Department of Transport and Main Roads

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Manual

Fauna Sensitive Transport Infrastructure Delivery
Chapter 20: Species profile – Invertebrates

June 2024

Queensland Government

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1 Invertebrates

1.1 Introduction

Invertebrates are animals that lack a backbone and comprise 95–99% of all species on earth. They are extremely diverse and range from insects such as beetles, bees, butterflies, and crickets (which collectively account for approximately 75% of invertebrate species), molluscs (7%), crustaceans (4%), spiders (8%), and other invertebrates like worms (5%)[1]. Approximately 1.4 million invertebrate species have been identified worldwide (compared to approximately 63,000 vertebrate species), however the actual number of species is likely much higher as many species remain undiscovered or uncatalogued. In Australia, 99,000 invertebrate species have been officially described, however it is estimated there is around 320,500 species in total[2].

Invertebrates play key roles in ecosystem function, providing critical ecosystem services such as pollination, decomposition, seed transportation, nutrient cycling, and pest control[3]. It is estimated that 80% of wild flowering plants are pollinated by insects[4]. Furthermore, the diet of many species of mammals, birds, amphibians, and reptiles consist partially or entirely of invertebrates, and many predators rely entirely on specific species of invertebrates.

Figure 1.1 – Native bees are a common pollinating insect

Source: © Matt Head

Recent reports indicate there have been significant global declines in invertebrates, in particular insects, with one study recording a 75% decline in flying insect biomass recorded over a 27-year period[5]. The loss, degradation, and fragmentation of habitat, as well as climate change, are key drivers in these reported declines, which is likely to have significant impacts on the maintenance of

[1] (Reck and van der Ree 2015)
[2] (Chapman 2009)
[3] (Hallmann et al. 2017, Sands 2018)
[4] (Ollerton et al. 2011)
[5] (Hallmann et al. 2017)

healthy functional ecosystems[6]. However, invertebrates are often underrepresented in conservation efforts[7].

Fourteen species of invertebrates within Queensland are considered threatened under the *Nature Conservation Act* 1992 (NC Act) and the *Environment Protection and Biodiversity Conservation* Act 1999 (EPBC Act) (Table 1.2).

1.2 Commonly encountered invertebrate species

Of the 14 threatened species of invertebrates in Queensland, only a small number are regularly encountered on transport projects (Table 1.2). For example, the Richmond birdwing butterfly (*Ornithoptera richmondia*) and the swordgrass brown butterfly (*Tisiphone abeona morrisi*) have both been a focus of Fauna Sensitive Transport Infrastructure Delivery (FSTID) efforts to benefit invertebrates on transport infrastructure projects in South East Queensland (Case Study 20.1). This is because they are:

- Threatened with extinction.
- A flagship species with relatively well-known ecological requirements to guide management actions, which are reasonably easy and cost-effective to implement.

Table 1.2 – Threatened invertebrate species in Queensland that are likely to be encountered on transport projects

SCIENTIFIC NAME	COMMON NAME	DISTRUBITION	HABITAT
		INSECTS	
Argynnis hyperbius inconstans	Australian fritillary butterfly	South East Queensland	In open swampy coastal areas where the larval food plant arrowhead violet *(Viola betonicifolia*) occurs.
Acrodipsas illidgei	Illidge's ant-blue butterfly	South East Queensland	Inhabits mangroves and adjacent areas along the east coast of Australia. A breeding population can only exist with the presence of ant colonies of the acrobat ant (*crematogaster*) species.
Hypochrysops piceatus	Bulloak jewel butterfly	Endemic to South East Queensland (Brigalow Belt). It is known to exist in only two locations, one being the Ellangowran Nature Reserve	Inhabits a single species of tree, the slow growing bull oak (*Allocasuarina luehmannii),* and is only found where there are populations of ant species of the *Anonychomyrma* genus.
Hypochrysops apollo apollo	Apollo jewel butterfly (Wet Tropics subspecies)	Endemic to Wet Tropics / Far North Queensland	Inhabits mangroves in the Wet Tropics where the larval food source, ant plant (*Melaleuca beccarii*), occurs.

[6] (Harvey et al. Potts et al. 2010, Hallmann et al. 2017)
[7] (Eisenhauer et al. 2019)

SCIENTIFIC NAME	COMMON NAME	DISTRUBITION	HABITAT
Jalmenus eubulus	Pale imperial hairstreak butterfly	Central and Southern Queensland (Brigalow Belt)	Old growth Brigalow (*Acacia harpophylla*) and Belah (*Casuarina cristata*) open forest and woodland on poorly drained clay soils on flat to gently undulating plains in warm sub-humid inland areas. Does not appear to colonise regrowth habitats following clearing or other major disturbance. Has recently been discovered to utilise yarran (*Acacia melvillei*) as a larval food plant.
Ornithoptera richmondia	Richmond birdwing butterfly	South East Queensland	Live in subtropical rainforest where its larval host plants grow, Richmond birdwing vine (*Pararistolochia praevenosa*) and mountain aristolochia vine (*Pararistolochia deltantha*).
Phyllodes imperialis smithersi	Pink underwing moth	South East Queensland	Found in subtropical rainforest below ~600 metres elevation. Potential breeding habitat is restricted to areas where the caterpillar's food plant, a native rainforest species called carronia vine (*Carronia multisepalea*), occurs.
Tisiphone abeona morrisi	Swordgrass brown butterfly	Southern Queensland, although locally extinct in South East Queensland.	Edges of subtropical and warm temperate rainforest and adjacent eucalypt tall open forest on the coast in south Queensland.
Trisyntopa scatophaga	Antbed parrot moth	Endemic to southern and central Cape York Peninsula, Queensland.	Occurs exclusively in association with golden-shouldered parrot (*Psephotus chrysopterygiu*) as the nestlings' excreta is eaten by moth larvae within the bird's nest.
MOLLUSCS (Woodland snail)			
Adclarkia cameroni	Brigalow woodland snail	Endemic to South East Queensland (Brigalow Belt)	Occurs in a small number of remnant and scattered Brigalow and eucalypt woodland patches (such as road verges and riparian corridors) on the Condamine River floodplain, especially in the area around Dalby and Chinchilla.
Adclarkia dawsonensis	Boggomoss snail	Endemic to South East Queensland (Dawson River catchment)	Restricted to alluvial flats and riparian environments between Mt Rose and south of Theodore. The preferred habitat is the floodplain of the Dawson River in places where there is good canopy cover, a moist environment, fallen logs, and deep leaf litter.

SCIENTIFIC NAME	COMMON NAME	DISTRUBITION	HABITAT
Adclarkia dulacca	Dulacca woodland snail	Endemic to South East Queensland (Brigalow Belt	Inhabits a variety of remnant and scattered habitats, such as vine thicket and Brigalow and eucalypt woodland patches on rocky outcrops, with clay to loam soils, in the area between Miles and Dulacca, and south to Meandarra. Also able to exist in areas of Brigalow regrowth and even in cleared paddocks but only where logs, woody debris, or other suitable microhabitat sites remain.
CRAYFISH			
Euastacus jagara	Jagara hairy crayfish	Endemic to Queensland	Restricted to highland rainforest, only known from a few small upland, headwater creeks in Main Range National Park.
Tenuibranchiurus glypticus	Swamp crayfish	Endemic to central-eastern Australia, including South East Queensland	Inhabits coastal wallum country and Melaleuca swamps. Prefers to burrow into damp clay but is occasionally found in peaty sand.
Euastacus sulcatus	Lamington spiny crayfish	South East Queensland	Occurs in streams at altitudes above 300 metres, in rainforest and wet sclerophyll forest. Inhabits mountains in a crescent from Mount Tamborine to Lamington Plateau, west along Macpherson Range and north via Cunningham's Gap into the Mistake Mountains, Queensland.

2 Ecology

Invertebrates occur Australia wide and inhabit almost every habitat type. Within Queensland, species diversity is generally highest in biodiversity hotspots such as South East Queensland, the Brigalow Belt, and the Wet Tropic bioregions. Many species are endemic to these areas. Many species, especially insects, can utilise a wide diversity of habitat and can often be found in less diverse and more modified habitats. Some species (such as the woodland snails and crayfish) have very specific habitat requirements and narrow geographic distributions. Subsequently, the loss, fragmentation and degradation of even relatively small areas can have a significant impact on such species.

This section is focuses on the three key invertebrate groups that are identified as threatened that are likely to be impacted by transport infrastructure in Queensland: Insects, woodland snails, and swamp crayfish.

2.1 Insects

Insects are an extremely diverse group, and their ecologies are incredibly variable, which is apparent with the large diversity in their appearance. There are five major groups which comprise 80% of all insect species:

- Beetles (*Coleptera*) – the most diverse animal group on earth.
- Wasps, ants, and bees (*Hymenoptera*).

- Butterflies and moths (*Lepidoptera*).
- Flies (*Diptera*).
- The true bugs (*Hemiptera*).

Insects inhabit a wide range of habitats, including both terrestrial and aquatic, and many species spend part of their life in water and part on land. Most undergo various degrees of change or metamorphosis throughout their development from egg to adult. Many insects at immature stages do not have the features of the adult phase, such as wings, and will have different resource requirements for their different life cycle stages. For instance, caterpillars, the larvae of butterflies and moths, feed almost exclusively on plants (mostly leaves but also seeds and flowers). Different caterpillar species have different 'host plants', which are needed to complete their life cycle. Some caterpillars are host plant generalists, able to utilise a range of plants from different families for their larval food. Others are specialists, adapted to only one plant species. Many also have complex relationships with ants, where ants protect the caterpillar from predators and feed off their energy-rich secretions. In contrast, adult butterflies require nectar as a food source and are typically able to utilise a wide range of nectar-producing flowering plants. However, to reproduce they need their larval host plants to be present in the area. The complexity of these life cycle requirements highlights the importance of conducting thorough flora and fauna assessments that assess potential impacts on invertebrate species at all stages of life.

Foraging ranges of flying insects can vary significantly among species and is often related to body size. Native bees, which are mostly small-bodied, have limited foraging ranges (150–600 metres)[8], whereas larger-bodied bees such as the introduced European honeybee (*Apis mellifera*) can fly distances of several kilometres. Some species of butterflies found in Queensland undertake seasonal migration, travelling hundreds of kilometres. This includes species such as the caper white butterfly (*Belenois java*), blue tiger (*Tirumala hamata*), and lemon migrant (*Catopsilia pomona*)[9].

[8] (Gathmann and Tscharntke 2002)
[9] (Dingle et al. 1999)

Figure 2.1 – Bulloak jewell butterfly (Hypochrysops piceata)

Source: © Matt Head

2.2 Woodland snails

Woodland snails in the *Adclarkia* genus are endemic to South East Queensland, occurring in remnant and fragmented patches of Brigalow and eucalypt woodland. They live under logs, rocks, and leaf litter where they feed on fungi, lichen, algae, and other decomposing organic matter. They are nocturnal and are most active during periods of higher humidity such as rain events. Little is known about their biology but based on similar species they are likely hermaphroditic and reach maturity at approximately two years. Their life expectancy is likely to be at least five years. Mature adults generally lay eggs in soil, under logs, and in leaf litter. Desiccation poses a risk to eggs of land snails, so in addition to moist ground debris, their habitats require canopy and shrub overstorey to maintain humidity levels and prevent the eggs from drying out. They have very limited mobility but can move between suitable areas of microhabitat if they are in close proximity and conditions are favourable (i.e. after rain). However, they can move long distances when an area floods[10]. Given their restricted mobility, consideration through a comprehensive assessment is essential to ensuring the ongoing protection of such a poorly known, yet threatened, species.

2.3 Crayfish

Jagara hairy crayfish is a smaller crayfish growing to a maximum length of 50 millimetres and weighing just 53 grams when fully grown. The biology of this species is not well understood but they

[10].(Threatened Species Scientific Committee 2016a, b)

are thought to be omnivorous and largely nocturnal, with increased activity until around midnight[11]. The entire distribution of the species is restricted to the Main Range National Park in Queensland, where they are confined to higher altitude rainforest. They are known from only a few sites where they inhabit stream riffles and pools[12], and burrows that extend into the streambank. Larger adults appear to spend most of the year in burrows, emerging into the creeks for the breeding season which starts between May and July[13]. The downstream limit of their distribution closely correlates with the change in habitat from rainforest to open forest. In particular, the presence of rainforest spinach (*Elatostema reticulatum*) is a good local indicator of suitable habitat for the species[14].

Swamp crayfish is Australia's smallest species of freshwater crayfish, reaching a length of 23-30 millimetres at maturity. It inhabits the acidic coastal *Melaleuca* swamps of central – eastern Australia, predominantly in shallow drainage channels with limited standing water which seasonally dry up[15]. They construct deep communal burrows in soil, usually in damp clay, but they have also been found in peaty sand where they spend a large portion of time when conditions are unfavourable. They are mostly active at night when they forage for food. Their diet consists predominantly of water weeds and decaying plant material, but they are also opportunistic scavengers[16]. The species' distribution is highly fragmented and very little suitable, quality habitat remains for this species[17]. They are threatened by urbanisation, particularly habitat destruction and pollution[18].

The Lamington spiny crayfish is a slow growing and long lived large freshwater crayfish (reaching up to 340 millimetres) which is restricted to a few mountaintops in South East Queensland and northern New South Wales[19]. It inhabits a variety of aquatic and semi-aquatic habitats, from moist gullies with no surface water to large, flowing streams in rainforest and wet eucalypt forest about 300 metres above sea level[20]. In Queensland, they are found in Lamington and Springbrook National Parks. They are mostly diurnal and make burrows in stream banks and the adjacent forest floor. Adult crayfish disappear from the streams during the cooler months, re-emerging in spring when the reproductive season commences[21].

[11].(McCormack et al. 2010, McCormack 2012, McCormack 2021)
[12] (McCormack et al. 2010)
[13] (McCormack 2012)
[14] (McCormack et al. 2010)
[15] (Dawkins et al. 2010)
[16] (Queensland Museum 2011)
[17] (Dawkins et al. 2010)
[18] (Coughran et al. 2010)
[19] (Furse and Wild 2002)
[20] (Coughran 2013)
[21] (Coughran 2013)

Figure 2.3 – Jagera Hairy Crayfish (Euastacus jagara), Lamington Spiny Crayfish (Euastacus sulcatus), Mt Lewis Spiny Crayfish (Euastacus fleckeri)

Source: © James Sparshott

3 Direct impacts

3.1 Wildlife-vehicle collision

Direct mortality from wildlife-vehicle collision (WVC) threatens invertebrates, although the severity is unknown because it is difficult to obtain accurate counts of mortality[22] and more research is urgently required. While there are reports of WVC and invertebrate mortality, there is little information about impacts of WVC at a population level. Moreover, the impact varies depending on taxon type. Flying invertebrates that attempt to cross roads and railways at lower heights are more at risk of WVC than species that are capable of crossing at greater heights above the ground. For instance, dragonflies with low flight-heights are more susceptible to WVC than dragonflies that fly higher[23]. Migrating butterflies, such as the monarch butterfly (*Danaus plexippus*) in North America have been observed crossing highways at heights greater than six metres[24]. Conversely, low to the ground (less than one metre) and zig-zagging flight patterns have been observed in other butterfly species along roads when presumably searching for resources[25], putting them at higher risk of WVC. However, there is little information available on road or railway crossing heights for flying taxa. In addition, species that move along the ground are also at high risk of WVC when they attempt to cross transport infrastructure. When such information is not readily available in the scientific literature, consultation with species experts should be undertaken to assess impacts and to determine and test invertebrate-sensitive design strategies.

Mortality rates vary depending on transport infrastructure conditions, such as traffic volume, infrastructure width, and corridor maintenance methods and regimes[26]. Research on butterflies, dragonflies, and bees have found that rates of mortality increase with increasing traffic volume and road width[27], that mortality rates are greater for more mobile species[28], and that the abundance of flying insects declines with increasing road traffic[29]. Roadside vegetation type has also been shown to influence insect mortality rates. For instance, rates of WVC of bees and butterflies were higher when

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[22] (New et al. 2020)
[23] (Soluk et al. 2011)
[24] (Mora Alvarez et al. 2019)
[25] (Severns 2008)
[26] (Tamayo et al. 2014)
[27] (Rao and Girish 2007, Phillips et al. 2020a, Dániel-Ferreira et al. 2022a)
[28] (Phillips et al. 2020a)
[29] (Martin et al. 2018)

the roads were bordered by lawn or meadows compared to wooded vegetation[30]. The presence of vegetated median strips also significantly increased WVC rates of various insect types.

Uncertainty remains around the net benefit of roadside vegetation to supporting insect populations. While the current available evidence suggests that the benefits outweigh the costs, particularly for pollinators[31], more research in this area is needed.

While not strictly WVC, invertebrates can be killed due to incorrect verge maintenance such as very low cutting heights or using suction mowers at certain times of the year[32].

3.2 Barrier effects

Roads and other linear infrastructure can be a barrier or filter to the movement of invertebrates[33]. Numerous factors increase the barrier effect, including infrastructure width, traffic volume, traffic noise, and road design features such as kerb height, which can trap flightless invertebrates, noise walls, and vegetation density[34]. The design of drainage structures (i.e. bridges and culverts) can affect the movement of invertebrates, including freshwater crayfish[35].

The species most affected are those that cannot fly (or have short flight ranges), are slow moving, and/or avoid roads[36]. For instance, areas isolated by one road had up to 50% fewer ground beetle species than expected based on known habitat preferences. This increased to an 80% reduction in species in areas with many roads. Furthermore, flightless species were disproportionately negatively impacted[37].

In other studies, significantly different bee and wasp communities have been observed on opposite verges of a large highway with comparable vegetation[38], and bees along a railway demonstrated high site fidelity, only rarely crossing the tracks despite having the ability to do so[39]. Both cases indicate that transport infrastructure can act as a barrier to movement for less mobile taxa. Even narrow roads can act as barriers and have been shown to inhibit the movement of land snails, leading to local extinctions of affected populations[40].

Some species that persist in areas with roads are additionally affected by a significant reduction in genetic variability, further threatening their viability[41].

Conversely, transport infrastructure corridors that provide habitat for more mobile species may facilitate movement across fragmented landscapes by acting as stepping-stones or corridors[42]. The barrier effects of transport infrastructure will thus vary among species, depending on the size of the

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[30] (Keilsohn et al. 2018)
[31] (Phillips et al. 2020a)
[32] (Steidle et al. 2022)
[33] (Mader 1984, Bhattacharya et al. 2003, Dániel-Ferreira et al. 2022b)
[34] (Fitch and Vaidya 2021, Dániel-Ferreira et al. 2022a)
[35] (Slutzker 2015)
[36] (Tamayo et al. 2014)
[37] (Pfister et al. 1997, cited in Reck and van der Ree 2015)
[38] (Andersson et al. 2017)
[39] (Bhattacharya et al. 2003)
[40] (Martin & Roweck 1988, cited in Reck and van der Ree 2015)
[41] (Keller and Largiadèr 2003)
[42] (Phillips et al. 2020a, Dániel-Ferreira et al. 2022b)

area occupied by the species, their mode of movement, and their ability to move across the landscape.

3.3 Habitat loss and modification

Construction of transport infrastructure causes significant disturbance to invertebrate habitat, the most obvious being the direct destruction and removal of native vegetation and habitat, such as logs and organic litter. In addition, the use of heavy machinery during construction can compact soil, which will negatively impact soil-dwelling invertebrates.

This is problematic because vegetation in transport infrastructure corridors in an otherwise cleared or modified landscape can provide important habitats, food sources, and corridors for some species and may play a critical role in insect conservation[43]. For instance, vegetation on transport infrastructure corridors, particularly in rural areas, supports the only known extant populations of some threatened species. These include the bulloak jewel butterfly in Queensland[44] and their larval host plants[45], the pale imperial hairstreak butterfly[46] and varied dusky-blue butterfly (*Erina hyacinthina simplex*) in New South Wales[47], and the arid bronze azure butterfly (*Ogyris subterrestris*) in Western Australia[48]. Vegetation in transport infrastructure corridors can also support diverse populations of insect pollinators such as native bees and hoverflies[49], flies, cockroaches, and snails[50], as well as beetles and ants[51]. Similarly, railway embankments have been found to provide important habitat for pollinators in agricultural landscapes[52].

3.4 Noise, vibration, and light pollution

Insect mortality can occur from street lighting and other sources of artificial light at night (ALAN) (Chapter 4). Mortality can occur from collision, overheating, and dehydration. In some places, the accumulated depth of dead insect bodies under street lights may be several centimetres thick. Street lighting also increases predation and can negatively affect insects across different stages of their life cycle, disrupting natural rhythms and reproductive success[53]. Insects are particularly attracted to lights with high wavelengths and are more sensitive to bluer wavelengths of light.

ALAN may also affect the movements and other behaviour of nocturnal invertebrates in similar ways to other species, such as birds, mammals, and amphibians.

The increasing replacement of conventional sodium street lights (narrow spectrum lighting which produce a single wavelength of yellow light) with more energy efficient LED white lights (broad spectrum lighting which emit light across the entire visible spectrum) will likely have negative impacts on insect populations[54].

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[43] (New et al. 2020)
[44] (Sands and New 2002)
[45] (Sands et al. 2016)
[46] (Taylor 2014)
[47] (Braby and Edwards 2006)
[48] (Gamblin et al. 2010)
[49] (Hopwood 2008, Phillips et al. 2020a)
[50] (Monteith and Joyce 1999)
[51] (Major et al. 1999)
[52] (Moroń et al. 2014)
[53] (Owens and Lewis 2018)
[54] (Boyes et al. 2021)

Traffic noise may also negatively affect insects because certain species will move away from roads due to acoustic interference (Chapter 4). For example, adult steppe grasshoppers (*Chorthippus dorsatus),* which rely on acoustic communication, avoid roads[55] despite being able to alter their calls in an attempt to be heard over traffic noise[56]. Similarly, cicada species have been found to increase the acoustic frequency of their calls in areas besides roads, which may have energetic costs[57].

Invertebrates, and especially spiders[58], are susceptible to substrate-borne vibration due to their small size, common association with habitat features that are especially impacted by vibration (such as webs, soil, and water), and common lack of aural receptors and dependence on vibrational cues. As an example, the Nicrophrinae burying beetle (*Nicrophorus marginatus*) breeds underground, exhibits biparental care, and uses vibration to communicate. When exposed to substrate-borne vibration in a captive population in the USA, parents took longer to prepare nesting and produced reduced brood sizes[59]. This could be because vibrations masked bi-parental communication and/or falsely signalled a threat above the ground, causing stress and behavioural changes and impeding reproductive behaviours.

The impacts of vibration on invertebrates are poorly studied but potentially significant. One study in Brazil found that field crickets (*Gryllinae spp.*) ceased calling in response to passing mining trucks. Ground-dwelling field crickets were more impacted than tree-dwelling crickets, suggesting that the substrate-borne vibration may have been more impactful than the air-born vibration (noise) for this species[60]. Vibration from traffic was assumed to be responsible for the small but significant negative correlation between the rate of attack of simulated prey and traffic volume by the jorō spider (*Trichonephila clavate*) in the southeastern United States[61].

3.5 Erosion and sedimentation

Aquatic invertebrates are often at risk during transport infrastructure construction, particularly following rainfall events, due to erosion of sediment that can cause siltation of waterways. Shifts in species composition of invertebrate communities have been observed in nearby streams during highway constructions[62]. In the Rhön Mountains in central Germany, one of the few remaining populations of the freshwater pearl mussel (*Margaritifera margaritifera*) became extinct due to sedimentation caused by poorly managed road construction[63].

3.6 Environmental pollution

Invertebrates are extremely susceptible to environmental pollution. Sources of pollutants include exhaust fumes and tyre wear from vehicles, dust from unsealed roads, diesel emissions, and lubrication products from trains. Pollutants can accumulate in soil and vegetation adjacent to transport infrastructure and impact invertebrate communities. For example, worms living near roads have

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55 (cited as Pfister et al. 1997, in Reck and van der Ree 2015)
56 (Lampe et al. 2012)
57 (Shieh et al. 2012)
58 (Mortimer 2019)
59 (Phillips et al. 2020b)
60 (Duarte et al. 2019)
61 (Davis et al. 2024)
62 (Barton 1977)
63 (Groh & Jungbluth 1993, cited in Reck and van der Ree 2015)

exhibited high levels of accumulated heavy metal contaminants (lead, cadmium, and copper)[64]. Other chemicals, such as ozone from traffic, appear to negatively affect foraging behaviour of parasitic wasps, which play an important role in regulating invertebrate pests such as aphids[65]. High levels of heavy metal pollutants have also been reported in waterways that bisect or border suburban railways[66].

The use of prescribed herbicide application to manage weeds in roadsides can also negatively affect invertebrates. The herbicide glyphosate has impacted the development and fertility of a lacewing species, a beneficial predatory insect[67]. Roadside verges in agricultural landscapes are particularly susceptible to unintentional spray drift of pesticides (including insecticides) from nearby farms[68]. Both direct herbicide spray (that impacts on their host plant) and indirect aerial drift of pesticides are a key threatening process for yellowish sedge-skipper butterfly (*Hesperilla flavescens flavia*)[69].

Indirectly, traffic and pesticide pollutants can change the composition of plant species along roadsides, thereby changing the suitability of the habitat for different species[70]. Moreover, pollutants can be passed from invertebrate prey to vertebrate predators, sometimes accumulating until toxic levels are reached, causing disease or death of individuals higher in the food chain.

The risk of chemical pollution to invertebrates may depend on length of exposure and how they are using the site. For instance, mobile invertebrates that only feed in transport infrastructure corridors will be exposed to pollution for shorter durations compared to invertebrates with low mobility or which are using the site for nesting and throughout all stages of larval development[71]. The effects of chemical pollution on invertebrates are still poorly understood and rarely included in impact assessments.

3.7 Fire regimes

Some sections of transport infrastructure corridors are burnt to reduce fuel loads and manage the risk of wildfires. However, managed burns to reduce fuel loads are a major threatening process for many terrestrial invertebrates[72]. The frequency, scale, and season of burns determines the degree of threat. For instance, many invertebrates are dormant or at developmental stages of least mobility in winter and early spring. Fuel reduction burns carried out at these times can have impacts on invertebrate survival as they are unable to move and escape the fire. Areas burnt regularly and extensively, without leaving any unburnt refuges, destroy habitat and exacerbate the effects of land clearing and habitat fragmentation[73]. Areas subject to frequent low-intensity fires may have a significantly lower number of litter dwelling invertebrates compared to nearby unburnt areas[74]. Many insects are considered at risk from fire mismanagement, including bees, ants, beetles, and moths[75].

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64 (Ash and Lee 1980)
65 (Gate et al. 1995)
66 (Levengood et al. 2015)
67 (Schneider et al. 2009)
68 (New et al. 2020)
69 (Coleman and Coleman 2000)
70 (New et al. 2020)
71 (Phillips et al. 2020a)
72 (Greenslade 1996, Sands 2018)
73 (New et al. 2010)
74 (York 1999)
75 (Schwarz and Hogendoorn 1999, York 1999, Driessen and Greenslade 2004)

4 Indirect impacts

4.1 Habitat degradation due to weed invasion

Many species of invertebrate have specific habitat requirements (e.g. vegetation structure, food species of plant, soil type, soil moisture). Weed invasion following transport infrastructure construction can alter site conditions and reduce habitat abundance. This is particularly problematic for species of invertebrates that rely on specific vegetation, microhabitat, and substrate conditions in transport infrastructure corridors, such as grasslands. For instance, weed invasion into grassy areas can decrease floral diversity as well as the amount of bare ground which provides nesting sites for ground-nesting native bees[76]. In addition to habitat degradation, the application of herbicides to control weeds can have detrimental and ongoing impacts on invertebrate populations and the species that feed on them (Refer to Section 3.6)[77].

5 Avoidance and minimisation

5.1 Avoidance

Avoiding critical habitat is the most effective method of reducing impacts of transport infrastructure projects on invertebrates. Transport infrastructure corridors with high conservation value (i.e. which contain threatened species or significant species richness) should be identified early in the concept phase as part of the impact assessment and prioritised for protection. Furthermore, sites need to be managed during the construction phase to ensure exclusion zones (Refer to Chapter 7) are adequately protected.

5.2 Design for invertebrates

Greater consideration of invertebrates such as their specific inclusion in impact assessments and mitigation measures, can significantly aid in their conservation[78]. For instance, identifying invertebrates of concern in the design phase, in consultation with subject-matter experts, can enable mitigation strategies, such as host plants for insects and waterway habitat for crustaceans, to be incorporated early in the landscape design.

5.3 Using indicator species

Compared to vertebrates, there has been significantly less research on the impacts of transport infrastructure on invertebrates, and even less on mitigation solutions. It is not appropriate to assume that the response and needs of invertebrates will be addressed if vertebrates are considered because both groups may respond differently. While legislation protects threatened species which must be included in impact assessments, impacts to common species are not often assessed. However, many invertebrates are critically important to the healthy functioning of ecosystems. Given the massive species diversity and range of life forms of invertebrates, and that the biology of many species is not well known, a practical and cost-effective approach is the use of ‘indicator’ species to guide impact assessments and help inform mitigation efforts.

An indicator species is an organism whose presence, absence, or abundance reflects the environmental conditions in a given location, and which can signal changes in ecosystem health.

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[76] (Hopwood 2008)
[77] (New et al. 2020)
[78] (Reck and van der Ree 2015)

Further research is required to better understand the impacts of transport infrastructure on invertebrates and identify indicator species in Queensland. In the context of impact assessments for transport projects, the species in the indicator groups should (Table 5.3):

- Be highly responsive to the proposed impact (e.g. road mortality, barrier effect, traffic noise, etc.).
- Occur at the location of the proposed development.
- Have a response that is representative of the actual target species / environmental condition of concern.
- Be related to the habitat type to be affected.

Table 5.3 – List of potential invertebrate indicator species that can be used in impact assessments and mitigation planning

BROAD HABITAT TYPE	POTENTIAL COMBINATION OF INDICATOR SPECIES
Waterbodies and banks	Dragonflies, macrozoobenthos, crayfish, molluscs, ground beetles
Agricultural land (arable fields)	Ground beetles, grasshoppers / crickets, spiders
Open habitats (incl. meadows and pastures) and forest edges	Ground beetles, butterflies, grasshoppers / crickets, wood-inhabiting beetles, bees, ants, moths, spiders
Forest and woodland	Ground beetles, butterflies, grasshoppers / crickets, wood-inhabiting beetles, bees, ants, moths, spiders
Caves	Ground beetles
Springs	Dragonflies, snails
Subterranean waterbodies	Snails, crustaceans

Source: Reck and van der Ree (2015)

6 Mitigation

6.1 Wildlife crossing structures

Invertebrates, just like other taxon groups, need effective measures to reduce road mortality and restore habitat connectivity. Unfortunately, most monitoring programs fail to assess the use of crossing structures by invertebrates. Those that have suggest that land bridges have the highest rates of use compared to long or dark underpasses[79]. However, many land bridges are designed only for vertebrates and are not suitable for some invertebrates, which have very different requirements, including specific soil type, soil profile, or vegetation structure. A barrier for invertebrates may not be a barrier for large vertebrates, and vice versa. Therefore there is a need to achieve multifunctional passages, which requires careful planning.

[79] (Sporbeck et al. 2013 cited in Reck and van der Ree 2015)

There is little information to guide the specifics of crossing structures for invertebrates. Nevertheless, the following principles apply:

- Crossing structures should contain a suitable substrate (e.g. soil type and depth, level of compaction), which is particularly important for burrowing species and land snails, but also for its effect on plant growth. Crossings with the most natural substrate conditions are likely to be most effective, whereas crossing structures with concrete floors (e.g. culverts and pipes) will only be suitable for a small number of species, most likely generalists. Where culverts or pipes are required, consideration should be given to the use of embedded or sunken culverts / pipes that are partially buried below bed level to create a flat floor with natural substrate.
- Depending on the needs of the target species, crossing structures could include longitudinal strips or patches of species-specific habitat components (e.g. rocks, logs, grasses, or dense canopy, etc.) to facilitate movement. The greater the diversity of microhabitats, the more effective the structure will be for a greater number of species.
- Invertebrates with low mobility will need crossing structures in close proximity to their habitats and movement corridors.
- For land snails, land bridges are only likely to be suitable during wet times of year and if the land bridge also has their preferred microhabitats and retains moisture. Snails are likely to dehydrate if they attempt to traverse large gaps or use culverts, unless the culvert has a mulch floor with a thin layer of standing water. Bridge underpasses with riparian habitats are likely to support the movement of land snails, particularly during floods.
- Land bridges should be designed to retain sufficient moisture to support plant growth, and, on some structures, a wet and dry habitat type may be required for different species.
- Underpasses should be relatively open and have visible light because some species avoid dark spaces. Similarly, invertebrates that require continuous vegetation cover are unlikely to use underpasses without such cover.
- Water passing through underpasses (culverts and bridges) should mimic the natural flow of waterways (i.e. varying velocities, natural pools and riffles, substrate with logs and rocks for shelter and no barriers).
- Artificial lighting should be avoided wherever possible and where necessary, following advice in Section 6.3.

6.2 Habitat creation and restoration

The creation and restoration of habitat for invertebrates along transport infrastructure and elsewhere has great potential in mitigating or offsetting some of the direct and indirect impacts of transport infrastructure on invertebrates. There are numerous examples in Australia and globally focussing on plantings in transport infrastructure corridors as ‘pollinator pathways’. Careful consideration and design is required to ensure the plantings are appropriate for the target species and do not result in the creation of sink habitats where mortality exceeds any net benefits.

6.3 Light management

Whenever street lighting is required and cannot be avoided (Refer to Section 3.4), the following mitigation measures to reduce the impacts of ALAN should be considered and adopted where possible:

- Only install lighting where it is required for user safety.
- Use the lowest intensity lighting possible.
- Use of sensors or timers to only provide lighting when required, such as when pedestrians or motorists are present.
- Keep lights as close to the ground as possible to direct light to areas that require lighting, and
- Use shielding of light fixtures to minimise light spill into sensitive areas, for example, crossing structures and entrances to crossing structures.

Case Study 20.1 – M1 Pacific Motorway (Varsity Lakes to Tugun) upgrade planting host plants for invertebrates

The M1 Pacific Motorway Varsity Lakes to Tugun (VL2T) Upgrade project recognised that invertebrate communities play an important role in sustaining healthy and diverse ecosystems, and that insect populations have declined dramatically in the past 50 years. As such, the M1 Pacific Motorway Upgrade project identified two butterfly species; the Richmond birdwing butterfly (*Ornithoptera richmondia*) and the swordgrass brown butterfly (*Tisiphone Abeona ssp. morrisii*), as target species for invertebrate sensitive road design.

Figure 6.3 – Swordgrass brown butterfly (Tisiphone Abeona ssp. morrisii)

Source: © Matt Head

Floral food resources and nectar plants for larval and adult butterflies were incorporated in the rehabilitation and landscaping design. These included over 20,000 tall sawsedge (*Gahnia clarkei*) planted at a density of five per square metre for the swordgrass brown butterfly, and 338 Richmond birdwing vines (*Pararistolochia praevenosa*). The plantings are intended to act as a 'stepping stone' corridor linkage between known populations of these species to expand their populations and range, improve genetic diversity, and reduce the risk of these insects becoming extinct. Other rare invertebrates that will benefit from the project's enhancement measures include the spotted sedge-skipper (*Hesperilla ornate*), the painted sedge-skipper (*Hesperilla picta*) as well as several dragonflies including coastal petaltail (*Petalura litorea*) and the giant dragonfly (*Petalura gigantea*) which are at risk of local extinction within the Gold Coast region.

This is the first transport infrastructure project in Australia that has directed fauna sensitive road design specifically to the benefit of invertebrates and resulted in extra innovation points being awarded for the Infrastructure Stability Design and As-built Rating assessment by Infrastructure Sustainability Council.

7 Construction

7.1 Translocation

Translocation is one approach to minimising direct impacts of construction activities on fauna, including invertebrates. Success rates of translocation efforts for all fauna can range from approximately 26–46%, depending on taxonomic group and definition of success, and should be a last resort in development projects[80]. In New Zealand, thousands of large endemic and endangered land snails (*Powelliphanta spp*) were translocated over a number of years due to a coal mine development. Monitoring over the first 18 months recorded a death rate of 30% which, given the species is slow to breed, was predicted by population modelling to be an unsustainable rate long-term[81].

Translocation is not commonly undertaken for insects, however the unexpected discovery of a population of threatened purple copper butterfly (*Paralucia spinifera*) during the advanced stages of road upgrade works in New South Wales lead to emergency relocation efforts[82]. This was a multi-staged, complex operation that included provision of 'bridging habitat' (short term replacement of larval food plant in the disturbed area while a relocation method could be developed). It also involved the transfer of caterpillars (and associated attendant ant species) to a new site, and improvement of habitat quality at the new site through rehabilitation efforts. Overall, the relocation was considered successful and ensured the short-term survival of the population. However, it was not the ideal outcome for the butterfly and was very expensive, highlighting the importance of thorough flora and fauna assessments prior to construction works taking place.

Translocations require a thorough understanding of the species ecology and biology before they are undertaken, and should always be evaluated within an adaptive management framework.

[80] (Germano et al. 2015)
[81] (Germano et al. 2015)
[82] (Mjadwesch and Nally 2008)

8 Maintenance and operation

The value of infrastructure transport corridor vegetation as habitat for invertebrate conservation in many landscapes is increasingly appreciated[83]. Simple principles should direct management and maintenance of transport infrastructure corridors to improve suitability for invertebrates, including the following:

- Avoid frequent mowing and include areas where grasses and low shrubs can grow fully. If mowing is conducted at the right frequency and time of year for the specific vegetation type, flowering can be optimised for flower-visiting insects.
- Maintain a naturally diverse mix of plant species and allow for natural succession.
- Restrict or exclude herbicide and pesticide use.
- Maintain natural soil types, profiles, and nutrient levels according to the needs of the target species.
- Design roadsides to be as natural as possible for invertebrates, with open ditches and slopes rather than impermeable surfaces, and avoid installing barriers or traps.
- Aim to maximise benefits for as many species as possible.
- Prioritise roadside plantings along roads with low traffic volumes.
- Where managed fires are needed to reduce fuel load, undertake ‘micro-mosaic patch burning’, retaining at least 10-15% of habitat at one time[84]. This enables the survival of invertebrates occupying the area, especially those that are less mobile (Section 3.7).
- Avoid installation and maintenance of ancillary infrastructure (e.g. powerlines, pipelines, shared use paths, etc.) and uses (e.g. stock grazing) at times when invertebrates and their habitat are sensitive to disturbance.

[83] (New et al. 2020)
[84] (Sands 2018)

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