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Excerpt
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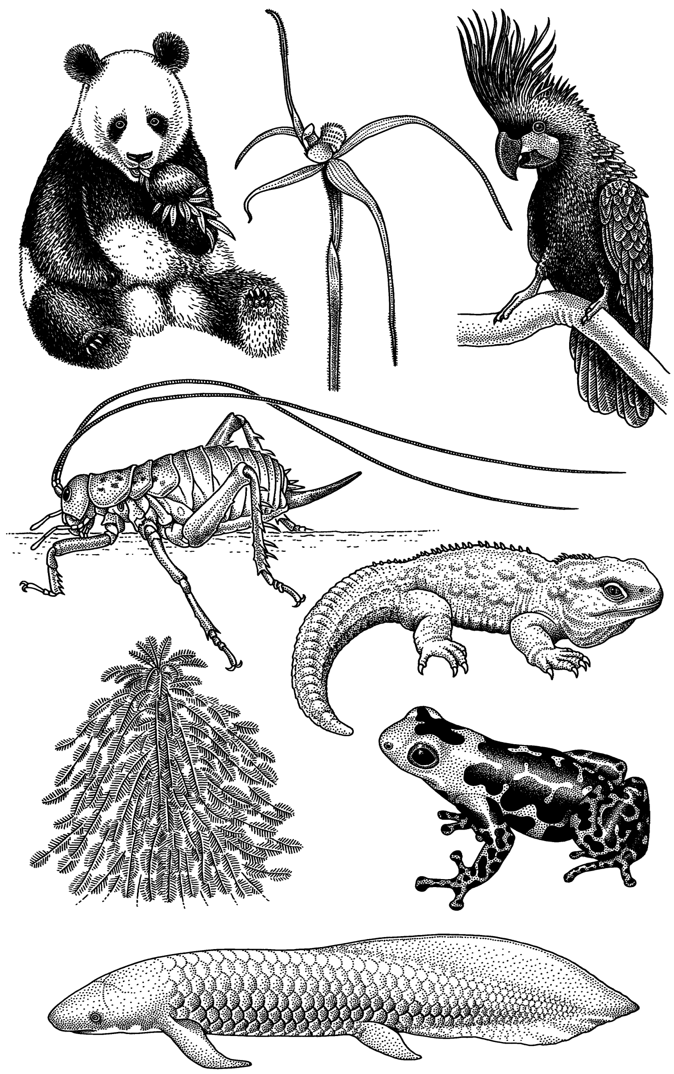
Chapter 1

Introduction

Conservation genetics is the application of genetics to preserve species as dynamic entities capable of coping with environmental change. It encompasses genetic management of small populations, resolution of taxonomic uncertainties, defining management units within species and the use of molecular genetic analyses in forensics and understanding species' biology.

Terms:
Biodiversity,
ecosystem services,
endangered,
evolutionary potential,
forensics,
genetic diversity,
inbreeding depression,
introgression,
meta-analysis,
outbreeding depression,
population viability analysis,
purging,
reproductive fitness,
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 New Zealand weta.

The 'sixth extinction'

The biological diversity of the planet is rapidly being depleted as a direct and indirect consequence of human actions

Biodiversity is the variety of ecosystems, species, populations within species, and genetic diversity within species. The biological diversity of the planet is being rapidly depleted as a direct and indirect consequence of human actions. An unknown but large number of species are already extinct, while many others have reduced population sizes that put them at risk (WCMC 1992). Many species now require benign human intervention to improve their management and ensure their survival. The scale of the problem is enormous, as described below. The current extinction problem 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. For example, the mass extinction at the end of Cretaceous 65 million years ago eliminated much of the previous flora and fauna, including the dinosaurs. However, this extinction made way for proliferation of the mammals and flowering angiosperm plants. The sixth extinction is different. Species are being lost at a rate that far outruns the origin of new species.

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

Why conserve biodiversity?

Four justifications for maintaining biodiversity have been advanced; the economic value of bioresources, ecosystem services, aesthetics, and rights of living organisms to exist

Humans derive many direct and indirect benefits from the living world. Thus, we have a stake in conserving biodiversity for the resources we use, for the ecosystem services it provides for us, for the pleasure we derive from living organisms and for ethical reasons.

Bioresources include all of our food, many pharmaceutical drugs, clothing fibres (wool and cotton), rubber and timber for housing and construction, etc. Their value is many billions of dollars annually. For example, about 25% of all pharmaceutical prescriptions in the USA contain active ingredients derived from plants (Primack 1998). Further, the natural world contains many potentially useful novel resources (Beattie 1995). For example, ants contain novel antibiotics that are being investigated for use in human medicine, spider silk may provide the basis for light high-tensile fibres that are stronger weight-for-weight than steel, etc.

Ecosystem services are essential biological functions that are provided free of charge by living organisms and which benefit humankind. They include oxygen production by plants, climate control by forests, nutrient cycling, natural pest control, pollination of crop plants, etc. (Daily 1999). These services have been valued at $US33 trillion ($10^{12}$) per year, almost double the $US18 trillion yearly global national product (Costanza *et al.* 1997).

Humans derive pleasure from living organisms (aesthetics), as expressed in growing ornamental plants, keeping pets, visits to zoos and nature reserves, and ecotourism. This translates into direct economic value. For example, koalas are estimated to contribute $US750 million annually to the Australian tourism industry (Australia Institute 1997).

The ethical justifications for conserving biodiversity are simply that one species on Earth does not have the right to drive others to extinction, analogous to abhorrence of genocide among human populations.

The peak international conservation body, IUCN (the World Conservation Union), recognizes the need to conserve the biological diversity on Earth for the reasons above (McNeely *et al.* 1990). IUCN recognizes the need for conservation at the levels of genetic diversity, species diversity and ecosystem diversity. Genetics is involved directly in the first of these and is a crucial factor in species conservation.

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

Endangered and extinct species

Extent of endangerment

Threatened species of animals fall into the categories of critically endangered, endangered, and vulnerable, as defined below. IUCN (1996) classified more than 50% of species in every one of the vertebrate classes into one of the threatened categories, as shown in Fig. 1.1.

Over 50% of vertebrate animal species and 12.5% of plant species are classified as threatened

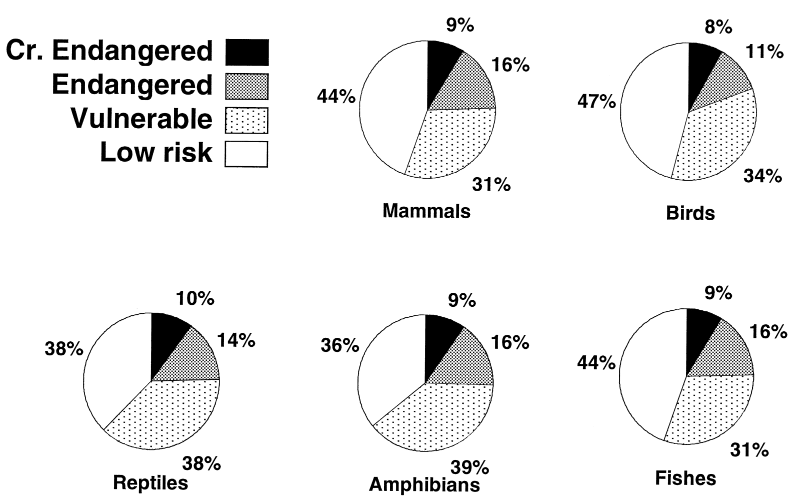


Fig. 1.1 Which vertebrates are the most threatened? Percentages of mammals, birds, reptiles, amphibians and fishes categorized as critically endangered, endangered, vulnerable and at lower risk (after IUCN 1996).

Table 1.1 Recorded extinctions, 1600 to present

Taxa	Number of extinctions on Island	Mainland	Ocean	Total	Percentage of extinctions on islands	Percentage 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

Notes:
[a] From Primack (1998).
[b] From WCMC (1992).

The situation in plants is similarly alarming. IUCN (1997) classified 12.5% of vascular plants as threatened, with a much higher proportion of gymnosperms (32%) than angiosperms (9%) being threatened. Estimates for invertebrates and microbes are not available as the number of extant species in these groups is not known.

Recorded extinctions

Over 800 extinctions have been documented since records began in 1600, the majority being of island species

Recorded extinctions since 1600 for different groups of animal and plants on islands and mainlands are given in Table 1.1. The proportions of species in different groups that have gone extinct are small, being only 1%–2% in mammals and birds. However, the pattern of extinctions is a matter for concern as the rate of extinction has generally increased with time (Fig. 1.2) and many species are threatened. Further, many extinctions must have occurred without being recorded; habitat loss must have resulted in many extinctions of undescribed species of invertebrates and plants (Gentry 1986).

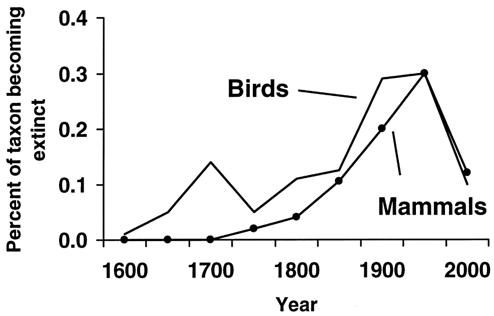


Fig. 1.2 Changes in extinction rates over time in mammals and birds (after Primack 1998, based on Smith *et al.* 1995). *Extinction rates have generally increased for successive 50-year periods.*

Table 1.2 Projected extinction rates for different groups based on a variety of arguments

Estimated extinction rate	Percent global loss per decade	Method of estimation
1 million species between 1975 and 2000	4	Extrapolation of past exponential trend
15%–20% of species between 1980 and 2000	8–11	Species–area curves and projected forest loss
12% of plant species in neotropics		Species–area curves
15% bird species in Amazon basin		As above
2000 plant species per year in tropics and subtropics	8	Loss of half the species in areas likely to be deforested by 2015
25% of species between 1985 and 2015	9	As above
At least 7% of plant species	7	Half of species lost in next decade in 10 'hotspots' covering 3.5% of forest area
0.2%–0.3% per year	2–3	Half of rainforest species lost in tropical rainforests are local endemics and becoming extinct with forest loss
5%–15% of forest species by 2020	2–5	Species–area curve; forest loss assumed twice rate projected by FAO for 1980–85
2%–8% loss between 1980 and 2015	1–5	Species–area curve; range includes current rate of forest loss and 50% increase

Source: WCMC (1992).

The majority of recorded extinctions, and a substantial proportion of currently threatened species, are on islands. For example, 81% of all recorded bird extinctions are insular, yet only about 20% of bird species have existed on islands (Myers 1979). We will return to vulnerability and significance of insular populations many times throughout this book.

Projected extinction rates

Projections point to greatly elevated extinction rates in the near future

Several projections of extinction levels into the future are given in Table 1.2. While these estimates are crude and vary widely, there is a consensus that extinction rates are destined to accelerate markedly, typically by 1000-fold or more above 'normal' background extinction rates.

Average lifespans of species provide an alternative way of viewing rates of extinction. The average lifespan of an animal species in the fossil record, from origin to extinction, is around 1–10 million years, with the higher number being more typical. For birds and mammals, rates of documented extinction over the past century correspond to species'

Table 1.3 Defining endangerment (IUCN 1996 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

lifespans of around 10 000 years. Three different methods suggest an average lifespan for bird and mammal species of around 200–400 years if current trends continue (Lawton & May 1995) i.e. current extinction rates are 5000–25 000 times those in the fossil record.

What is an endangered species?

Endangered species are those with a high risk of immediate extinction

The IUCN (1996) has defined criteria to classify species into **critically endangered**, **endangered**, **vulnerable** and **lower risk**. These are based on population biology principles developed largely by Mace & Lande (1991). They defined a **threatened** species as one with a high risk of extinction within a short time frame. For example, a critically endangered species has a risk of extinction of 50% within 10 years or three generations, whichever is longer (Table 1.3).

IUCN (1996) set out simple rules to define these categories in terms of the rate of decline in population size, restriction in habitat area, the current population size and/or the probability of extinction. A critically endangered species exhibits any one of the characteristics described under A–E in Table 1.4, i.e. it has either an 80% or greater decline in population size over the last 10 years (or three generations), or an extent of occupancy of less than 100 square kilometres, or a population size of less than 250 mature adults, or a probability of extinction of 50% or more over 10 years (or three generations), or some combination of these. For example, there are only about 65 Javan rhinoceroses surviving in Southeast Asia and the 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 threatening characteristics required to categorize species as endangered, or vulnerable. Species falling outside these categories are designated as lower risk. IUCN has also defined categories of extinct, extinct in the wild, conservation dependent, near threatened and data deficient (IUCN 1996).

While there are many other systems used throughout the world to categorize endangerment, the IUCN categorization system is used as the basis of listing species in the IUCN Red Books of endangered animals (IUCN 1996). In general, we have used the IUCN system throughout this book.

Table 1.4 Information used to decide whether species fall into the critically endangered, endangered or vulnerable IUCN categories (IUCN 1996).

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

Importance of listing

It is of great importance to define endangerment, as it 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. In addition, trade in threatened species is banned by countries that have signed the Convention on International Trade in Endangered Species (CITES; Hutton & Dickson 2000). This provides important protection for threatened parrots, reptiles, cats, fish, whales, etc.

Listing a species or sub-species as endangered provides a scientific foundation for national and international legal protection from exploitation and trade, and may lead to remedial actions to recover it

What causes extinctions?

Human-associated factors

The primary factors contributing to extinction are directly or indirectly related to human impacts. Since the human population is growing rapidly (Fig. 1.3), the impacts of these factors are continually increasing. The human population reached 6 billion on 12 October 1999, the last billion increase (20%) having occurred in only 12–14 years. The human population will continue to increase. By 2050, the population is projected to rise to 8.9 billion, with a range of projections between 7.3 and 10.7 billion. However, the rate of increase has declined from a peak of just over 2% per year to below 1.5% in the early 1990s (Smil 1999).

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

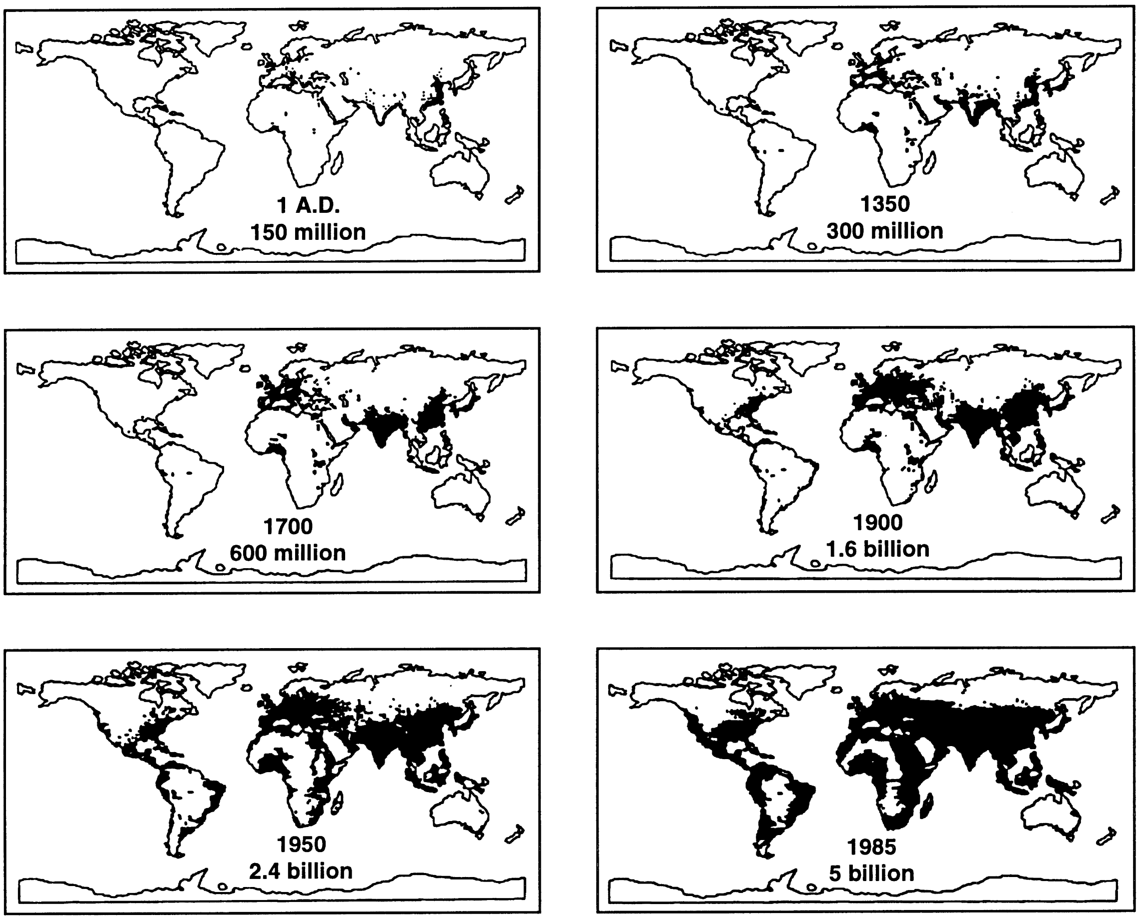


Fig. 1.3 Visual representation of human population growth in different parts of the world (from Tanton 1994).

The total human population is projected to climax at 10–11 billion around 2070 and then begin to decline (Pearce 1999). Even the lower projection of a peak population size of 7.7 billion in 2040 represents a 28% increase above the current population. Consequently, human impacts on wild animals and plants will continue to worsen in the foreseeable future.

Stochastic factors

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

Human-related factors can reduce species to population sizes where they are susceptible to stochastic effects. These are naturally occurring fluctuations experienced by small populations. These may have environmental, catastrophic, demographic, or genetic (inbreeding depression, and loss of genetic diversity) origins. Stochastic factors are discussed throughout the book. Even if the original cause of population decline is removed, problems associated with small population size will still persist.

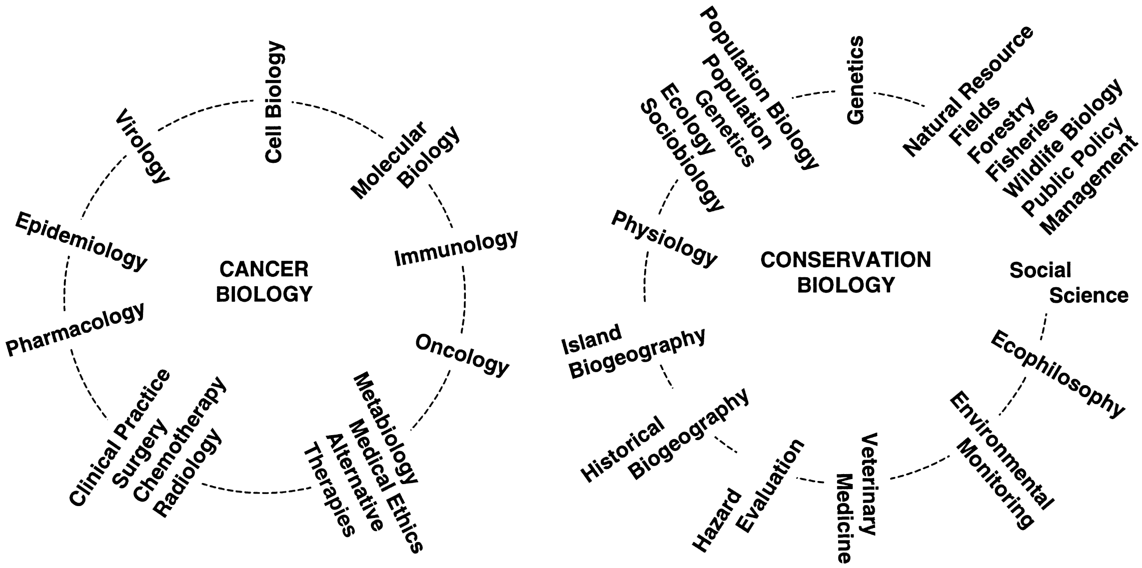


Fig. 1.4 Structure of conservation biology and the position of genetics in it (after Soulé 1985). *Conservation biology is a crisis discipline akin to cancer biology, to which it is compared.*

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 collaborated with Michael Soulé of the USA on the first conservation book that clearly discussed the contribution of genetic factors (Frankel & Soulé 1981). Frankel strongly influenced Soulé's entry into conservation biology. Soulé is 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, Michael 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. 1.4).

What is conservation genetics?

Conservation genetics aims to minimize the risk of extinction from genetic factors

Conservation genetics deals with the genetic factors that affect extinction risk and genetic management regimes required to minimise these risks. There are 11 major genetic issues in conservation biology:

- The deleterious effects of **inbreeding** on reproduction and survival (**inbreeding depression**)
- Loss of **genetic diversity** and ability to evolve in response to environmental change

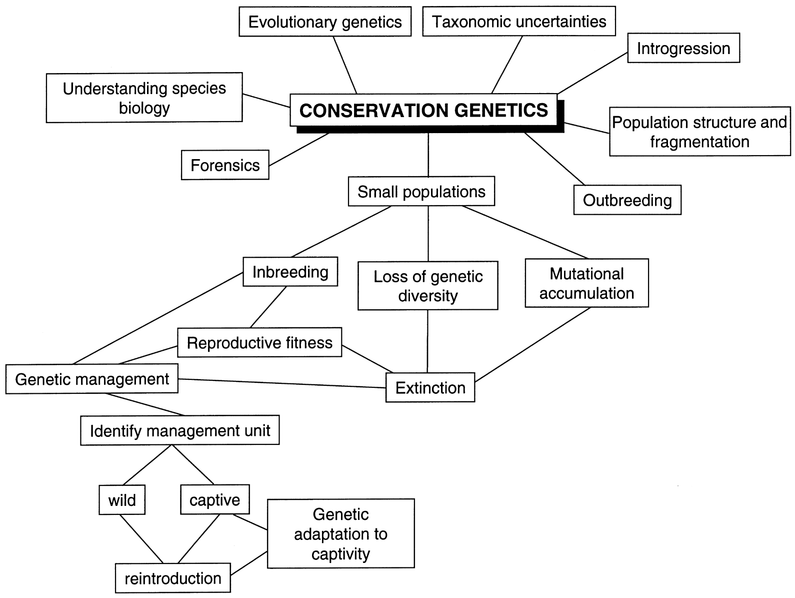


Fig. 1.5 Structure and content of conservation genetics.

- 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
- Resolving taxonomic uncertainties
- Defining management units within species
- Use of molecular genetic analyses in forensics
- Use of molecular genetic analyses to understand aspects of species biology important to conservation
- Deleterious effects on fitness that sometimes occur as a result of outcrossing (**outbreeding depression**).

The effects of small population size are of major concern in conservation biology, since endangered species have small and/or declining populations. Small populations suffer from inbreeding and loss of genetic diversity resulting in elevated extinction risks. Consequently, a major objective of genetic management is to minimize inbreeding and loss of genetic diversity.

This textbook is concerned with the 11 issues listed above.

The structure and content of conservation genetics is illustrated in Fig. 1.5. Conservation genetics is an applied discipline that draws heavily upon evolutionary, population and quantitative genetics and taxonomy.