Chapter 10
Invasions and Insect Conservation

10.1 Introduction: Insects in the Anthropocene

This book endorses much of the theme expressed by Vermeij (1996) – that in invasion biology 'particulars of individual cases have obscured broader patterns' – but in the intervening years since his essay the variety of examples and of contexts across which many taxa can be appraised have increased considerably. However, the four main foci suggested by Vermeij for seeking generalities (Table 10.1) remain valid, and tantalising in their complexity.

Many biologists have focused, overtly or tacitly, on only one of these themes but, in arguing that study of invasion biology should be integrated more widely into biology and draw on the broad principles of ecology and evolution, Vermeij foreshadowed recent debates on the validity of any distinct 'invasion biology', and calls for precise understanding of terms such as 'invasive' (Shah and Shaanker 2014). None of this, however, lessens the reality and often irreversible impacts and importance of biological incursions, linked with accelerating development of Anthropocene environments. General predictive rules for the processes remain elusive. One popular 'rule', known widely as the 'Tens Rule', asserts that approximately 10 % of arriving species become established and, of these, about 10 % become invasive and are widely considered 'pests' in the new environment. Those (very generalised and approximate) ratios and impacts are often difficult to both detect and measure – not least because details of most of the numerous resulting ecological interactions are not fully understood (Jaric and Cvijanovic 2012), so that caution is necessary in applying this (or any other) suggested rule and in so conveying misleading messages to management authorities. Extending from this, Jaric and Cvijanovic also urged extreme caution in seeking to introduce species with no apparent or documented effects on receiving ecosystems.

Roles of alien species, and their potential to become invasive and harmful in their new environments, are often highly uncertain. Predicting success of invasion remains so, and Prins and Gordon (2014a) urged that 'In ecology neither modelling

T.R. New, *Alien Species and Insect Conservation*,
DOI 10.1007/978-3-319-38774-1_10

Table 10.1 The four key themes suggested to help seek generalities beyond the particulars of each individual invasive species (After Vermeij 1996)

1. How invaders differ from non-invaders in the arrival, establishment and infestation phases of invasion
2. How regions or communities that have produced many successful invaders differ from those in which few resident species have been able to extend their ranges
3. How recipient ecosystems with many successfully established invaders differ from those in which few species have invaded
4. How invasion affects evolution of the invader itself and of species in the receiving community with which the invader interacts

Table 10.2 The series of hypotheses derived from ecological theory and used by Prins and Gordon (2014a, b) to explore how biological invasions may occur

Hypothesis
1. A species will not be able to invade an area that has abiotic conditions that are outside its physical tolerance levels
2. The extent of an invasion is negatively correlated to species diversity of functional guild competitors in the invaded environment
3. An invasive species will not be able to replace a native species if they occupy the same niche and are in all other ways equal
4. A species will not be able to invade areas that harbour pathogens (that cause disease) or predators (that prey on the invading species) that it has not encountered before
5. A species will not be able to invade an area if its coevolutionary species (those necessary for parts of the invader's life cycle) is/are not present in the area
6. Species that occur at low population densities in their natural range will not be invasive
7. A species will not be able to invade an area if it has a lower use efficiency of its limiting resource than a native species that occupies the same location
8. Species can more easily invade highly disturbed areas; this disturbance can be man-made or natural
9. Species from older lineages are more vulnerable to being replaced by invasive species that occupy a similar niche
10. A species will only be able to invade an area if it has a life-history strategy which is more r-selected (or 'weedy') than that of the species which already is occupying the niche
11. There are no rules concerning whether a species is invasive or not; it all happens by chance

nor theorising, although they are great fun, is a substitute for the hard work of case-by-case reasoning'. That comment arose from asking 34 experienced field ecologists writing on the Australian environment and their individual specialised fields within this to appraise a series of 11 ecologically based hypotheses dealing with invasion (Table 10.2). None of the 20 major chapters in the resulting book dealt with invertebrates but the considerable variety in levels of support for each of the various hypotheses arising from expert opinion of better understood vertebrate and plant taxa demonstrates the uncertainties involved. In some cases, hypotheses were rejected, and some authors could not address particular hypotheses even when those represented basic or traditional tenets of community or population ecology.

Two revealing outcomes were (1) each hypothesis was rejected by at least one author, and (2) other than rejections, no single hypothesis received unequivocal support. Only two hypotheses (numbers 8, 10 in Table 10.2) appeared to withstand reasonable scrutiny but even they were occasionally rejected – and the thoughtful discussion in the concluding chapter (Prins and Gordon 2014b) is important and sobering reading in leading to their conclusion that the outcomes of invasion events are not predictable. This reflects that the interactions between populations of animals and plants in natural communities are too complex to necessitate any regular or predictable outcome when a new species is introduced. Field research may be the most important avenue toward improving this situation.

A comment by Komdeur and Hammers (2014) that 'Any species could, in principle, establish successfully somewhere, but some species are more successful than others. It is of great interest to conservation biologists to identify which species have a greater chance of successful establishment' encapsulates much of the thought and effort attending modern studies of invasion biology. The variables outlined in Chap. 4, linking with the hypotheses noted above, display the difficulties of doing this reliably or consistently.

No species' range in an area in which functional dispersal is possible is likely to be static, except in relation to limitation by distribution of more static critical resources. Most native species continually expand or change their distribution range as conditions alter and, paralleling true alien invaders, can enter novel areas and ecological communities in ways that are not conventionally regarded as 'invasive'. Over recent decades, such local distribution changes attributed to climate change have been reported in many groups of organisms. The northward movements of Lepidoptera and Odonata in Britain, for example, have been studied in considerable detail (below) and are paralleled by less effectively documented southward range changes in Australia and elsewhere in the southern hemisphere. Some such movements are accompanied by corresponding vacation of range at the other extreme, again as conditions change. Accompanying range changes, invasive species may undergo substantial changes to their developmental patterns in a new environment as they adapt to new climates and ecological contexts, sometimes with changes in voltinism and diapause regimes.

10.2 Climate Change

The gradual elevational and latitudinal shifts in native species' distributions attributed to climate change are an increasing focus in conservation, as new associations and interactions occur and can parallel those associated with more 'conventional' alien invasions. Putative influences of global warming reflect the widespread scenarios that temperature and precipitation are important determinants of species' regional distributions through influences on physiological parameters, and set limits to elevational and latitudinal ranges of many taxa (Wilson et al. 2007). However, firmly establishing any such causal link between range limits and climatic factors is difficult: as Gaston (2009) noted, relevant evidence may take the form that conditions that exceed levels within the current range preclude completion of the normal life cycle or impose excessive mortality. Experimental studies on the Pine processionary moth (*Thaumetopoea pityocampa*, Notodontidae) are one of few examples of attempts to link range expansion with increased winter temperatures marking climate change (Battisti et al. 2005), highlighting need to explore such trends for species that may require management as their range expands and, in some cases, indicating the urgency and relative priority amongst invasive species.

There is little doubt that climate change (broadly 'global warming') has enabled many alien species to expand their ranges and rates of invasion. In surveying the themes involved, Walther et al. (2009) noted (1) new opportunities for introductions; (2) facilitating colonisation and reproduction; and (3) enabling population persistence and spread. However, additional complications occur, and can hamper clear interpretation of how such changes eventuate. Some European insects, for example, have both spread gradually northward as warming occurs and also now occur in isolated populations far 'ahead' of the natural diffusive spread as a result of human-aided dispersal.

A practical problem in dealing with climate changes is simply that many effects are relatively long-term and difficult to predict or evaluate, so that needs for any attention or management may not become clear until after change is well-entrenched. The complex implications of climate changes for invasive species can create very different concerns from those for non-invasive species, with those concerns centering respectively on control or conservation (Hellmann et al. 2008), and additional species possibly becoming unwanted invasives. From the sequence of well-defined stages of the invasion process (Chap. 3), Hellmann et al. discussed five possible consequences of climate change as (1) changes to mechanisms of transport and introduction; (2) changed climatic constraints on the invading species; (3) changed distributions of existing invasive species; (4) changed impacts of existing invasive species (including biocontrol agents); and (5) changed effective management strategies for those invasive species. Applicable to many different taxa, and not mutually exclusive, these changes are unified through impacts of any invasive species being a result of range size, average abundance over that range, and per capita (or per unit biomass) impact – so that significance to any native species reflects the size of the native population or scarcity of the native resources as affected by climate change (Fig. 10.1).

Most discussion of range changes with climate has focused more on details of individual species rather than aspects of 'invasion' and impacts in the extended, previously unoccupied area. A major exception is the importance of 'climate matching', using CLIMEX or some other model in seeking and introducing classical biological control agents (Chap. 6), exercises that clearly endorsed that climate tolerance and suitability is essential to establishment success. However, the four general conclusions on insect conservation in a changing climate made by Wilson et al. (2007) (Table 10.3) all raise issues of very wide concern. Not least, and as recognised widely by others, the contrast in responses between generalist and specialist taxa parallels some characteristics of 'more invasive' versus 'less invasive'

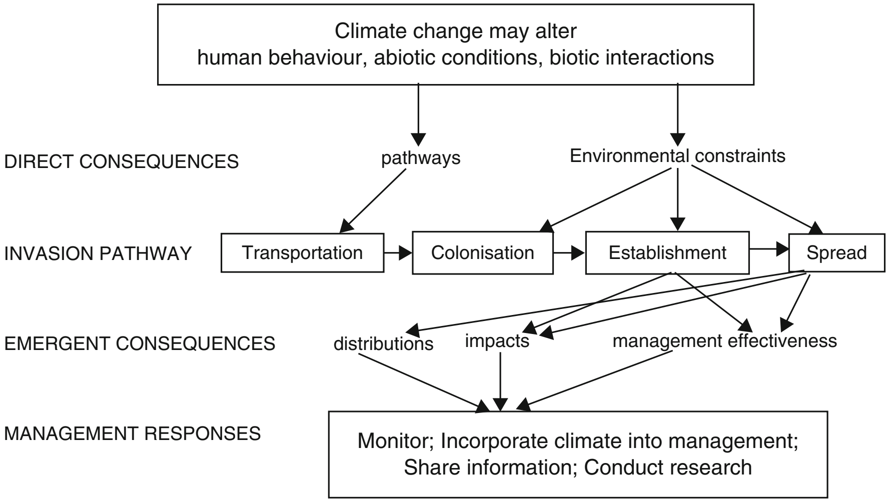

Fig. 10.1 Relationships between invasion pathway and the five consequences (see text) for invasive species under climate change (Based on Hellmann et al. 2008)

Table 10.3 The four general conclusions relevant to insect conservation in a changing climate, as listed and discussed by Wilson et al. (2007)

1. Climate change disproportionately threatens species with small or isolated populations or distribution sizes, narrow habitat requirements (or narrow distribution of resources in space or time) and poor dispersal abilities
2. Priority conservation management may be required in habitats or regions whose biodiversity is particularly sensitive to the effects of climate change
3. At regional scale, landscape-scale habitat management of reserve networks and the wider environment will be important both to maintain current populations of species and to increase their likelihood of colonising locations or habitats that become more favourable
4. The maintenance of habitat heterogeneity at local and landscape scales may favour species' persistence: (1) habitat associations of species change with climate over time and over geographical range, so that provision of a variety of habitats/mutualists allows species to exploit conditions that are the most favoured at a particular time; (2) habitat heterogeneity may act as a buffer against extreme conditions, allowing populations to survive when other places become unfavourable

species in other contexts. Wilson et al. noted that widespread generalist species at their cool range margins commonly expand their distributions, whilst localised ecologically specialised species and those at their warm margins have declined. Promoting landscape heterogeneity may both assist colonisations of newly-favourable areas and conserve the species elsewhere. Climate change is most likely to increase threats to those specialised or restricted species that are already of conservation concern.

Ecological influences of climate change, examined in a pioneering book by Dennis (1993), reflect the complexity of understanding the mechanisms and processes that underlie how an insect may adapt as its 'comfort zone' changes. New physical and biological environments, changed resource supply, enforced novel interactions, likely changed phenology and risks of lost synchrony with food supplies, and many other factors intervene. Imposed continued range modifications, however, are inevitable for many taxa. Species' responses encompass biogeographical, phenological, physiological, behavioural and genetic changes, each with implications for the fitness and survival of the individual species and the ecosystems it either enters or leaves – and one common difference from many 'traditional invasives' is that part of an occupied distribution may be vacated, a circumstance that might facilitate establishment of further invaders there.

Britain has proved an ideal arena in which to explore such changes, for reasons that largely parallel other initiatives in advancing insect conservation within that fauna. Those reasons include (1) broadly, all species are named and identifiable, with popular diurnal groups of Lepidoptera and Odonata extremely well documented in relation to many other places; (2) for most, a strong historical record of species incidences and distributions over at least a century, often more, provides clear baseline information against which change may be appraised; (3) the development of recording schemes based on standard mapping units (10×10 km^2) and to which numerous volunteer naturalists contribute records to centrally coordinated data bases (such as the United Kingdom Biological Records Centre), with standardised methodology allowing for strong quantitative inferences (Pollard and Yates 1993) and through which evidence of seasonal and abundance changes can also be assessed; and (4) a limited fauna contains many species on the northward fringe of their European range, in a region with room for them to expand northward into areas known to be unoccupied previously, so constituting a dynamic frontier for changes as climate warming occurs. Recent discussions confirm the widespread reality of changes, with extent, rates and species-specific responses all variable. The changing status of Odonata in Britain shows arrival of several novel species in recent years, some with their major distribution in the Mediterranean regions of southern Europe (Parr 2010). The pattern for *Anax parthenope* (Aeschnidae) recorded by Parr illustrates the more general pattern of (1) initial unsubstantiated record in the mid-1980s; (2) substantiated record in 1996; (3) annual records thereafter accumulating to several hundred individuals over the next decade or so, most of them migrants but with record of successful breeding; and (4) record numbers seen in 2006, with oviposition at at least five sites, as a clear colonist that has continued to thrive. Many species are currently undergoing range changes, mostly expanding to the north and west, and parallel phenological changes are evident, with emergence earlier in the season.

Mason et al. (2015) concluded that, self-evidently, resource and wider habitat suitability and availability are critical in an expanding range, but it is often unclear how other range-determining factors – such as natural enemies and competing species – influence differences observed between broader taxonomic groups. Closely related species can differ greatly in their responses to different aspects of climate change and linkages to key resources. Local rates of change produce idiosyncratic responses that may link with abundance and habitat availability, but most impacts of gradually range-expanding species are unknown, with most studies exploring rates

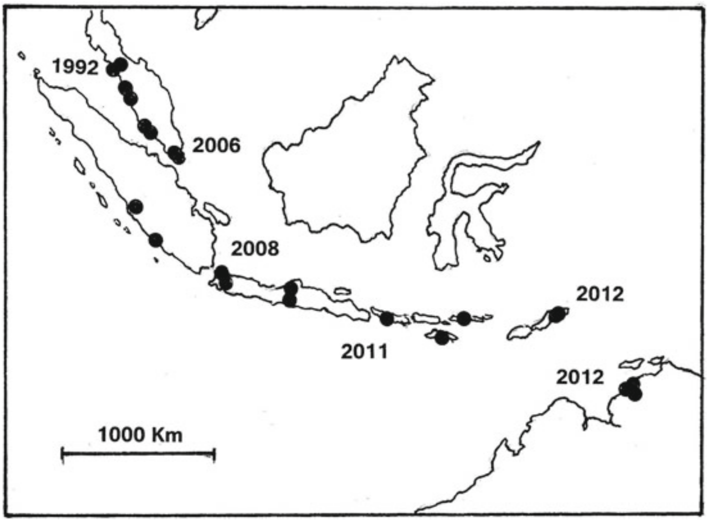

Fig. 10.2 The changing distribution of the butterfly *Acraea terpsicore* in south-east Asia and reflecting its invasion of northern Australia, indicating known locations (*black spots*) and years of first detection from Malaysia to Australia (Braby et al. 2014)

and extent of changes, rather than possible invasive impacts and resultant faunal changes. It can be difficult to distinguish relative roles of climate and habitat changes in such expanding ranges that clearly occur along possible climatic gradients.

The Tawny coster butterfly (*Acraea terpsicore*, Nymphalidae) was first recorded in Australia in April 2012, and has spread rapidly (Braby et al. 2014). Native to lowland areas of India and Sri Lanka, the butterfly has become widely distributed in much of south east Asia, thence in Indonesia and subsequently arriving in northern Australia; this progressive range expansion is summarised in Fig. 10.2. As with *Danaus plexippus* (p. 41), the mechanisms of this expansion are not wholly clear, and Braby et al. indicated at least three possible hypotheses as (1) accidental recent introduction to IndoChina from India; (2) natural expansion from India to colonise Thailand via Myanmar; and (3) it has always existed there but in low numbers, and has become more abundant as the degraded habitats favoured by larval food plants, have increased. Braby et al. suggested that this habitat modification may be a key influence, not least because the most frequented environments in Australia are highly modified open areas, including disturbed grassland and degraded savanna woodland. That biotope form, together with climatic suitability, are key features for the predicted future spread of *A. terpsicore* in Australia, to potentially occupy much of northern Australia and some north eastern coastal areas of Queensland.

The recent extensive spread of the Yellow-legged hornet (*Vespa velutina*, p. 40) in Europe is likely to increase markedly as climates increase in suitability (Barbet-Massin et al. 2013), mainly into parts of central and eastern Europe. In those regions, increased hornet predation on honeybees and other pollinators (such as Syrphidae) could become a serious concern. Barbet-Massin et al. emphasised that bee-keeping activities could become under severe threat in this expanded hornet range, with considerable disruption to plant-pollinator interactions.

Use of models to predict climatic changes and their influences on distributions of invasive species has developed rapidly, and with increasing sophistication, as a tool in anticipating management needs, with finer details reflecting the methodology used in extrapolation. Thus, two studies on the Australian Bronze bug (*Thaumastocoris peregrinus*, Thaumastocoridae) using different climate modelling schemes (CLIMEX: Saavedra et al. 2015; WorldClim 1.3: Montemajor et al. 2015) both forecast considerable future spread of the bug, largely in association with *Eucalyptus* plantations, but with some differences in detail of likely intensity of invasion across the largely overlapping predicted ranges. Many such models involve predictions of a suitable 'bioclimatic envelope', but many are based on uniform increases of temperature or precipitation levels, which may render them over-simplistic (Mika and Newman 2010).

10.3 Moving Species Deliberately

Natural modifications to range due to climate change are generally a very gradual process. Deliberately moving insects is a recognised component of species conservation, most commonly in the form of 'translocations' to enhance small populations or to re-introduce species to restored secure sites within their native range. The process can be very complex, and decisions over numbers, stages, season, and methods needed to maximise chances of success parallel those inherent for introducing classical biological control agents – but, most commonly from the basis that the species' biology is reasonably well understood, and that the operation is taking place within its current or recently historical range (New 2009). The context is fundamentally 'non-alien', but similar conservation considerations have led directly to more distant movements based on 'assisted migration' for insects (notably, some butterflies), expanding the principles of conventional translocations, to move species to places outside their historical distribution range, where they function essentially as aliens introduced into novel environments that are anticipated to increase their chances of survival as currently occupied areas become unsuitable because of climate changes. For some species confined to small or isolated vulnerable habitat patches and that are unable to track landscape changes themselves, this may be the only viable conservation option, but may not always be possible, not least because of regulatory restrictions (Shirey and Lamberti 2010). One proposed case tacitly raised the issue of defining 'historical range', with considerations of the feasibility of bringing back to Britain two species of butterflies that became extinct there early in the twentieth century (so are not part of the current fauna), but have remained in mainland Europe and where they are currently declining (Carroll et al. 2009). That case could provide valuable experience for later assisted migrations of other European butterflies, never known to be resident in Britain, to follow (Thomas 2011). Increased understanding through both climate modelling outcomes for relatively local transfers (Carroll et al. 2009) and experimental transfers (Willis et al. 2009) of butterflies in Britain illustrate many of the consequences that must be considered for geographically wider exercises.

Such assisted movements, however, could lead to new problems if the focal species becomes invasive or significantly outcompetes previously resident species in their newly expanded range (Mueller and Hellmann 2008). That risk may generally be small, but could occur at various scales – from relatively short-range to intercontinental transfers. As Mueller and Hellmann put it 'Assisted migration is a drastic solution to a pressing problem', with some opinion that any such operation has potential for some disruption to the receiving systems, as for any 'proper' invading species. In general, success rates for insect translocations, of any sort, are low – a feature suggested to reflect a combination of inadequate awareness of species' biology and selection of release sites (Heikkinen et al. 2015). As in more typical invasions, factors such as propagule pressure and receiving site quality may be critical, with a key practical consideration being whether to spread a limited number of foundation individuals across several new sites or focus on a single site with a larger innoculative population. In either context, prior enhancement of critical resources is likely to be beneficial both in facilitating establishment and enabling population increase and subsequent spread across the new landscape.

Assisted migrations, and indeed other translocations, have potential to separate co-dependent or mutualistic species (Moir et al. 2012). Whilst presence of suitable host plants for insect herbivores is an obvious need, hosts for associated parasitoids with unknown wider host ranges may not be so, as wider constituents of the relevant community. The focal species itself is clearly the primary focus of any assisted migration exercise, with the complications of changes to multitrophic interactions often neglected – in many cases necessarily so through lack of knowledge. Monitoring and evaluation is a clear need. The wider perspective of consequences and strategies generated by the dual considerations of individual species wellbeing and restoration of ecological process as motivations for assisted migration (Lunt et al. 2013) may be assessed in relation to three contrasting approaches (Fig. 10.3). The most familiar context for insects (and most other taxa) is of a species threatened by climate change being moved to one or more recipient sites where survival is predicted to be higher as conditions change, and the taxon sustained for the future. For ecosystem processes, one or more taxa are transferred to a recipient site to sustain or restore a process or function that has declined with climate change or loss of provisionary species. The two outcomes may be achieved together if transfer of a threatened species also restores declining ecosystem services in the receiving site. These options have been termed 'push', 'pull' and combined 'push and pull', respectively (Lunt et al. 2013). Expectations of ecological impacts from any imported species could also constitute some acceptance of risk. However, those same ecological benefits, enhancing a wide range of processes and taxa, may also grant them priority over single threatened species conservation if costs are similar and the risks considered acceptable.

Other contexts for 'moving species' occur, and can create controversy. Much commercial apiary in Australia, for example, depends on migratory bee-keeping,

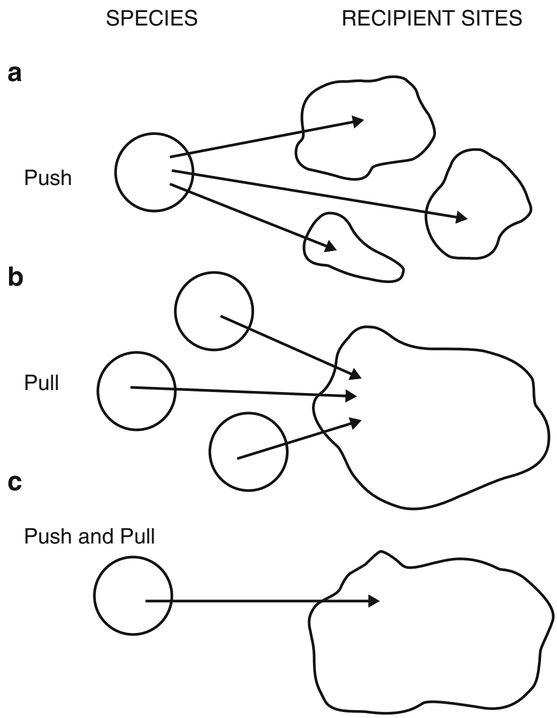

Fig. 10.3 Three forms of assisted colonisation: (**a**) specific species assisted colonisation: a specified taxon threatened with decline under climate change is moved ('pushed') into one or more receiving sites where future persistence is predicted to be high; (**b**) ecological replacement assisted colonisation: one or more taxa are relocated ('pulled') to a specific receiving site to maintain or restore and ecosystem process/function that is declining there due to climate change; (**c**) assisted colonisation used to 'push' a threatened taxon into a receiving site, but this also restores and ecosystem process/function that is declining due to climate change, so achieving the joint outcomes anticipated from the previous two options, so 'push and pull'. Primary motivations are concerns for the source species (**a**), receiving site (**b**) or both (**c**) (After Lunt et al. 2013)

through which hives are shifted to track seasonal nectar supplies. Because of denudation of many natural landscapes for agriculture, pressures have increased to site hives in national parks and other areas where native flora continue to thrive and these pressures have provoked strong dissension between bee-keepers whose livelihoods depend on assured nectar supplies and conservationists who see the intrusion of aggressive alien honey bees likely to induce competition with native pollinator species harboured in those reserve areas whose existence is founded in a conservation role. The arguments are complex (Paton 1996), but regulations in each relevant State impose considerable restrictions on unfettered access, through licensing only limited sites within protected areas. As the New South Wales National Parks and Wildlife Service (2002) commented 'The impact of bees may need to be considered in areas of identified critical habitat or threatened species or communities', and relocation of hives to more suitable areas undertaken should known threatened species be susceptible to activities of foraging honey bees.

10.4 Information

Earlier chapters have exemplified widespread uncertainties over all stages of alien species invasiveness and of the impacts of many alien species in the receiving environments. Whilst the impacts of some are indeed clear, and salutary warnings of harm to native insects that might befall from other alien species, documenting and monitoring the trajectories and effects of a wider array of invasive plants and animals is a key conservation need, in providing fundamental information to managers. Gathering and summarising information on invasive species, and making that information available through centralised databases is a continuing need and key component of monitoring and managing those species, with each phase of prevention, surveillance and response, and control and eradication drawing on such information. As with the British 'Great Britain Non-Native Species Information Portal' discussed by Roy et al. (2014), inventory can increase awareness of the impacts of invasive species, indicate their relative presence and impacts in different biotopes, and contribute to the chronological and biological knowledge that enables those roles to be clarified and, where necessary, countered. Britain's long history of biological monitoring imparts that scheme considerable reality and, at the end of 2011, insects were clearly the most numerous invasive animal group (344 species), although still well behind higher plants (1376 species), a significant component of the total 1958 established non-native species recorded.

Widespread lack of knowledge generates uncertainty, and has led to statements such as 'Uncertainty is at the root of the precautionary principle, not theory' (Prins and Gordon 1914a), in urging protection for Australia against invasive species because 'we do not know whether we will lose wonderful native species if alien species are allowed to invade'. Although insects are not conventionally recognised amongst the 'wonderful native species' (except by entomologists!), many are indeed amongst the most vulnerable native taxa to many alien invaders. The sentiment expressed by Prins and Gordon extends far beyond Australia, to embrace ecologically specialised endemic species of many parts of the world.

10.5 Concluding Comment

The seemingly endless taxonomic and ecological variety of alien species renders any suggestions on their overall impacts on native insects tentative, and perhaps superficial and naïve. Many aliens, viewed initially as disruptive threats, may prove to be critical supplementary resources augmenting or replacing those already lost to transformations such as urbanisation (New 2015), in areas where the roles of even a few alien species can appear pervasive. Each alien species that invades a new environment may potentially affect the dynamics of the receptor community, influence the composition of local food webs, and induce losses of native species. However, because many such changes are context-specific and site-dependent, predicting outcomes is highly unreliable.

Thus, the significance of use of many of the diverse non-native plants by native insects in urban 'green spaces' is very difficult to interpret. Their use as food by larval Lepidoptera, discussed by Burghardt et al. (2010), does not itself clarify whether those alien plants are the 'ecological equivalents' of native species they have replaced in local food webs – and several studies cited earlier demonstrate the differing levels of consumer fitness that may ensue. The thesis advanced by Burghardt et al., based on studies of the Lepidoptera of Delaware (United States) and noted for urban landscapes by New (2015), reflected the relevance of taxonomic relationships between alien and native plants: Lepidoptera laid eggs and larvae fed on congeneric alien plants (which may be linked by common chemical features) more often than on alien plants not related to native hosts. However, there is little doubt that continued adoption of alien host plants by native insect herbivores (1) contributes to homogenisation of faunas (for butterflies, demonstrated by Graves and Shapiro 2003), and (2) may facilitate invasions of additional plant and consumer species. Shifts within local food webs are augmented by increasing numbers of alien species – leading to increased expressions of concern for ecologically specialised native insects, most fundamentally (1) herbivores existing in small localised populations (or metapopulations) that become increasingly vulnerable to losses of their restricted natural hosts, or to the competitive impacts of adaptable native species on those hosts, and (2) the changed prey or hosts of natural enemies, whether these are deliberately or accidentally presented.

Highly anthropogenic environments are traditionally considered those most vulnerable to alien species invasions – and are those in which such species come most readily to notice, and where their impacts are most obvious and best documented. However, few – if any – more natural terrestrial or freshwater environments have escaped some level of alteration from, especially, invasive insects or plants, and the interactions between these – with both each other and higher level alien or native consumers and in some cases leading to considerable wider impacts on native communities and ecological processes. In short, alien invasive organisms are universal, inevitable and many are essentially harbingers of permanent changes, often to the detriment of native biota in the invaded environments. Conservation of native insects, many of the species signalled as high priority, ecologically specialised and vulnerable to the onslaughts of more adaptable generalists (typified by many invasive species), inevitably confronts alien influences at both individual species and wider community levels. Most concerns from invasive aliens arise from more generalised species, for which vagaries in outcomes from individual circumstances are largely irrelevant in view of their pervasive adaptability – and from which chances of adverse or undesirable non-target impacts are greatest, often augmented by good dispersal powers and large numbers of invaders.

The lessons from pest management and allied ‘applied’ disciplines involving alien species furnish much of the scientific understanding on which practical conservation actions can be founded, and alien species’ impacts on native insects understood and countered. Whilst many direct impacts are intuitively obvious, although commonly far more difficult to quantify, the complexities of many more indirect effects, such as changes to complex native food webs, are more insidious and can often be only inferred. Suppression or eradication of invasive aliens is advocated commonly but, again, can pose complexities – such as introductions of further aliens (biological control agents) with likely or possible further harmful effects. Whilst many concerns over such practices have been raised, and ‘general rules’ to assure safety pursued sincerely and diligently, the great differences between impacts of the same species in different receiving environments and between different species in the same or similar environments ensure that some element of risk may remain, or be perceived. ‘Threat’ from alien invasive species is a very widespread supposition. In concert with direct losses and changes to habitats and erosion of critical resources needed by specialised native insects, alien insects and plants (in particular) are frequently associated with such disruptions as facilitating environments for those invasives are progressively created. The twin features of habitat change and invasive alien species are major contributors to accelerating onset of the Anthropocene. The overviews in this book of some key themes relevant to insect conservation reflect the complex and pervasive processes that attend invasions by alien species and their parts in leading toward biotic homogenisation accompanying the largely unheralded losses of numerous insect species and associated disruptions of intricate and long-coevolved ecological dependencies.

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