable
A	Actual or projected decline in population size and continuing threat	80% over the last 10 years or 3 generations	50%	30%
B	Extent of occurrence:	$<100\ km^2$	$<5000\ km^2$	$<20\,000\ km^2$
	or area of occupancy of:	$<10\ km^2$	$<500\ km^2$	$<2000\ km^2$
	and any two of:			
	(i) severely fragmented or known to exist at:	a single location	≤5 locations	≤10 locations
	(ii) continuing declines, and			
	(iii) extreme fluctuations			
C	Population numbering and an estimated continuing decline	<250 mature individuals	<2500	<10 000
D	Population estimated to number:	<50 mature individuals	<250	<1000
E	Quantitative analysis showing a probability of extinction in the wild of:	at least 50% within 10 yrs or 3 generations, whichever is the longer	20% in 20 yrs or 5 generations	10% in 100 yrs

While many other systems are used throughout the world to categorize endangerment, the IUCN provides the only international system for listing of species in the IUCN *Red Books* of threatened species (de Grammont & Cuarón 2006; IUCN 2007). Rankings obtained using the IUCN classifications are related, but not identical to rankings from two other widely used systems, and all are related to extinction risks determined using computer models (O'Grady *et al.* 2004). We primarily use the IUCN system throughout this book.

Importance of listing

Listing a species or sub-species as endangered provides a scientific foundation for national and international legal protection, and may lead to remedial actions for recovery

Endangerment is the basis for legal protection for species. For example, most countries have Endangered Species Acts that provide legal protection for threatened species and usually require the formulation of recovery plans. Threatened species are also protected from trade by the 172 countries that have signed the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2007). This provides important protection for approximately 28 000 species of plants and 5000 species of animals, including threatened cats, primates, whales, parrots, reptiles, amphibians, fish, etc.

What causes extinctions?

Human-associated factors

The primary factors contributing to extinction are directly or indirectly related to human impacts and to human population size. The human population has grown exponentially, reaching 6.6 billion in late 2007. The last 1.5 billion increase (30%) occurred in only about 20 years. By 2050, the population is projected to rise to 7.8–10.8 billion (United Nations Population Division 2007). Consequently, human impacts on wild animals and plants will continue to worsen.

The primary factors contributing to extinction are habitat loss, introduced species, over-exploitation, pollution and climate change. These factors are caused by humans, and related to human population growth

Additional threats in small populations

Human-related activities often reduce species to population sizes where they are susceptible to additional environmental, catastrophic, demographic or genetic factors. These factors are discussed extensively throughout the book. Even if the original cause of population decline is removed, problems associated with small population size will still persist.

Additional demographic, environmental, catastrophic and genetic factors increase the risk of extinction in small populations

Environmental stochasticity is random unpredictable variation in environmental factors, such as rainfall and food supply. **Demographic stochasticity** is random variation in birth and death rates and sex-ratios due to chance alone. **Catastrophes** are extreme environmental events such as tornadoes, floods, harsh winters, disease epidemics, etc.

Genetic factors encompass the deleterious impacts on species of inbreeding, loss of genetic diversity and the accumulation of deleterious mutations. **Inbreeding** (the production of offspring from related parents), on average, reduces birth rates and increases death rates in the inbred offspring (**inbreeding depression**: Chapters 12 and 13). **Genetic diversity** is the raw material upon which natural selection acts to bring about adaptive evolutionary change. Consequently, loss of genetic diversity reduces the ability of populations to adapt to changing environments (Chapters 6, 8 and 11).

Environmental and demographic stochasticity and the impact of catastrophes interact with inbreeding and genetic diversity in their adverse effects on populations (Chapters 2 and 22). If populations become small for any reason, they become more inbred, further reducing population size and generating additional inbreeding. Smaller populations also lose genetic diversity and suffer reductions in their ability to adapt to changing environments. This feedback between reduced population size, loss of genetic diversity and inbreeding is referred to as the **extinction vortex**. The complicated interactions between genetic, demographic and environmental factors can make it extremely difficult to identify the immediate cause(s) of any particular extinction event.

Recognition of genetic factors in conservation biology

Sir Otto Frankel, an Austrian-born Australian, was largely responsible for recognizing the importance of genetic factors in conservation biology, beginning with papers in the early 1970s (Frankel 1970, 1974; see Soulé & Frankham 2000 for biographical information). Subsequently, Frankel strongly influenced Michael Soulé of the USA and collaborated with him on the first conservation book that clearly discussed the role of genetic factors (Frankel & Soulé 1981). Soulé is recognized as the 'father' of modern conservation biology, having been instrumental in founding the Society for Conservation Biology, serving as its first President, and participating in the establishment of *Conservation Biology*, the premier journal in the field. Throughout the 1980s, Soulé had a profound influence on the development of conservation biology as a multidisciplinary crisis field, drawing on ecology, genetics, wildlife biology and resource biology (Fig. 1.2).

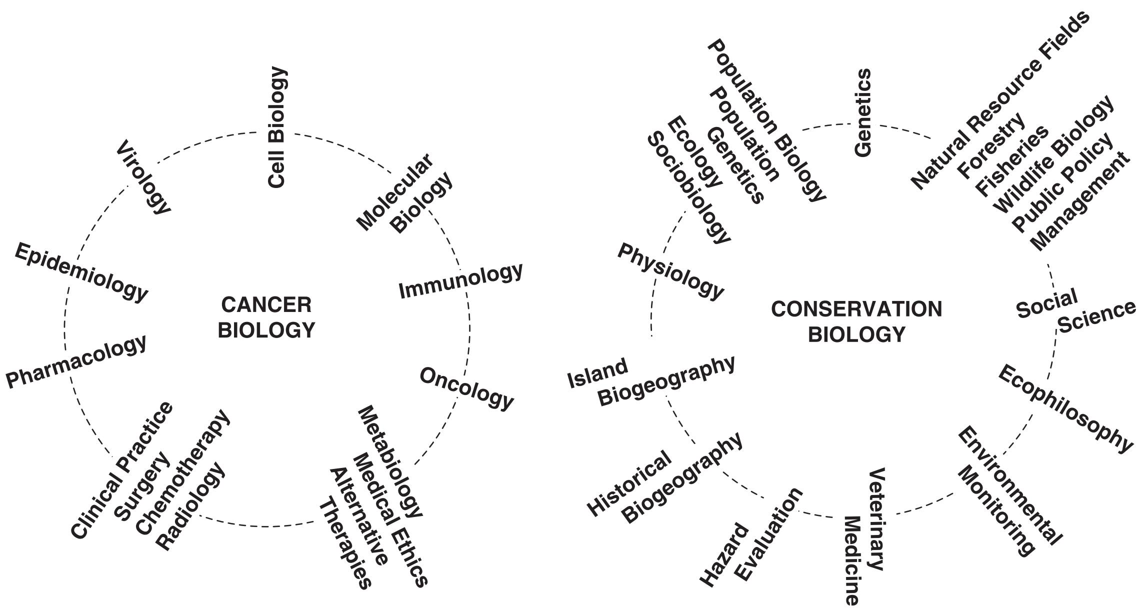


Fig. 1.2 Structure of conservation biology and the position of genetics in it (after Soulé 1985). *Conservation biology is a crisis discipline akin to cancer biology, to which it is compared.*

What is conservation genetics?

Conservation genetics aims to minimize the risk of extinction

Conservation genetics encompasses the use of genetic theory and techniques to reduce the risk of extinction in threatened species. Its longer-term goal is to preserve species as dynamic entities capable of coping with environmental change. Conservation genetics is derived from evolutionary genetics and from the quantitative genetic theory that underlies selective breeding of domesticated plants and animals. However, these theories generally concentrate on large populations where the genetic constitution of the population is governed by predictable deterministic factors. Conservation genetics is now a discrete applied discipline focusing on the genetic consequences arising from reduction of once large, outbreeding populations to small units where stochastic factors and the effects of inbreeding are paramount.

This textbook addresses the major issues in the field, including:

- the deleterious effects of **inbreeding** on reproduction and survival (**inbreeding depression**)
- loss of **genetic diversity** and consequent reduced ability to evolve in response to environmental change (loss of **evolutionary potential**)
- fragmentation of populations and reduction in gene flow
- random processes (**genetic drift**) overriding natural selection as the main evolutionary process
- accumulation and loss (**purging**) of deleterious mutations
- genetic adaptation to captivity and its adverse effects on reintroduction success
- evolutionary processes in invasive species and their impacts on threatened species
- resolving taxonomic uncertainties
- defining management units within species
- deleterious effects on fitness that sometimes occur as a result of outcrossing (**outbreeding depression**)
- use of molecular genetic analyses in **forensics** and to understand aspects of species biology important to conservation.

The structure and content of conservation genetics is illustrated in Fig. 1.3.

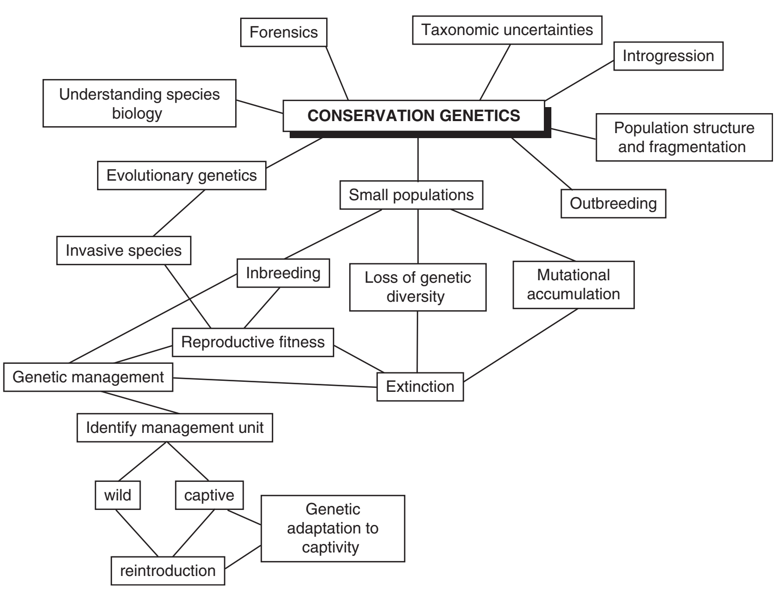


Fig. 1.3 Structure and content of conservation genetics.

Cambridge University Press
978-0-521-70271-3 - Introduction to Conservation Genetics: Second Edition
Richard Frankham, Jonathan D. Ballou, David A. Briscoe and Karina H. McInnes
Excerpt
More information

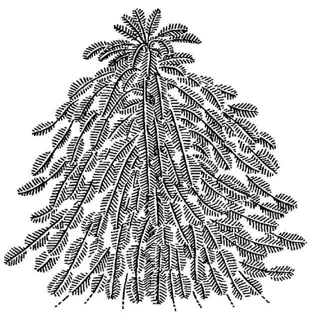
Examples of the use of genetics to aid conservation

Knowledge of genetics aids conservation in the following ways.

Florida panther

Reducing extinction risk by minimizing inbreeding and loss of genetic diversity

Due to a long period of small population size, the endangered Florida panther was affected by several genetic problems, including low genetic diversity and inbreeding-related defects (poor sperm and physical abnormalities). These effects have been alleviated by introducing individuals from its most closely related sub-species in Texas (Chapter 17). Captive populations of many endangered species (e.g. golden lion tamarin) are managed to minimize loss of genetic diversity and inbreeding (Chapter 19).



Wollemi pine

Identifying species or populations at risk due to reduced genetic diversity

Asiatic lions exist in the wild only in a small population in the Gir Forest in India. This population has a very low level of genetic diversity, indicating it has a severely compromised ability to evolve (Chapter 11), as well as being susceptible to demographic and environmental risks (Chapter 22). The recently discovered Wollemi pine, an Australian relict species previously known only from fossils, exists as a small population with no genetic diversity among individuals. Its extinction risk is extreme. All individuals that were tested were susceptible to a common dieback fungus. Its management involves keeping the site secret and quarantined, plus the propagation of plants in other locations and the commercial sale of plants throughout the world.

Red-cockaded woodpecker

Resolving fragmented population structures

Information regarding the extent of gene flow among populations is critical to determine whether a species requires human-assisted exchange of individuals to prevent inbreeding and loss of genetic diversity (Chapter 14). Wild populations of the red-cockaded woodpecker are fragmented, causing genetic differentiation among populations and reduction in genetic diversity in the smaller populations. Consequently, part of the management of this species involves moving (translocating) individuals between populations to minimize inbreeding and to maintain genetic diversity.

Resolving taxonomic uncertainties

The taxonomic status of many invertebrates and lower plants is unknown (Chapter 16). Thus, an apparently widespread and low-risk species may, in reality, comprise a complex of distinct taxa, some rare or endangered. Molecular genetic studies have shown that Australia is home to well over 100 locally distributed species of velvet worms

