Management options for conserving and restoring fauna and other ecological values of urban streams in the Melbourne Water region

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Summary

Catchment-scale management of stormwater runoff is likely to be the most effective approach for the protection and restoration of urban streams, but will require long-term investment and widespread social and cultural change. In the interim, reach-scale management actions will be required in degraded urban streams of Melbourne: for social amenity, property protection, and for the ecological values of riparian ecosystems. The potential ecological gains from reach-scale actions in degraded urban streams need to be assessed to help prioritize reach-scale management actions.

For 66 stream-dependent animal species found in Melbourne deemed to be tolerant of catchment urbanization, we used distributional data and ecological information from the literature to a) assess the degree of urban tolerance, b) identify management actions at reach and catchment scales that would be most suitable to protect or restore populations of each species, and c) identify knowledge gaps. Using this group of animals, and other ecological indicators, we assessed the relative ecological gains likely from reach-scale versus catchment-scale management actions in urban streams. Urban streams were defined as those with >1% directly connected catchment imperviousness (DCI).

Only 26 of the 66 species were solely dependent on stream habitat for at least part of their life history. Of these, only 7 were classed as urban tolerant (occurrence either not or positively correlated with DCI), while 10 were completely absent from streams with >1% DCI. 40 of the 66 species were not as strongly dependent on stream ecosystems, as they were able to use riparian or wetland habitats for breeding and feeding. Twenty-one of those species were urban tolerant.

The potential ecological gains from reach-scale actions on urban streams are small. There are, however, benefits in management of urban riparian zones and wetlands, the latter in particular, can provide valuable refuge habitats for some stream-dependent species that cannot maintain populations in urban streams.

We do not recommend management actions to improve populations of urban tolerant species in urban streams: their existence in degraded urban streams suggests none are required, and we postulate potential negative effects of doing so (possible benefits to associated pest species, and eutrophication arising from overabundance). Three *Galaxias* species were classed as urban-tolerant, but conservation of these species is more appropriately aimed at rural streams where they are likely to be limited by competition and predation by trout, rather than in urban streams which might provide a refuge from interactions with trout.

For most stream-dependent species that are found less commonly in urban streams, reach-scale management is not likely to result in re-establishment or increase of populations in urban streams, without catchment-scale mitigation of stormwater impacts. Removal of barriers to migration in the Yarra and Maribyrnong rivers is likely to improve rural populations of migratory fish, but we posit that populations will not be re-established in urban reaches.

We posit that riparian revegetation along urban streams will have no effect on the distribution of any of the stream-dependent species considered, and only small effects on some in-stream ecological processes, unless catchment stormwater impacts have first been mitigated. Urban wetland conservation (including provision of riparian shading, stormwater control and control of exotic predators) is an important action for two urban-sensitive fish species (*Galaxiella pusilla*

and *Nannoperca australis*), to provide short-term survival of urban populations that are unable to sustain populations in urban streams.

Reach-scale protection and restoration of riparian vegetation, and of riparian and non-riparian wetlands are likely to benefit a range of species that are not solely dependent on stream habitat.

We recommend that decisions on the management of urban streams be set in concert with other management policies that aim to prioritize in-catchment stormwater retention. High priority sub-catchments should be chosen using criteria that maximize ecological return on investment: the effort required to adequately mitigate stormwater impacts, and the quality of ecological values that can be protected. This review has identified several sub-catchments that are likely high priorities based on ecological values, because they support imperiled populations of platypus together with several other urban sensitive species.

For high-priority sub-catchments that are targeted for in-catchment stormwater-retention, riparian restoration and barrier removal are primary reach-scale actions, before or during catchment-scale works, followed by habitat restoration. For low priority sub-catchments, conservation, restoration and creation of urban wetland refuges (in turn prioritized by presence of valued species) and point-source controls are primary reach-scale actions.

These recommendations are made on the assumption catchment stormwater management is strictly regulated by building and road-construction regulations, and that in-catchment stormwater retention is standard practice in all new development. If this assumption is false, many kilometres of healthy streams across the metropolitan area are likely to be soon degraded as a result of urban expansion in-fill development.

We recommend many avenues for future research and development. Recommendations include a review of data management; a series of targeted distributional and ecological studies of selected species; studies of species that appear to respond differently to urbanization in different parts of the metropolitan area (which could shed light on the major mechanisms driving urban degradation of streams); studies of frog distributions along streams to complement past studies of urban effects on non-riparian wetland frogs; assessment of the potential for urban tolerant species to serve as indicators of different types of urban impact; study of competition between exotic and native fish species in an urban environment; and spatial studies of approaches to mitigating habitat fragmentation across the region.

We urge that management actions and research be integrated to allow a truly adaptive approach to urban stream management in Melbourne that will conserve our remaining natural assets and restore at least some of those that we have lost.

Introduction

The streams and rivers of the Melbourne metropolitan area, like those of cities around the world, are generally in poor ecological health. The biological values of a stream, and the ecological services it provides, are almost always compromised if there is urban land use in its catchment with a conventional stormwater drainage system. Stream managers need to manage reaches of urban streams for a variety of reasons: social amenity, property protection, and for the ecological values of their riparian systems (Brooks *et al.*, 2002; Nilsson *et al.*, 2003). Such reach-based management is what Booth (2005) described as short-term, local-scale enhancement. However, there is scant evidence that this type of reach-scale management of urban streams can produce in-stream ecological benefits, if the ecological structure and function of the stream is limited by the impacts of urban stormwater runoff.

To date, most attempts to improve ecological condition of streams in urbanized catchments have focused on reach-scale enhancement of physical habitat or establishment of riparian vegetation (Brown, 2000). Unfortunately, ecological effects of such habitat enhancement often are not assessed (Davis *et al.*, 2003). In almost all cases where assessments were done, changes in biotic composition were small, with only a few taxa colonizing new habitat (Larson, Booth & Morley, 2001; Purcell, Friedrich & Resh, 2002; Sudduth & Meyer, 2006; Suren & McMurtrie, 2005; Walsh & Breen, 2001).

A few studies have shown some limited success is possible in certain circumstances. Charbonneau & Resh (1992) reported significant improvements in the composition of urban stream animal assemblages following restoration, but that restoration involved both reach-scale habitat improvement and catchment-scale actions such as the removal of sewage pollution from the creek. Larned *et al.* (2006) successfully displaced an exotic submerged macrophyte from weed beds with a native macrophyte species in a Christchurch stream, although this change in macrophyte species composition had no effect on the degraded macroinvertebrate assemblage in the stream. Groffman *et al*. (2005) showed that retention structures in severely degraded urban streams acted as hot spots for nutrient processes. However, such small-scale studies of nutrient retention need to be assessed against the efficiency of in-catchment nutrient retention, and such a comparison has not yet been made. Furthermore retention structures are often unsustainable in the highly modified flow regime of urban streams (Booth, 2005; Frissell *et al.*, 1986).

The weight of evidence suggests that urban stream ecosystems are generally limited in their ecological capacity by the impacts of urban stormwater runoff (Paul & Meyer, 2001; Walsh *et al.*, 2005b). Attempts at restoration of stream ecosystems by in-stream or riparian habitat improvement are, therefore, likely to fail because they do not match the scale of the restoration action to that of the constraining impact (Hobbs & Norton, 1996; Lewis *et al.*, 1996). This situation is more strongly true for urban (than rural) catchments because links between the catchment and the stream are more pronounced.

Melbourne’s stormwater system, like those of other cities, is designed primarily to minimize flooding risks, but it also drains stormwater away from the catchment in small, frequent rain events, when there is no flooding risk. The consequence of this frequent, efficient stormwater removal from all parts of catchments, is the severe degradation of receiving stream ecosystems, which are not well adapted to the abrupt, frequent delivery of polluted stormwater (Paul & Meyer, 2001; Walsh *et al.*, 2005b).

The condition of stream ecosystems is correlated with the proportion of catchments covered by impervious surfaces (i.e. roofs and paved surfaces) that are directly connected to the waterway by drainage pipes or sealed drains (Booth & Jackson, 1997; Paul & Meyer, 2001; Walsh *et al.*, 2005b). The proportion of directly connected catchment imperviousness (hereafter DCI) has been referred to as 'effective imperviousness' (Booth & Jackson, 1997), but we will not use this term here, as it has been used in different ways, giving rise to ambiguity (Walsh, Fletcher & Ladson, 2008).

DCI explains variation in the ecological condition of Melbourne's streams well. Eastern Melbourne streams with near-zero DCI remain in good ecological condition in the absence of non-urban impacts (Walsh, Fletcher & Ladson, 2005a), but streams with even very low levels of DCI (as little as 1%: see next section), show multiple symptoms of ecological degradation. The degradation in ecological condition associated with DCI encompasses the structure of animal and plant assemblages (Newall & Walsh, 2005; Walsh, 2004), water quality (Hatt *et al.*, 2004), algal growth (Taylor *et al.*, 2004), and ecosystem functions such as community metabolism (M.R. Grace, personal communication), and leaf breakdown rates (Imberger, Walsh & Grace, 2008). DCI is associated with the loss of many sensitive species of stream invertebrates, and increased numbers and biomass of a smaller assemblage of pollution tolerant species (Walsh, 2004).

However, the most important and hopeful finding of these studies was that streams with substantial urbanization in their catchments (as much as 12% total imperviousness, TI) remained in good ecological condition, as long as the impervious surfaces of the catchment were not connected to the stream by pipes. So, Sassafras Creek with 10% TI, and other healthy streams like it, remain in good condition, because most of its roads are unsealed or built with 'rural seals' (i.e. drain to a swale or an earthen drain), most of its houses drain to gardens or rainwater tanks, and where roads are drained by curb and channel, the pipe drains to the side of the hill several hundred metres above the stream: its DCI is near zero. This suggests that if stormwater drainage can retain runoff from small, frequent storms, to allow for infiltration, evapo-transpiration or use, then the conservation and restoration of streams in urban catchments is possible. Conversely, with even a little conventionally drained impervious area, the ecological condition of streams will be compromised in many ways.

The study of Walsh *et al.* (2005) remains the only published study to have directly measured DCI on a catchment scale (Gillies 2008). In the south and east of Melbourne, DCI as low as 2-3% can diminish stream biodiversity; in the north and west, this number may be as little as 1-2% (Walsh *et al.*, 2005a; Walsh *et al.*, 2001). The decline in most ecological indicators is similarly non-linear, with a steep decline to 5-10% DCI, beyond which streams are uniformly severely degraded. Figure 1 shows water quality data from the broader Melbourne metropolitan area (a wider geographic area than the eastern Melbourne streams considered by Walsh *et al*. 2005). For these and other water quality and biological indicators used to assess compliance with the State Environment Protection Policy (Government of Victoria, 2003), compliance is almost never reported above 1% DCI, and even less frequently above 5% DCI.

It must be emphasized that the severe structural and functional degradation of eastern Melbourne streams, resulting from small levels of DCI are observed in catchments with almost solely residential, and no industrial land use.

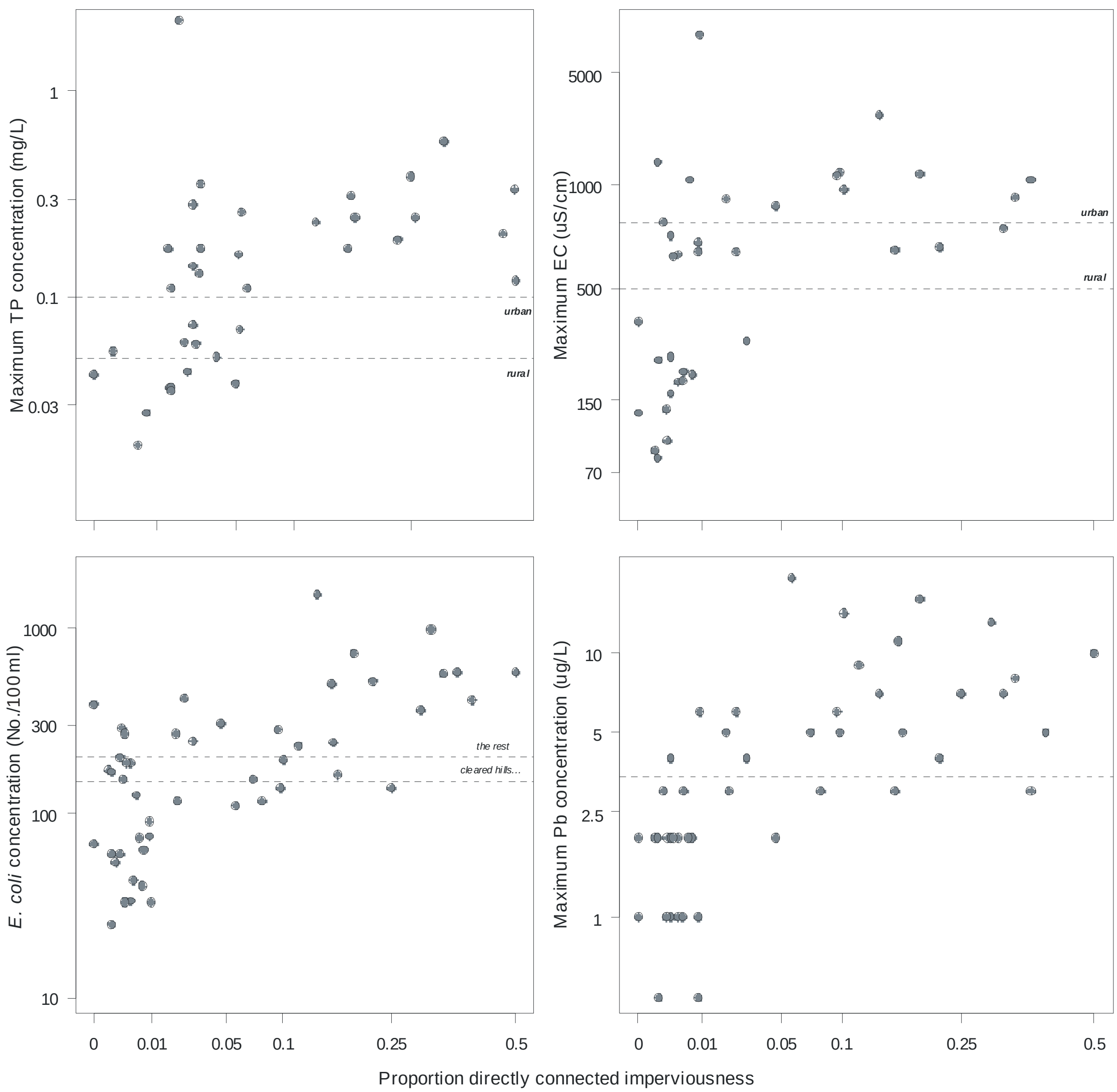

Figure 1. Four water quality indicators used to assess compliance with the State Environment Protection Policy from sites across Melbourne (from Bunyip River catchment to Kororoit Creek catchment) for which DCI data are available. Other indicators (both water quality and biological) show similar patterns. The dashed lines indicate the SEPP compliance values for each section (where objectives differ between sections). Note that the x-axis is square-root transformed. Few sites with DCI > 1% achieve SEPP objectives, and failure is even more certain above ~5% DCI.

If DCI is the primary agent of stream degradation in urban areas, then the restoration and protection of urban streams requires new drainage methods to retain stormwater in the catchment, to mimic the pre-urban catchment hydrology more closely. Such an undertaking for a city the size of Melbourne will require substantial investment, resources and time to turn around 150 years of drainage practice. In the mean time, Melbourne Water must continue to manage its urban streams as sustainably as possible.

This review has been commissioned to identify management methods that are most appropriate to maintain and improve the ecological values of urban streams currently degraded by DCI. We do this by:

1. Testing the current distribution of 66 species selected by Melbourne Water as tolerant of catchment urbanization against DCI;
2. Classifying each species by its urban tolerance, inferred from its current (and if possible, historic) distribution, and from ecological information gained from the literature;
3. Assessing and recommending management options for the conservation of each group, with particular emphasis on possible reach-scale actions in urban streams;
4. We then consider groups of management actions and recommend a decision hierarchy for prioritizing actions on sub-catchment characteristics
5. Finally, we consider the range of research questions raised by this review that will permit a more robust adaptive management approach to stream management for the Melbourne area.

Appendix 2 contains short reviews of the distribution, biology and recommendations for management of each of the 66 species (steps 1 and 2 above). The methods and data that we used in the reviews are detailed in Appendix 1. This main document aims to synthesize these reviews and their recommendations (steps 3–5). Appendix 3 is a discussion of stream management for in-stream functions, focusing on organic matter retention, as an example of an alternative perspective on stream management that must underlie management for biodiversity. Appendix 4 is a brief review of management implications of a recent report on ecological values of estuaries in the Melbourne Water region, pointing to some similar constraints and management themes with stream management.

The urban streams of Melbourne

Ecological impacts of catchment urbanization are observed in all streams with >1% DCI, and beyond 5-10% DCI all streams are severely degraded by most measures. In this report, we therefore define all streams with >1% DCI as urban, and note that beyond 5-10% DCI, streams are universally severely degraded by urbanization.

Table 1 lists the major streams of Melbourne (excluding some streams of the Mornington Peninsula and Pakenham corridor) that have urban reaches and the range of DCI over the length of the urban reaches.

While the Yarra and Maribyrnong Rivers flow through the metropolitan area, neither river is heavily urbanized at the catchment scale (Figure 2). The Maribyrnong never exceeds 2% DCI: its upstream tributary, Jacksons Creek has DCI slightly >2% below Sunbury. The Yarra only becomes substantially degraded by catchment urbanization downstream of Mullum Mullum Creek (below Warrandyte) (Walsh *et al.*, 2007). The influence of this creek increases DCI to over 1%, and by the estuary, the river has reached 4% DCI[1].

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[1] The DCI values cited here should be considered indicative. Work is in progress to produce more accurate values: estimates for the Yarra catchment are likely to be underestimates and those for the Maribyrnong and Kororoit Creek catchments are likely to be overestimates.

Table 1: Reaches of Melbourne's streams classified as urban in this report (>1% DCI). In each case the most upstream point at which they are classed as urban and important points of change along their length are listed. Urban streams of the Mornington Peninsula or the Pakenham corridor east of Eummemmering Creek are not included in this table.

Stream	Urban reaches	DCI	Comment
Yarra River	Mullum Mullum confluence	1.3%	
	head of estuary (Johnson St Bridge)	4.0%	
	mouth	5.8%	
Moonee Ponds Ck	Atwood Ck confluence, Westmeadows	1.9%	Also, its tributary, Yuroke Ck
	Yarra confluence, Docklands	15.0%	
Merri Ck	Headwaters at Wallan	3.6%	
	upstream of Kalkallo confluence	1.5%	Kalkallo Ck reduces DCI to < 1%
	Malcolm Ck confluence, Craigieburn	1.3%	Also, its tributary, Edgars Ck
	Yarra confluence, Abbotsford	19.0%	
Darebin Ck	Epping ~2km upstream of Hendersons Rd drain	1.7%	
	Yarra confluence, Alphington	19.0%	
Plenty R	Mill Park, Heaths Ct drain confluence	1.1%	
	Yarra confluence, Viewbank	2.3%	
Diamond Ck	Research Ck confluence	1.1%	
	Yarra confluence, Eltham	2.3%	
Gardiners Ck	Headwaters in Blackburn	39.0%	
	Yarra confluence, Glenferrie	32.0%	Also its similar tributary, Scotchmans Ck
Koonung Ck	Headwaters in Nunawading	33.0%	
	Yarra confluence, Bulleen	34.0%	
Ruffey Ck	Headwaters in Doncaster East	39.0%	
	Yarra confluence, Templestowe	37.0%	
Mullum Mullum Ck	Headwaters in Ringwood North	30.0%	
	Yarra confluence, Templestowe/Warrandyte	23.0%	
Andersons Ck	Headwaters in Ringwood North	13.0%	
	Yarra confluence, Warrandyte	9.6%	
Jumping Ck	Headwaters in Ringwood North	31.0%	
	Yarra confluence, Warrandyte	9.6%	
Brushy Ck	Headwaters in Mooroolbark	7.6%	
	Yarra confluence, Wonga Park	15.0%	
Chirnside Drain	Headwaters in Chirnside Park	27.0%	
	Yarra confluence, Chirnside Park	9.6%	
Olinda Ck	Cambridge Rd drain confluence, Lilydale	1.4%	
	Yarra confluence, Yering	4.0%	
(Little) Stringybark Ck	Headwaters in Mt Evelyn	17.0%	
	Coldstream	1.2%	DCI <1% by confluence with Yarra
(Wild Cattle) Wandin Yallock Ck	Headwaters in Wandin North	2.2%	
	~3 km downstream of Wandin Yallock	1.0%	
Sassafras, Emerald Ck	for ~1km downstream of Emerald	~1.0%	
Maribyrnong River	Jacksons Ck, Sunbury-Deep Ck confluence	2.2%	
	at confluence of Jacksons and Deep cks	1.0%	
	at head of estuary (Canning St)	2.0%	
Taylors Ck	Full length to Maribyrnong confluence	~30%	
Steeles Ck	Full length to Maribyrnong confluence	~40%	
Kororoit Ck	Caroline Springs	1.0%	
	mouth	~10%	
Laverton Ck	From Laverton Nth to mouth	1-~5%	
Skeleton Ck	Truganina to mouth	1-~10%	
Dandenong Ck	Liverpool Rd Retarding Basin	1.2%	
	outlet of pipe ~3km ds Liverpool Rd RB	5.4%	
	Police Rd Retarding Basin	16.8%	
	at estuary (Pillars Crossing)	~20%	
Bungalook Ck	Headwaters at Montrose	4.1%	
	Dandenong Ck confluence, Bayswater	13.6%	
Dobsons Ck	Claremont Av, The Basin	2.0%	
	Dandenong Ck confluence	1.7%	
Blind Ck	Headwaters at Ferntree Gully	2.9%	
	Dandenong Ck confluence, Wantirna	19.6%	
Ferny Ck	Headwaters in Ferny Ck	2.6%	
	Monbulk Ck confluence	13.8%	
Monbulk Ck	Birdlands Reserve, Belgrave	1.0%	
	Ferny Ck confluence	1.5%	Likely underestimates
Corhanwarrabul Ck	confluence of Ferny and Monbulk	8.4%	(given recent development)
	Dandenong Ck confluence	11.8%	

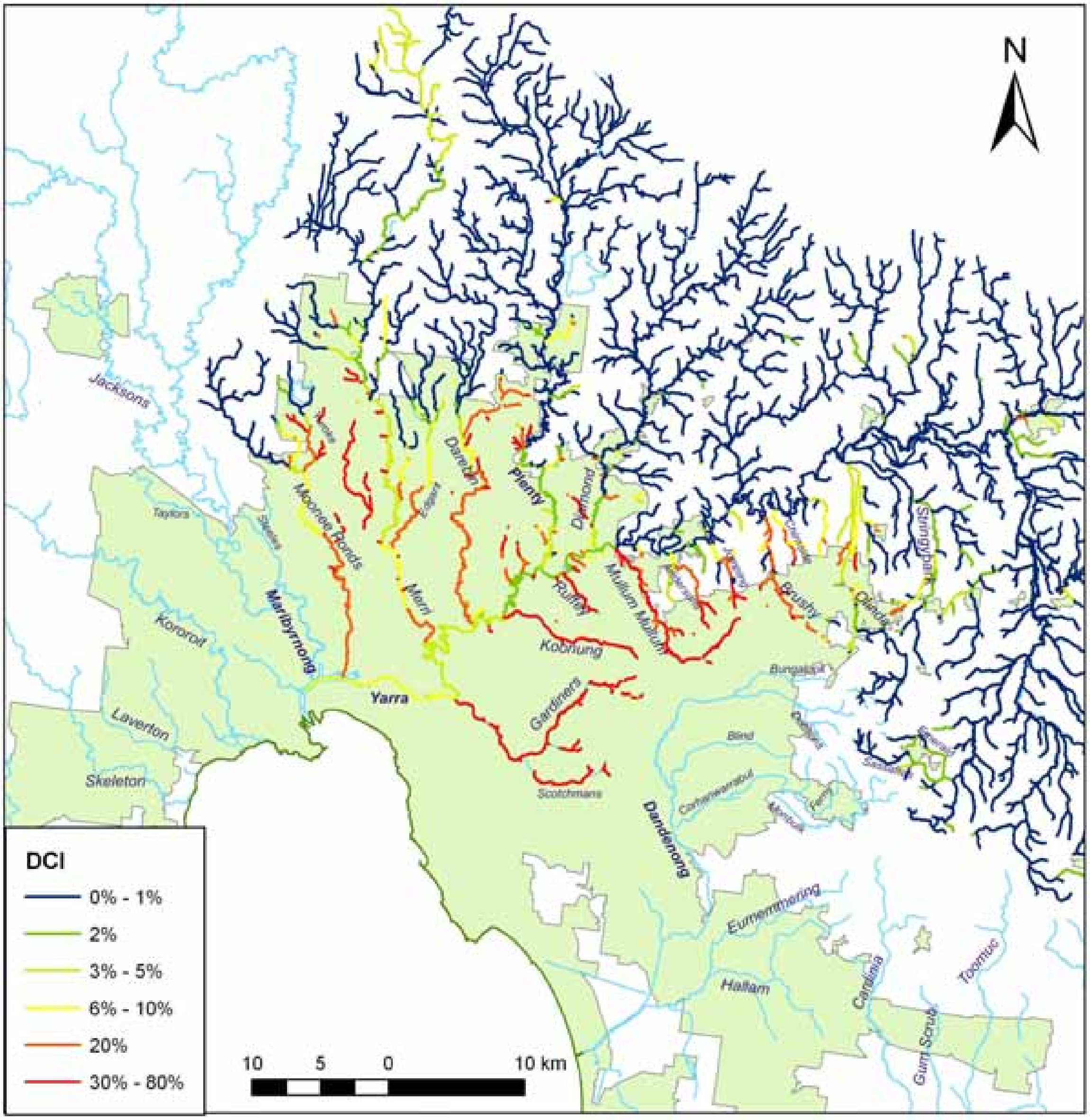


Figure 2. Streams of the Melbourne Metropolitan area for which DCI has been estimated. DCI of the light blue streams to the west and southeast was estimated using coarser imagery and subcatchment divisions (and DCI of reaches is not illustrated). For the Yarra catchment, DCI estimates as illustrated have been determined for short reach lengths (Note the Yarra DCI values are slight systematic underestimates and are currently under revision. The northwest estimates are likely to be slight overestimates). Streams with at least some urban reaches (DCI > 1%) are identified. The green shaded area is the 2030 urban growth boundary for Melbourne.

While there is substantial urban development in some of the small catchments of the Dandenong Ranges, many areas do not have formal stormwater drainage and their streams remain in good ecological condition. Therefore, streams such as Hughes, Olinda, Dandenong and Sassafras, which have substantial headwater urbanization are not classed as urban in their headwaters because their DCI remains <1%.

Table 2: Categories of urban tolerance for animal species associated with streams of the Melbourne Water region.

Category	Definition
A *Urban tolerant species*	Abundance or occurrence is either not correlated or positively correlated with DCI.
B *Transient species*	Recorded occurrences in urban streams are likely to be transient: either during migration or for non-resident use of urban stream habitat.
C *Urban sensitive species*	Abundance or occurrence is negatively correlated with DCI. (i.e. while they might occur in urban streams they are less abundant or common than in rural streams)
D *Urban intolerant species*	Species with near zero probability of being observed at a site with >1% DCI

With the exception of urban streams of the Mornington Peninsula (e.g. Boggy Creek) and of the Pakenham corridor east of and including Eummemmering Ck (e.g. Hallam main drain, lower Cardinia Creek, lower Pakenham Creek), streams that are not listed in Table 1 are not considered to be urban in this report. We argue that reach-scale management that does not address the catchment scale limitation of urban stormwater runoff will have little or no effect on most indicators of ecological structure or function in urban streams, and is more likely to succeed in non-urban streams.

Categories of urban tolerance

We reviewed the ecology of 66 water-dependent species considered by Melbourne Water to be tolerant of urban impacts[2]. In considering appropriate management actions, we classified each species into one of four categories of tolerance to urban impacts (Table 2).

We also classified species according to their degree of dependence on stream habitats. Twenty-six species were solely dependent on stream ecosystems for at least some of their life history. These species (Table 3, urban tolerance categories without subscripts) are likely to be most strongly affected by urban stream management actions. Thirty-seven species were not necessarily dependent on stream ecosystems, and could also use riparian or wetland habitats for feeding and breeding habitat. For these species (Table 4, urban tolerance categories with subscript 'r'), they are likely to benefit more directly from management actions directed at improving the ecological condition of riparian zones or wetlands than from improvement of stream health. Finally, three species (Table 4, denoted by the subscript 't') were considered to have ecological requirements more relevant to terrestrial environments and are therefore considered to be little affected by stream management actions.

[2] This list of 66 species (Table 3) excludes 26 bird species from an original list of 102 species proposed by Melbourne Water, and includes 4 invertebrate taxa added after discussions with Melbourne Water. It also excludes 14 species deemed not relevant to the aims of this report. See Appendix 1 for details.

Table 3: Twenty-six species that are solely dependent on stream ecosystems for at least some of their life history, their classification of urban tolerance (Cat: for definition of the categories, see Table 2), and management recommendations as described in more detail in Appendix 2.

Species	Common name	Cat	Management recommendation
Cherax destructor	Common yabby	A	No action required in urban streams, but could be a useful indicator organism for testing effectiveness of reach-scale actions such as point-source controls, or organic matter retention.
Anguilla australis	Short-finned eel	A	No action required in urban areas.
Galaxias maculatus	Common galaxias	A	1. In urban streams: possibly restoration/modification of fish-ways; 2. To expand populations outside metropolitan area: control of exotic species (trout).
Galaxias truttaceus	Spotted galaxias	A	As for *G. maculatus.*
Galaxias brevipinnis	Climbing galaxias	A	1. In urban streams: no action identified; 2. To expand populations outside metropolitan area: control of exotic species (trout).
Philypnodon grandiceps	Flat-headed gudgeon	A	1. In urban streams: no action identified; 2. Research into factors affecting distribution in urban streams.
Chelodina longicollis	Eastern long-necked turtle	A	1. Reduce habitat fragmentation; 2. Migration barrier management; 3. Distributional research.
Geotria australis	Pouched lamprey	B	1. Confirmation of distribution; 2. To increase populations in urban streams: in-catchment stormwater retention, and possibly remedial sediment management.
Mordacia mordax	Short-headed lamprey	B	To increase populations in urban streams: in-catchment stormwater retention, and possibly remedial sediment management.
Neochanna cleaveri	Australian mudfish	B	1. Basic distributional and ecological research; 2. Barrier removal.
Prototroctes maraena	Australian grayling	B	1. Barrier removal and management; 2. To expand into urban streams: In-catchment stormwater retention; 3. Environmental flow management.
Pseudaphritis urvilli	Tupong	B	1. Barrier removal and management; 2. To expand into urban streams: In-catchment stormwater retention; 3. Ecological research.
Paratya australiensis	Freshwater shrimp	C	1. Research into causes of regionally different responses to urbanization; 2. in-catchment stormwater retention likely required for restoration of eastern metro populations.
Galaxiella pusilla	Dwarf galaxias	C	1. Protection of urban wetland refuge habitats (revegetate and prevent draining), creation of new refuge wetlands; 2. Re-establishment of urban stream populations: in-catchment stormwater retention; 3. Control exotic fish populations; 4. Basic distributional and ecological research.
Nannoperca australis	Southern pygmy perch	C	1. Protection of urban wetland refuge habitats (revegetate and prevent draining), creation of new refuge wetlands 2. Re-establishment of urban stream populations: in-catchment stormwater retention 3. Research on interactions with exotic species
Retropinna semoni	Australian smelt	C	1. For expansion into urban streams: In-catchment stormwater retention; 2. Basic ecological research;
Ornithorhynchus anatinus	Platypus	C	1. In-catchment stormwater management, beginning with isolated populations; 2. Selected reach-scale recommendations of Williams and Serena for rural populations, urban populations within 4km of rural river, urban catchments receiving catchment management.
Austrogammarus australis	Dandenong amphipod	D	1. Existing populations: retrofit of existing connected stormwater pipes; regulation of new developments including road upgrades; 2. Targeted catchments with lost or endangered populations: retrofit for in-catchment stormwater retention, and riparian vegetation and in-stream habitat restoration.
Austrogammarus haasei	Sherbrooke amphipod	D	1. Existing population: retrofit of existing connected stormwater pipes; regulation of new developments including road upgrades; 2. Basic research on biology and distribution.
Engaeus urostrictus	Dandenong crayfish	D	1. Basic distributional and ecological research required; 2. Existing populations: regulation of stormwater and wastewater from urban areas.
Euastacus yarraensis	Yarra spiny crayfish	D	1. For potential reintroduction to the lower Yarra: retrofit of existing stormwater system and regulation of new developments including road upgrades; 2. For remaining non-urban populations: riparian reafforestation.
Leptoperla kallistae	Kallista stonefly	D	1. Existing populations: retrofit of existing connected stormwater pipes; regulation of new developments including road upgrades; bushfire management; protection of riparian forests; 2. Targeted catchments with lost or endangered populations: retrofit for in-catchment stormwater retention, and riparian vegetation and in-stream habitat restoration
Megaloptera	Dobsonflies and alderflies	D	1. Expansion into metro streams will require widespread in-catchment stormwater retention and riparian replanting; 2. In streams with up to 2% DCI, riffle restoration can promote Corydalidae
Hyriidae	Freshwater mussels	D	1. For potential reintroduction to metro streams: retrofit of existing stormwater system and regulation of new developments including road upgrades; 2. For non-urban populations: adaptive management of land use, riparian vegetation and flow regimes.
Gadopsis marmoratus	River blackfish	D	1. Isolated populations on urban fringe require urgent protection through in-catchment stormwater retention, and habitat management (refuge & spawning sites); 2. In-catchment stormwater retention required more widely before restoration of lower Yarra populations possible; 3. In reaches without stormwater impacts, habitat management is appropriate.
Nannoperca obscura	Yarra pygmy perch	D	Further research required for a management plan, but recovery unlikely in streams with DCI >1%

Urban tolerance of selected animals

The biology of each species is reviewed and their urban tolerance category justified in Appendix 2. All of the 26 truly stream-dependent animals, except platypus, were invertebrates or fish. Only 7 of these 26 species are tolerant of catchment urbanization and were collected commonly throughout the metropolitan area (Table 3). Despite numerous records from urban streams, platypus were classed as urban sensitive (category C). Platypus demonstrate a very strong negative correlation with DCI, when only records of confirmed residents are considered, and when records are excluded from urban streams at locations close enough to an adjoining, non-urban river to allow for feeding excursions outside the urban stream, (Figure A72).

Five category B (transient) species were migratory and were either rarely or never recorded in urban streams. The distribution of grayling, mudfish and tupong were likely in part limited by barriers to migration, but their absence from urban streams where barriers are absent suggests an intolerance of urban impacts. The two lamprey species were recorded in urban streams rarely, but were more numerous in non-urban streams.

For the 37 species (7 frog, 27 bird, and 3 mammal species) that were not solely dependent on stream habitats for their persistence, a larger proportion (57%) were tolerant of catchment urbanization and were observed or collected commonly throughout the metropolitan area. A further 9 species were also common in urban areas, but are most likely transient visitors. Only 7 of the 37 species showed a negative correlation with urbanization (4 of these were completely absent from urban areas). Because this group of 37 species is less strongly dependent on stream ecosystems, it is likely that DCI has only an indirect influence on their distribution. Those that are sensitive to or intolerant of urbanization are likely to be influenced by other urban-related factors as well or instead.

Three species (Altona skipper butterfly, golden sun moth, and swamp antechinus) were considered insufficiently dependent on stream habitats to be affected by stream management, but all three appear to be sensitive to urban impacts (Table 4). We do not discuss management priorities for these three species here, but see Appendix 2 for a more detailed consideration.

Options for managing species by urban tolerance

Urban category A: Urban tolerant species

Of the 26 stream-dependent species (deemed a priori to be urban tolerant), only seven showed evidence of being truly urban tolerant. This is consistent with widespread findings that catchment urbanization reduces aquatic biodiversity and alters ecosystem function (Paul & Meyer, 2001; Walsh *et al.*, 2005b). Generally, management actions aimed at conserving or improving populations of such urban tolerant, stream dependent species in urban streams are not recommended.

Because urban tolerant animals are able to sustain populations in degraded urban streams, there are few management actions that are required for their conservation. There might even be negative consequences in doing so, if managing for their habitat preferences also favours pest species. This study has not directly assessed the distribution of exotic animals, but the Melbourne Water fish database shows that exotic species such as mosquito fish, carp and weatherloach all occur commonly in degraded metropolitan streams.

Table 4. Thirty-seven species (subscript r) that are not necessarily dependent on stream ecosystems, and can also use riparian or wetland habitats for feeding and breeding habitat, and three more terrestrial species (subscript t) likely to be little affected by stream management actions. (See for more details).

Species	Common name	Cat	Management recommendation
Litoria ewingi	Southern brown tree frog	A_r	1. Protection of existing habitat (riparian vegetation, fencing, hydrology, stormwater control); 2. Reconnection of fragmented habitats; 3. Exotic predator control; 4. Creation of new wetland habitats.
Crinia signifera	Common froglet	A_r	As for *Litoria ewingi.*
Limnodynastes dumerilii	Pobblebonk	A_r	As for *Litoria ewingi.*
Limnodynastes peroni	Striped marsh frog	A_r	As for *Litoria ewingi.*
Limnodynastes tasmaniensis	Spotted marsh frog	A_r	As for *Litoria ewingi.*
Ardea pacifica	White-necked heron	A_r	1. No management identified in urban streams; 2. Monitor for potential toxicant accumulation in stormwater treatment wetlands.
Egretta novaehollandiae	White-faced heron	A_r	As for *Ardea pacifica.*
Cygnus atratus	Black swan	A_r	As for *Ardea pacifica.*
Nycticorax caledonicus	Nankeen night heron	A_r	1. Riparian forest protection and restoration along urban streams; 2. Exotic predator control.
Porphyrio porphyrio	Purple swamphen	A_r	1. No action required in urban streams; 2. Protection and provision of wetland habitat.
Fulica atra	Eurasian coot	A_r	As for *Porphyrio porphyrio.*
Gallinula tenebrosa	Dusky moorhen	A_r	As for *Porphyrio porphyrio.*
Phalacrocorax melanoleucos	Little pied cormorant	A_r	As for *Ardea pacifica.*
Phalacrocorax varius	Pied cormorant	A_r	As for *Ardea pacifica.*
Phalacrocorax sulcirostris	Little black cormorant	A_r	As for *Ardea pacifica.*
Phalacrocorax carbo	Great cormorant	A_r	As for *Ardea pacifica.*
Anhinga melanogaster	Darter	A_r	As for *Ardea pacifica.*
Todiramphus sanctus	Sacred kingfisher	A_r	1. No action required in urban streams; 2. Protection and provision of woodland (including riparian) habitat.
Acrocephalus australis	Australian reed-warbler	A_r	Protection of stream and wetland reed beds.
Cisticola exilis	Golden-headed cisticola	A_r	As for *Acrocephalus australis.*
Hydromys chrysogaster	Water rat	A_r	1. Distributional and ecological research; 2. Riparian habitat protection; 3. Exotic predator control; 4. Community awareness programs.
Anas superciliosa	Pacific black duck	B_r	Abundant through the metropolitan area under current management regime. 1. Provision and protection of wetlands and their riparian margins; 2. Exotic predator control.
Anas gracilis	Grey teal	B_r	As for *Anas superciliosa.*
Anas castanea	Chestnut teal	B_r	As for *Anas superciliosa.*
Chenonetta jubata	Australian wood duck	B_r	As for *Anas superciliosa.*
Ardea intermedia	Intermediate egret	B_r	As for *Ardea pacifica.*
Ardea alba	Great egret	B_r	As for *Ardea pacifica.*
Egretta garzetta	Little egret	B_r	As for *Ardea pacifica.*
Platalea flavipes	Yellow-billed spoonbill	B_r	1. Ecological research; 2. Provision and protection of wetlands and their riparian margins
Himantopus himantopus	Black-winged stilt	B_r	1. Not a primary target for management in urban areas. 2. Protection of wetland habitats and exotic predator control in known breeding areas.
Tadorna tadornoides	Australian shelduck	C_r	1. Provision and protection of wetlands and their riparian margins; 2. Exotic predator control; 3. Ecological/distributional research (incl. monitoring of health in treatment wetlands).
Ixobrychus minutus	Little bittern	C_r	1. Ecological research; 2. Provision and protection of wetlands and their riparian margins; 3. Exotic predator control.
Botaurus poiciloptilus	Australasian bittern	C_r	As for *Ixobrychus minutus.*
Litoria raniformis	Growling grass frog	D_r	As for *Litoria ewingi.*
Egernia coventryi	Swamp skink	D_r	1. Re-establishment in urban areas unlikely; 2. Protection, restoration and connection of existing habitats; 3. Exotic predator control
Myotis macropus	Large-footed myotis	D_r	1. For potential expansion into urban area, in-catchment stormwater retention; 2. promotion of old-growth floodplain trees; 3. Riparian forest connectivity; 4. Distributional research
Rattus lutreolus	Swamp rat	D_r	1. For potential expansion into urban area, in-catchment stormwater retention; 2. Riparian vegetation and bank restoration and protection; 3. Exotic predator control
Synemon plana	Golden sun moth	C_t	Protection of selected grasslands; reduce habitat fragmentation; active grass management.
Hesperilla flavescens flavescens	Altona skipper butterfly	C_t	Parkland and wetland management, including vegetation replanting; fire management; runoff management and research into the dependent animal/plant relationship
Antechinus minimus	Swamp antechinus	D_t	Reduce habitat loss and fragmentation; Review fire management practices

Galaxias spp. might benefit from improvements in fishway designs that are recommended for other species (below), but given their existence in urban streams, additional management actions to conserve these populations are likely to be unnecessary. Conservation of *Galaxias* spp. in the Melbourne Water region would be more appropriately aimed at rural streams, where they are likely to be limited by competition and predation by exotic species, such as trout (Table A2).

Of the stream-dependent species that we classed as urban tolerant, our classification of *Chelodina longicollis*, the long-necked turtle, is the most uncertain, because of the quality of the available distributional data. It is possible that better data could show that *C. longicollis* is less abundant in urban streams, which could potentially be caused by barriers to migration between habitat patches (Ryan & Burgin, 2007). Further distributional research for this species is recommended.

Managing for the conservation of urban tolerant species that are less dependent on stream ecosystems should also be undertaken with caution. Overabundance of urban tolerant bird species (and some abundant transient species) might be detrimental to stream ecosystems, and a reduction in certain species might benefit other animal assemblages. Abundant urban tolerant bird species might have a direct negative impact on stream ecosystems through enrichment with their excreta. Waterbirds foraging in terrestrial environments are often net importers of nutrients to an aquatic ecosystem (Hahn, Bauer & Klaassen, 2008). For such species, programs that control their population sizes might be more appropriate. Discouraging the feeding of waterbirds (including introduced species) in recreational parks combined with an education campaign that explains why birds shouldn't be fed might reduce nutrient loads to metropolitan streams and wetlands.

In general, populations of urban tolerant birds and frogs will benefit from protection of existing wetland habitats (and the creation of new ones), protection of riparian forests, and the protection of wetland and waterway reed-beds. While potentially benefiting urban tolerant species, these actions are likely to benefit many less tolerant species as well (see below).

We have classified *Hydromys chrysogaster*, the water rat, as not solely stream dependent because it is able to use terrestrial food sources. We posit that along urban streams, where their preferred prey items (large stream invertebrates) are uncommon, water rats are more dependent on terrestrial food sources (and suggest this as an area for research). The failure of a habitat restoration project in a section of Scotchmans Creek to increase the abundance of water rats (Wilson, Quin & Crowfoot, 2005) suggests that in-stream habitat complexity is not limiting water rats in urban environments. However, because water rats appear to be more abundant in urban streams than in rural streams (Williams & Serena, 2004), we do not recommend management actions targeted at increasing urban water rat populations until further ecological research has been conducted to clarify the factors driving their distribution.

Urban category B: Transient species

It is unlikely that any of the five fish species that we classed as transient (Table 3) are able to tolerate conditions in degraded urban streams. Any management plan aimed at returning these species to streams in metropolitan Melbourne will require widespread in-catchment stormwater retention.

For Australian grayling, tupong, and perhaps *Galaxias* spp., physical barriers to migration are likely preventing migration through the metropolitan sections of rivers such as the Yarra and the

Maribyrnong to healthy rural rivers upstream. Melbourne Water's current program of barrier removal is therefore an appropriate response. (We also suggested barrier removal as a management action for the Australian mudfish, but a single record from the Yarra system suggests that investment in removing barriers for this species will result in limited returns).

Degraded urban streams themselves could possibly act as barriers to migration, and full recovery of migratory populations of grayling and tupong to rural streams might still require widespread in-catchment stormwater retention.

For the nine bird species that we classed as transient (Table 4), no management of urban streams is recommended. As for urban tolerant birds, transient birds will benefit from protection of existing wetland habitats (and the creation of new ones), protection of riparian forests, and the protection of wetland and waterway reed-beds (see below). Managing for overabundance, as discussed above for urban tolerant birds, is possibly also required for transient duck species.

Urban category C: Urban sensitive species

For the five stream-dependent species classed as urban sensitive (Table 3), re-establishment or expansion into metropolitan streams from which they are currently absent, will most likely require widespread in-catchment stormwater retention.

The shrimp *Paratya australiensis* is a single exception. It's occurrence is negatively correlated with DCI in southeastern Melbourne streams (Figure A9). However it does occur in degraded urban streams of the basaltic north-west region. This variation in response across Melbourne regions raises some interesting opportunities to explore the factors driving this urban response. If the persistence of *P. australiensis* in northwestern metropolitan streams is the result of low-flow refuges, then it might be possible to restore south-eastern metropolitan streams by provision of low-flow refuges. If, on the other hand, it is because of a toxicity-salinity interaction, then reach-scale habitat restoration is unlikely to be effective.

For the three bird species (not entirely dependent on stream habitats) that are classed as urban sensitive (Table 4), we recommend the protection of existing riparian and non-riparian wetlands (and possibly the creation of new wetlands), the protection and restoration of wetland riparian vegetation, and protection from exotic predators. The protection and creation of wetlands in the metropolitan area is likely to benefit a range of species from urban categories A, B and C, that are not entirely dependent on stream habitats. However, the use of wetlands for the combined objectives of stormwater treatment and biodiversity conservation should be approached with caution (Helfield & Diamond, 1997). We recommend that bird species that colonize stormwater treatment wetlands (particularly the egrets, herons and cormorants) be monitored for potential toxicant accumulation.

The Australasian and little bitterns, *Botaurus poiciloptilus* and *Ixobrychus minutus dubius*, are particularly shy birds that are easily disturbed by human associated activities and may need areas known to currently support them to have restricted access. The complete closure to humans of wetlands associated with bittern occurrence, particular the little bittern, would be preferred and may secure their fragile status in urban Melbourne.

Wetland conservation is also an important management action for two fish species classed as urban sensitive (*Galaxiella pusilla* dwarf galaxiid, and *Nannoperca australis* southern pygmy perch). Each of these species is rare or absent from urban streams, but are found more commonly in wetlands in the metropolitan area. Conservation and creation of urban wetland refuges for these species is necessary for the short-term survival of these species in the metropolitan area. Wetlands managed for the conservation of these species should not receive stormwater runoff directly from pipes or sealed drains. A priority management action should be stormwater retention and treatment in the catchments of such wetlands. In the longer term their re-establishment into streams of the metropolitan area will require more widespread in-catchment stormwater retention.

Although mosquito fish, *Gambusia holbrooki*, have been proposed as a competitive or predatory threat to small native fish such as *G. pusilla* and *N. australis*, we found no evidence suggesting the occurrence of these fish were negatively influenced by the presence of *G. holbrooki* in urban streams (Tables A5, A6). These results are based on presence absence, so we recommend further research into possible interactions between these species. However, our analyses suggest that the removal of *G. holbrooki* from urban wetlands and streams would not be sufficient to re-establish populations of *G. pusilla* or *N. australis.*

We class *Ornithorhynchus anatinus* (platypus) as urban sensitive (Table 3, and see Appendix 2). There is strong evidence that resident platypus populations have been lost from most of Melbourne's streams as the suburbs have developed and expanded. While platypus have been recorded visiting urban reaches of several streams, they are resident in only two moderately urbanized streams (Ruffey and Mullum Mullum creeks). In both cases, the platypus reside within 2–4 km (well within their home range) of the Yarra River, largely unimpacted by urbanization and supporting a large population of platypus. When records from these two streams are excluded from consideration, resident platypus are not found in streams with more than ~2% DCI, suggesting they are very sensitive to catchment urbanization.

Serena & Williams (2008) recommended a number of reach-scale management actions for the protection of platypus. We believe that most of their recommendations for habitat improvement will help to promote platypus populations only in streams that are not affected by catchment urban stormwater (DCI <1–2%), and that they should not be applied in urban streams, except for those reaches that are within 4 km of a rural river (i.e. the lower reaches of Ruffey and Mullum Mullum creeks). The recommendations of Serena & Williams (2008) for the reduction of incidental impacts of urbanization such as walking track design, fisher regulation and dog and fox management are more widely applicable in reaches of urban streams that are used seasonally or by transient platypus. Such reaches include the Yarra mainstem to the estuary, Mullum Mullum Creek upstream to the Deep Creek Reserve and the lower Plenty River. In addition the management of physical barriers to migration to allow platypus passage is likely to be an important management action for such reaches.

Opportunities to build ‘platypus friendly’ lakes and wetlands are likely to be limited in urban environments, and each of the examples listed by Serena & Williams (2008) present new problems for stream ecosystems that are likely to outweigh any perceived benefit to platypus populations. Toorourrong Reservoir in the upper Plenty River catchment presents a significant barrier to migration of many aquatic fauna and the Liverpool Road retarding basin presents a major barrier that contributes to the isolation of the upper Dandenong Creek population; the Hull Road wetlands along Olinda Creek divert baseflows from the creek, and alter thermal and chemical state of the creek downstream (Walsh *et al.*, 2004a).

The primary management action for platypus in the Melbourne Water region should be aimed at conserving the isolated populations identified by Serena & Williams (2008) as being in danger of extinction. For the isolated populations in the Olinda, upper Dandenong and upper Monbulk catchments, the primary threats are a) increased urban stormwater impacts from new development, b) isolation of the population by barriers to stream migration formed by severely degraded urban reaches downstream and associated physical barriers such as Lilydale Lake and the piped section of Dandenong Creek below Liverpool Rd and possibly c) lack of overland corridors to permit inter-catchment dispersal and recruitment. For the isolated population in Stringybark Creek, urban degradation of the creek below Little Stringybark Creek might contribute to the isolation, but the primary problem is channel diversion and degradation in the agricultural land at the bottom of the catchment (Serena and Williams, 2008). In addition to actions to connect these populations with others, their protection and re-establishment will require targeted actions to retrofit stormwater infrastructure in each of the isolated catchments, and careful regulation of new development. As all the isolated urban populations rise in the Dandenong Ranges, the ongoing road upgrade program of the Shire of Yarra Ranges is a particular threat that requires regulation for the protection of platypus.

Urban category D: Urban intolerant species

For species that are not found in areas with >1% DCI, no reach-scale management action is likely to re-establish populations in metropolitan areas, whether they are solely stream dependent or not. For stream-dependent species in this category, re-establishment of urban populations is highly unlikely until in-catchment stormwater retention has been implemented across whole catchments to achieve DCI of <1%. For species that are not solely dependent on stream habitats, it is likely that other urban-related impacts are restricting their distribution, possibly in combination with stormwater impacts.

The conservation of species intolerant of urbanization requires management of threats to existing populations as well as targeted actions in catchments where they are absent, but where limiting factors could potentially be controlled to allow the re-introduction of the species. It must be emphasized that populations of several of the species we have classed as urban intolerant persist in catchments with substantial urbanization: primarily those in the Dandenong Ranges (e.g. *Austrogammarus australis*, the Dandenong amphipod; *Leptoperla kallistae*, the Kallista stonefly). The likely remediating factor allowing the persistence of these species in these catchments is the combination of both good riparian forests and a lack of stormwater drainage systems discharging to streams. These catchments of the Dandenong Ranges are priority assets for Melbourne Water, that also support isolated populations of platypus (see above). A primary recommendation of this report is therefore strict management of stormwater drainage in catchments of the Dandenongs, including that associated with road upgrades. We also recommend riparian forest conservation and restoration, particularly along any stream reaches of the Dandenongs that do not fall within existing reserves.

Reach-scale management for the conservation of urban intolerant species is appropriate in rural areas, and covers many management approaches already being undertaken by Melbourne Water (Tables 3, 4). Of particular importance for species that are not solely dependent on stream habitats, is the establishment of corridors of riparian and non-riparian forest to allow connection between isolated populations. If such actions were begun to be implemented now, then colonization of urban stream habitats once stormwater impacts have been minimized will be more likely. Long-term planning for riparian vegetation is required for *Myotis macropus* in particular, which requires old-growth floodplain trees.

Reach-scale management options

We have identified few reach-scale management actions not currently employed by Melbourne Water that could be aimed at conserving aquatic animals. No reach-scale actions are likely to re-establish sustainable populations of stream-dependent species that have been lost through catchment urbanization.

The majority of the reach-scale actions that we recommend concern the protection or creation of wetland or riparian habitat, to conserve or improve populations of animals that can use these habitats for functions no longer viable in degraded urban streams.

Reach-scale management of stream channels that is required for purposes other than ecological improvement (e.g. property protection) might provide opportunities to test if our assessment of the low probability of ecological improvement is true. Any substantial change in ecological condition in urban streams would be an important research finding. If any ecological change is intended as a result of any reach-scale action, we recommend strongly that a budget be included for ecological assessment of the project. The project should be conducted with assessable objectives and a well-designed experimental assessment of changes in the target indicator as a result of the project. Here we list the main reach-scale management actions that could be applied in urban streams, and postulated ecological responses that could be tested in such a way so that stream works can be conducted in an adaptive management framework.

Point-source controls

The prevention of pollution from point sources, such as industrial effluent, or from sewage outfalls is an essential first step in protecting the health of urban streams. Cities of the developed world, including Melbourne, have shown impressive recovery of their major waterways following removal and treatment of sewage and industrial effluents (Gameson & Wheeler, 1977; Walsh, 2000). In the twentieth century, the lower Yarra transformed from a stinking health hazard, flowing red with blood from abattoirs in places, to a highly valued natural amenity for the city of Melbourne. Now, most direct industrial effluents have been removed from the Yarra and its tributaries, and the quality and quantity of those that remain are strictly regulated.

But, although improved and now much less of a human health hazard, most of Melbourne's urban streams remain in poor ecological health, mainly because of the thousands of kilometres of stormwater pipes and sealed drains that ensure that every spill, or accidental cross-connection with the sewerage system, that occurs anywhere in the catchment (even the most upland parts of urban subcatchments), is delivered directly to the stream (Figure 3). The problems of industrial effluents and sewage pollution have now shifted from being easily manageable outfalls directly into rivers, to being immensely difficult-to-find illegal discharges into the stormwater system. They have shifted from being point-sources to being part of the diffuse-source problem that is the stormwater system.

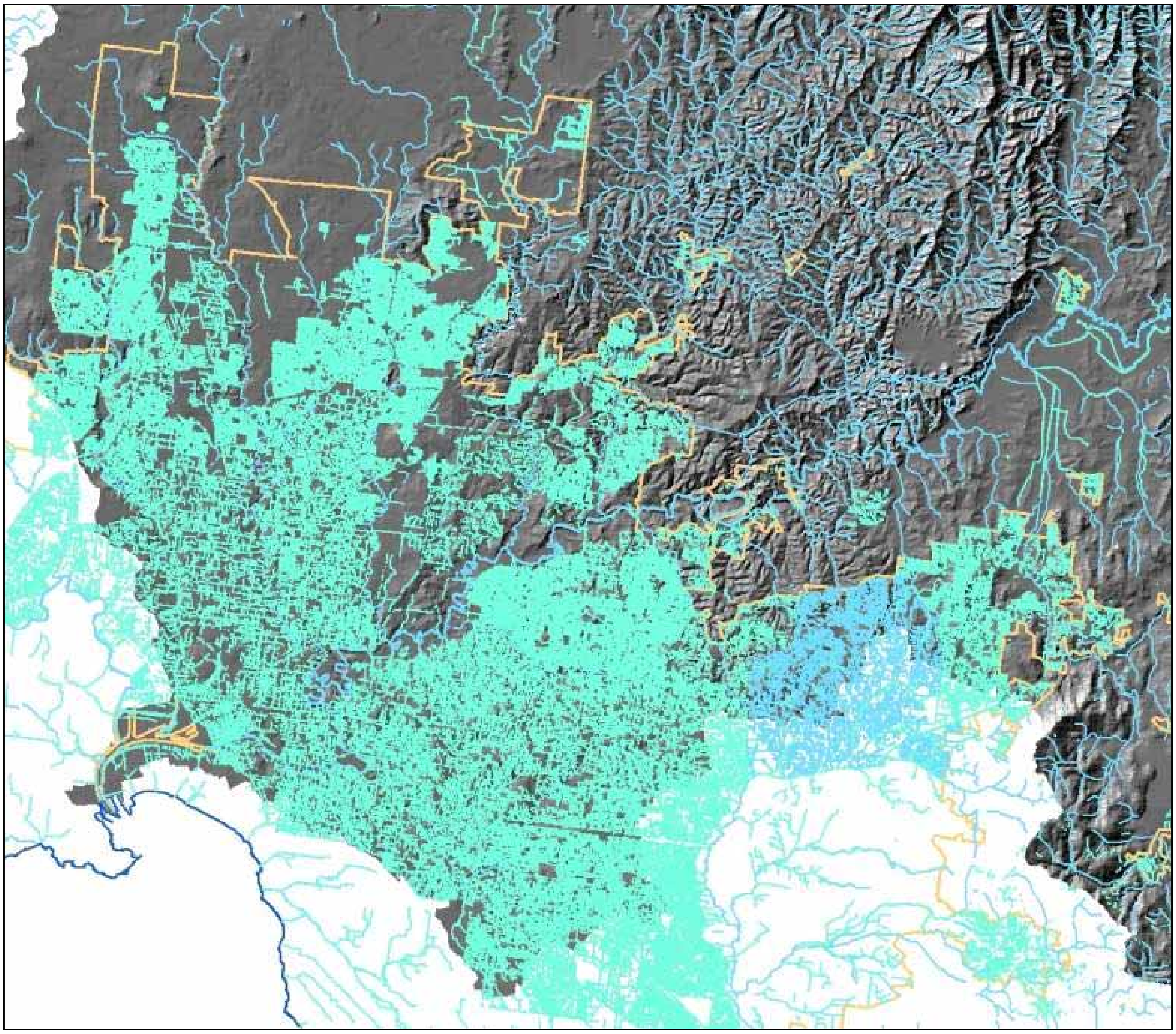


Figure 3. A map of the stormwater drainage system (light blue lines: note many pipes are missing because of incomplete council records) in the lower Yarra River catchment (underlying grey digital elevation model), showing an extremely high drainage density within the urban growth boundary (yellow line), that ensures efficient hydraulic connection between even the most upland part of each subcatchment with the urban mainstem Yarra and its tributaries (source, Melbourne Water).

Melbourne Water and EPA Victoria have important programs in place to reduce illegal discharges into the stormwater system. Most ecological indicators, including those of the State Environment Protection Policy (Figure 1) are unlikely to show detectable improvements from such programs for two reasons.

1. Ecological degradation (as measured by many indicators) is observed in streams with DCI >1% and with no industrial land use, and the degree of degradation is uniformly severe in streams with DCI >5-10% in catchments with or without industrial land use. The removal of industrial effluents will therefore be insufficient to effect improvement in most ecological indicators. Any improvements are more likely to be assessable by changes in targeted chemical variables, or perhaps by selected urban-tolerant fauna identified in this review e.g. *Cherax destructor*. It is possible that surveys of abundance of target species such as this could provide

evidence of improvement undetectable by most other measures. Before such an approach is taken, surveys of the distribution and abundance of target organisms together with analyses to assess if their distributions are explained by different types of urban land use could help to assess if it is likely to be successful.

2. The design of the stormwater system maximizes the risk that any spill or illegal connection in the catchments will reach the stream. In a dynamic city of several million people, multiple such spills or cross-connections must occur daily, so any program to seek out such problems will not remove the problem. Only an overhaul of the stormwater system to designs that ensure retention of stormwater in the catchment in all but those rain events that pose a flood risk, will remove the risk of spills leaving the catchment.

Riparian revegetation and fencing along streams

We posit that riparian revegetation along urban streams will have no effect on the distribution of any of the stream-dependent species considered in this review (Table 3), before substantial improvements are made in catchment stormwater management.

More broadly, riparian revegetation is likely to have only minor effects on the ecology of streams that are limited by catchment urban stormwater impacts, i.e. with DCI >1% (Walsh *et al.*, 2007). In small urban streams, the effects of shading can have local effects on algal growth (Hession *et al.*, 2004; Roy *et al.*, 2005), but Catford *et al.* (2007), working in Melbourne streams, found that shading effects on algal growth are likely to be small compared to the effects of catchment urbanization. In Melbourne, increased algal growth in urban streams is most likely caused by increased phosphorus concentrations from stormwater runoff, and local decreases in algal growth are likely to only shift eutrophication problems downstream (Catford *et al.*, 2007; Taylor *et al.*, 2004).

Conservation and restoration of riparian vegetation along urban streams are likely to have some positive effects for fauna that are not entirely dependent on stream ecosystems (Table 4), although greater gains are likely to be had from revegetation of riparian margins of wetlands (see section on wetland management below). On a larger scale, replanting of riparian forests through the metropolitan area will be an important element of reconnecting habitat fragments across the Melbourne Water region (see section on habitat fragmentation below).

In rural streams riparian vegetation is the primary source of organic matter, which in turn is the primary source of energy for stream-dependent fauna. In urban streams organic matter inputs become dominated by delivery from the stormwater system, and the importance of riparian inputs is diminished (Appendix 3). Long-term recovery of urban stream ecosystems requires the establishment of healthy riparian forests in tandem with catchment-scale measures to address stormwater runoff impacts.

The fencing of replanted riparian vegetation in urban and rural streams is important for several reasons. Plants are most at risk to grazing pressures (rabbits, cattle etc) when young. Fencing is unlikely to have much benefit in urban areas but measures such as tree guards and planting semi-mature trees may reduce rabbit grazing and accidental damage by humans. Foxes and domestic cats are likely to circumnavigate all types of fences that are practical to build around replanted vegetation so small mammals and birds are likely to still be exposed to predation regardless of fence status. Riparian vegetation does however provide many more predation refuge points for native fauna, regardless of urban gradient. In rural streams, fencing is much more likely to be successful as it reduces the impact of cattle grazing establishing vegetation.

Removal of dispersal barriers

Melbourne Water currently has a program in place to identify and remove reach-scale barriers to fish dispersal. Of the species considered in this review, *Galaxias* spp., *Neochanna cleaveri* (Tasmanian mudfish), *Prototroctes maraena* (Australian Grayling) and *Pseudaphritis urvilli* (Tupong) are most likely to benefit from barrier management. We posit that the last three species are likely to be also sensitive or intolerant to urban stormwater runoff. Almost certainly barrier removal will not result in these species returning to urban streams. Furthermore, the potential for rural streams to be reached might be limited in the Yarra catchment if the poor condition of the lower Yarra is itself a barrier.

Barriers to dispersal were also identified as a potential threat for *Chelodina longicollis* (long-necked turtle), but in that case, the most important barriers are likely to be overland between water bodies, which is more appropriately addressed below under habitat fragmentation.

Barriers to dispersal are an implicit problem for the isolated populations of platypus that need urgent management. These barriers are both overland (connecting populations across the subcatchments of the Dandenongs), and in-stream (the degraded reaches and impoundments/diversions of the lower Olinda and Stringybark creeks). See below for further consideration.

Reconnection of habitat fragments

Dispersing individuals need suitable habitat corridors to successfully disperse between habitat patches. If animal species are to expand their current distributions, they need a) a suitable habitat to disperse into and b) safe passage to the habitat. Urbanization creates a fragmented landscape by reducing the amount of suitable habitat and introducing migration barriers over multiple scales (Garden *et al.*, 2006).

While it is difficult to create large amounts of suitable habitat within urban centres, dispersal barriers preventing safe passage between habitat patches can be addressed. The type of barrier varies with species but the major ones relevant to this review include roads, gutters and fences for terrestrial or semi-aquatic species (Way & Conole, 2002), and weirs and dams for fish and aquatic invertebrates (McGuckin, 2001; 2005a; 2005b; 2007; 2008).

Many habitat fragmentation problems cannot be addressed in reach-scale management because the number and extent of barriers across the landscape requires a catchment scale response.

Reconnecting habitat patches has a number of benefits to animal assemblages but in order to achieve maximum benefit to a range of animals, research effort needs to be concentrated on examining those areas that will most benefit from reconnection (see future research directions, below).

Reintroducing habitat complexity

Artificial riffle construction, or other habitat improvement measures such as large woody debris reintroduction, might have small localized benefits to a restricted subset of species in streams with up to 5% DCI. However the returns on habitat restoration investments are likely to be greater in streams with lower DCI. No species considered in this review is likely to respond to habitat restoration with increased numbers in streams with >5%DCI (and very few will increase in streams with >1% DCI).

Managing constructed wetlands for habitat

Conservation, restoration and even creation of wetlands appear to be the small-scale management actions with the greatest hope of achieving improvements in population sizes and diversity of aquatic fauna in metropolitan Melbourne. Wetlands are potential urban refuges for two stream-dependent species that have been lost from urban streams (*Nannoperca australis* and *Galaxiella pusilla*). And urban wetlands are primary habitats for the conservation of the urban tolerant, transient, and some of the urban sensitive species that are not solely dependent on stream habitats (Table 4).

Conservation and restoration of riparian and littoral vegetation, the provision of breeding sites, and the management of stormwater quality and quantity flowing into wetlands are the major management actions required for wetlands. Mature trees that overhang rivers, streams and riparian wetlands are important nesting habitat for many bird species(Briggs, Lawler & Thornton, 1998; Chambers & Loyn, 2006; Kingsford & Norman, 2002; Kingsford *et al.*, 1999), and reeds are important habitat for several bird species. Fencing and exclusion of people and exotic animals is likely necessary for the conservation of some sensitive species such as *Ixobrychus minutus* and *Botaurus poiciloptilus* (bitterns).

Wetlands constructed for stormwater treatment can also be attractive to wildlife. We urge caution if such wetlands are also to be managed as habitat for wildlife. Wetlands do not permanently remove contaminants such as nutrients, metals and organic and inorganic compounds, but rather temporarily store them. In particular, the chance of processes within the wetland converting benign compounds into toxic compounds is substantial and the consequences to aquatic and semi-aquatic animal assemblages that live in constructed wetlands dire (Helfield & Diamond, 1997). As discussed below, we recommend monitoring the health of birds that are attracted to stormwater treatment wetlands to guard against the possibility of bio-accumulation of toxicants.

In wetlands that are created or managed for wildlife conservation, then in-catchment stormwater management is required to maintain water quality and quantity in the wetland. Fortunately for most wetlands, catchment areas are small, and the task of adequate stormwater treatment is more tractable than for most streams.

Control of exotic predators and competitors

Control of exotic terrestrial predators such as foxes, cats and dogs around wetlands and streams will likely benefit a range of frog, bird and mammal species that currently exist in urban areas (Lane & Mahony, 2002; Lilith *et al.*, 2006; Markovchick-Nicholls *et al.*, 2008; White *et al.*, 2006), but we postulate that such controls alone will not result in re-establishment of urban-sensitive or urban-intolerant animals that are no longer present in urban areas. We are, however, aware that control of exotic species is likely an intractable problem in urban areas.

Our analyses suggest that eradication of *Gambusia* in urban wetlands or streams is unlikely to return absent native fish populations, but further research of this hypothesis is warranted. *Gambusia holbrooki* prefers high water temperatures (and tolerates the associated low dissolved oxygen) so management to reduce water temperatures such as provision of wetland shading with riparian vegetation, could give species like *Galaxiella pusilla* a competitive edge (Coleman, 2008). The complete draining of wetlands that sustain high abundances of *Gambusia*, in order to eradicate them, has also been trialed with limited success. The translocation of native fish into storage facilities during wetland draining, and the time that wetlands need to be dry to ensure all exotic fish are dead - implies that this is not a viable solution on larger scales (or in streams) and should only be considered in extreme circumstances.

Environmental flow management

A clearer understanding of environmental flow problems of urban streams is required by environmental flow practitioners generally. The effects of urban stormwater on stream flows are complex. Reduced infiltration resulting from impervious surfaces reduces baseflows (although this effect can be masked by leakage of water from water supply infrastructure, or worse, sewerage infrastructure). As a result, diversion of water from urban streams during base flow (or from large pipes that carry some baseflow originating from pervious runoff) is not recommended.

Urban stormwater infrastructure increases the volume and frequency of runoff following rain events, so stormwater harvesting from rain events is an important management action for stream protection. This is most effectively done at or near-source, so any applications for diversion licences from urban streams should have first exhausted all alternative options for harvesting water directly from impervious surfaces at source. If stormwater is harvested at- or near-source in tandem with the retention and treatment of runoff from other impervious surfaces in rain-gardens, then the baseflows can be augmented and frequency and volume of large flows can be reduced. Thus, the in-catchment stormwater management actions that we advocate are aimed at restoring environmental flows to urban streams.

Stormwater runoff increases the size of peak flows following small rain events, and these flows are polluted and a threat to stream health. Flow in the Yarra River at Chandler Highway should not be used as a trigger for decisions on water extraction at Yering Gorge, because the size and quality of flows in this urban part of the river are not indicative of rurally-sourced flows in the river, that should be the criteria to make flow-release decisions in the rural part of the river.

Ecological return on investment

Investments in the conservation and restoration of natural resources require a prioritization of expenditure that begins with protecting existing values (Rutherfurd, Jerie & Marsh, 2000). Most of the 66 species that we were asked to review persist in the many kilometres of healthy rural streams of the Melbourne Water region—for many of them, their only current sustaining populations are in rural streams. The conservation of these healthy streams should be an ongoing priority.

In this review, we do not concentrate on recommendations for management of non-urban streams. Our brief was to concentrate on urban streams (those with current DCI of >1%) and, as for the broader question of return for investment, the greatest returns in biodiversity and ecosystem management will come from protecting existing assets first. Many kilometres of streams within Melbourne's growth boundary continue to support diverse, healthy, functioning ecological communities, and most are threatened by urban expansion and infill development, Current building and road construction regulations continue to allow standard stormwater drainage practices that are a direct threat to stream ecosystems. Furthermore current best environmental guidelines for stormwater management (Victoria Stormwater Committee, 1999) are inadequate to protect stream ecosystems, as they do not directly address DCI reduction as a primary requirement (Fletcher & Walsh, 2007; Walsh & Fletcher, 2006). We urge Melbourne Water to accelerate processes to change stormwater drainage practice and its regulation across the Melbourne Water region. Without such changes, many kilometres of healthy stream ecosystem are in imminent danger of falling to the urban stream syndrome (Walsh *et al.*, 2005b). Reaches in greatest danger of rapid decline in condition include:

- Jacksons Creek and the Maribyrnong River downstream of Sunbury, as this river, currently supporting a platypus population, is at the critical 1–2% DCI level, and lies in a rapidly urbanizing part of the city;
- upper Merri Creek, that continues to support a blackfish population (and the growling grass frog), and is vulnerable to new developments spreading within the urban growth boundary, and to the expansion of Maldon;
- The streams of the Dandenong Ranges, currently supporting many high-value species. Because their catchments are small, the low level of urban consolidation and road upgrading in their catchments is a large threat.

Here we propose a hierarchy to prioritize management actions in urban streams for the greatest return on investment. An underlying assumption of our recommendations is that any further declines in ecological condition will be arrested by the changes in stormwater management practice recommended above.

We recommend that decisions on management of urban streams initially be set in concert with other Melbourne Water management policies that aim to prioritize in-catchment stormwater retention. The primary criterion for priority setting to date is the potential return (as measured by length of stream for which DCI can be reduced to < 1%) per unit effort in stormwater retention and treatment[3] (Table 5).

The major split in recommended management actions rests on the priority set for catchment-scale reduction of stormwater impacts (Table 5). Priority sub-catchments will be chosen by at least two criteria. The first will be based on spatial models of DCI (C. J. Walsh, work in progress), that will determine the optimal order for DCI reduction for each of several thousand stormwater drain sub-catchments in the metropolitan area, to maximize the rate at which stream lengths can be reduced to DCI <1%. A preliminary trial of such an analysis suggested that headwater catchments with small areas of impervious surface were the best place to start (Walsh & Fletcher, 2006), but it is likely that further analysis will find a more complex prioritization approach more successful. Once a set of priority sub-catchments has been selected for which adequate stormwater management is tractable, a second criterion of ecological values should be used to further prioritize DCI reduction.

This review has identified several sub-catchments that are likely candidates of high ecological value. The iconic platypus is a useful starting point for assessing ecological values. Serena and

[3] This work is in progress by C. J. Walsh, in collaboration with Melbourne Water's catchments group, contributing to Better Bays and Waterways and regional water quality strategies

Table 5. A decision support hierarchy for reach-scale management of urban streams. Directly connected imperviousness (DCI) management refers to the application of in-catchment stormwater retention measures (WSUD) to return stormwater hydrology closer to the pre-development state. Multiple actions labeled priority 1 are equally important.

DCI	Priority for DCI management[a]	Management actions and priority
<1%		Non-urban: management actions not considered here
>1%	High	1. Riparian restoration (in concert with WSUD planning[b]) 1. Barrier management (including connection of fragments) 2. Re-introduce in-channel habitat complexity only after DCI reduced[c]
	Low	1. Conservation, restoration and creation of urban wetland refuges 1. Point-source controls if necessary (with research on appropriate assessment) 2. Assess possible ecological gains (if any[d]) from reach-scale works conducted for non-ecological reasons

[a]*Prioritization of sub-catchments for DCI management will be based on DCI modeling (see text) and on ecological values (e.g. the three urban catchments with endangered platypus populations also support many other species of biodiversity value, and should be high priority)*

[b]*The hydrologic disconnection of floodplains from streams can affect floodplain plant assemblage composition, so floodplain bioretention systems might allow a better re-recreation of floodplain hydrologic conditions for incised urban streams*

[c]*Habitat structures are likely to be more sustainable once stormwater hydrology has been mitigated*

[d]*Recovery of some species and functions are more likely in streams with DCI <5%, and these should be targeted for such actions.*

Williams (2008) have identified four isolated populations that are in danger of extinction, all of which have streams suffering urban impacts. We recommend strongly that a primary and urgent management action for Melbourne Water is to remove and regulate the likely primary stressor in these catchments: urban stormwater runoff. Of these four catchments supporting imperiled platypus populations, three also support multiple urban intolerant species (Table 6), making them likely highest priorities for DCI reduction.

Once DCI reduction programs have been put in place or are planned for priority subcatchments, reach-scale actions are appropriate, as they are likely to aid recovery of streams once urban stormwater impacts have been mitigated. Riparian restoration and removal of barriers to migration are the two first priority actions in such sub-catchments (Table 5).

Table 6. Subcatchments with records of multiple urban-sensitive or urban-intolerant species, that are likely high priorities for catchment-scale stormwater management (subcatchments with records of each species are marked by a tick).

Ecological value	Sub-catchment (most upland in all cases)					
	Dandenong (upper + Dobsons)	Olinda (to Lilydale)	Monbulk (all)	Emerald	Sassafras	Merri (to Kalkallo)
Austrogammarus australis	✓	✓	✓	✓	✓	
Austrogammarus haasei	✓		✓		✓	
Engaeus urostrictus	✓		✓			
Leptoperla kallistae		✓	✓			
Gadopsis marmoratus		✓	✓	✓	✓	✓
Imperiled platypus population	✓	✓	✓			

Riparian zones should be revegetated in concert with DCI reduction measures. If urban streams have become incised, they are likely to have become hydrologically isolated from their floodplains through a lowering of the water table relative to the floodplain surface (Groffman *et al.*, 2003). In such cases the drier more aerobic soils of the floodplain support a different flora, and are likely to turn from net sinks of nitrogen to net sources of nitrogen. To counter this effect, bio-infiltration systems could potentially be built along floodplains as a final stormwater treatment measure that would allow the floodplain soils to remain saturated and promote denitrification. The design of these systems will affect the choice of riparian species selected for revegetation.

Management of barriers to dispersal is also important to allow colonization of restored reaches, and also in the case of the isolated platypus populations, to allow for re-connection with other larger populations.

While it is desirable to begin riparian restoration and barrier management before DCI reduction is complete, restoration of channel habitat complexity is best left until after stormwater hydrology has been mitigated. Structures in streams with flashy hydrographs resulting from urban stormwater runoff are likely to be unstable and ineffective (Booth, 2005).

For lower priority streams for which DCI is not planned in the short-term, ecological gains from reach-scale management actions are likely to be very limited. For these streams, we recommend ongoing management of riparian and non-riparian wetlands, which can serve as refuges for species that are unable to survive sustainably in urban streams. Priorities for wetland conservation, restoration and creation could be made based on known distributions of valued species such as *Galaxiella pusilla*, *Nannoperca australis* or *Ixobrychus minutus*.

Of course, pollution from point sources is undesirable in any stream, and actions to mitigate any such problems are recommended in urban streams, particularly if the actions can be matched to a well-designed monitoring study of the response of a well-chosen indicator (see the next section).

Finally, it is recognized that management actions will be undertaken in urban streams for other than ecological reasons. Such actions should be undertaken with clear aims, and if it is considered that an ecological improvement is a potential outcome, then we strongly recommend a well-designed monitoring program, because any such outcomes will be of scientific and management importance. Ecological improvements are most likely in streams with DCI <5%, with the probability of an improvement increasing with decreasing DCI.

Future research directions

Data management

Many of the inferences made in this report are limited by the quality of the available data. We recommend a review of Melbourne Water's data collection, quality control, and storage practices. Important elements unavailable to us in at least some of the data provided to us include:
a) description of site locations (other than co-ordinates, as an important redundant check that allows assessment of the accuracy of coordinates, and whether sites that are close to each other are really the same site). We also recommend a standard, intuitive site-coding system as used in the Melbourne Water macroinvertebrate database;
b) methodological details for each sample, and grouping variables that allows samples from the same study and studies using the same sampling methods to be grouped;

c) records of absences. With certain database structures (in which occurrence or abundance data are linked to specific samples and taxonomic lists), this is not explicitly required, but the spreadsheet structure in which most of the data were provided allows no strong inference as to whether a species was absent from a particular site;
d) a scheme that allows for assessment of data quality by users of the data;
e) a scheme that allows revision, correction and lumping of taxonomic classifications
f) a simple process for timely inclusion of new data. We are aware that the data that we have used lack many records from recent studies commissioned by Melbourne Water.

Species for which we need more knowledge

We recommend studies of distribution, abundance in the Melbourne Water region (and in some cases of basic life-history and biology) be commissioned for the following species: *Leptoperla kallistae*, *Austrogammarus haasei*, *Engaeus urostrictus*, *Galaxiella pusilla*, *Neochanna cleaveri*, *Retropinna semoni*, *Nannoperca obscura*, *Prototroctes maraena, Tadorna tadornoides*, *Platalea flavipes, Ixobrychus minutus dubius*, and *Myotis macropus*.

The variation in response of *Paratya australiensis* to urban land use between the north-western and eastern streams of Melbourne (Figure A9) raises some interesting opportunities to explore the factors driving urban-related loss of species. If the persistence of *P. australiensis* in northwestern metropolitan streams is the result of low-flow refuges, then it might be possible to restore southeastern metropolitan streams by provision of low-flow refuges. If, on the other hand, it is because of a toxicity-salinity interaction, then local scale habitat restoration is unlikely to be effective.

A difference in response to urban streams between north-western and eastern streams was also observed in *Philypnodon grandiceps*, the flat-headed gudgeon (Figure A36). This urban-tolerant species is entirely absent from eastern rural streams, but occurs in eastern urban streams. This, in turn, presents an interesting research question as to the factors associated with urbanization that promote its occurrence in eastern metropolitan streams. Urban stormwater runoff raises salinity of the eastern streams and dilutes the salinity of the northwestern streams, resulting in the baseflow EC of metropolitan streams typically 350-400 µS/cm (Walsh *et al.*, 2001). It is possible that the salinizing effect of stormwater on Dandenong, Gardiners, and Mullum Mullum is promoting colonization of *P. grandiceps*.

A similar line of research is raised by the observation of several fish species that occur commonly in urban estuaries (and rural streams), but are rare or absent from urban streams (e.g. *Pseudaphritis urvilli*, the tupong, and *Prototroctes maraena*, the Australian grayling). How do these species cope with urban stormwater impacts better in estuaries than in streams?

Some excellent research has been conducted on the effects of urbanization on the ecology of frogs in the Melbourne Water region (e.g. Parris, 2006), demonstrating that a major threat resulting from urbanization is the fragmentation and isolation of habitat. However, Parris (2006) deliberately restricted her study to non-riparian ponds and wetlands, because she considered wetlands associated with streams to be more likely connected through riparian corridors. This assumption remains to be tested, and the question of the importance of riparian connectivity in the distribution and abundance of frogs in Melbourne remains an important research area to be explored. The extent to which frogs use in-stream habitats is also a knowledge gap. We recommend that research be commissioned to address these questions, which are not adequately answerable using the current frog-census framework.

With the possible exception of yabbies, the large aquatic invertebrate prey species that dominate diet of *Hydromys chrysogaster*, the water rat, are not abundant in degraded urban streams. It is therefore likely that water rats inhabiting urban streams are more reliant on terrestrial food sources than their rural counterparts. Research into variations in diet and more targeted surveys of *H. chrysogaster* populations in urban and peri-urban streams are warranted.

More targeted research into the urban distributions other urban-tolerant animals would help to refine management programs. We suggest *Cherax destructor*, the yabby, as a candidate organism that might be a useful indicator for assessing the success of point-source control measures. This will only be the case if the distribution and abundance of *C. destructor* is well explained by variations in the nature of urban land use within the metropolitan area. We remain uncertain of the urban tolerance category for *Chelodina longicollis*, the long-necked turtle. A targeted survey of distribution and abundance of these species, and perhaps other urban tolerant species is thus warranted.

Habitat fragmentation

We recommend research into habitat fragmentation in the Melbourne Water region for a range of species (e.g. *Hydromys chrysogaster*, *Egernia coventryi*, *Chelodina longicollis* and frogs). Spatial studies are required to determine which habitat patches are the best candidates for reconnection to maximize reconnection of isolated populations. For fully aquatic species in urban areas, degraded sections of streams might act as barriers to dispersal, so only catchment scale improvements are likely to benefit these species. Research is needed to determine those catchments to target for WSUD retrofit that will give the best ecological return per unit of management effort (this work is currently being conducted by C. J. Walsh).

As a secondary process, those patches in urban, semi-rural or rural areas that are most easily reconnected should also be identified. This may prove more effective at securing certain species (such as the swamp skink) within the urban environment rather than greatly increasing distributions or abundances (Jellinek, Driscoll & Kirkpatrick, 2004) but may be particularly important in the urban fringe if disturbances such as bush fire devastate a local population of sensitive species.

Exotic species control and interaction with native species

With the available data, we were able to identify likely competitive interaction only between *Galaxias maculatus* and trout. However, the literature suggests a wide range of competitive and predator-prey interactions between species considered in this review and exotic species. *Gambusia holbrooki* compete for resources with all small native fish; brown and rainbow trout prey on juvenile native fish and also consume benthic macroinvertebrates; foxes, cats and dogs prey on small ground dwelling mammals, ground nesting waterbirds and frogs. Our failure to detect other interactions could have been a result of the quality of the available data.

To better assess the importance of such interactions in driving sensitivity to urban land use, we suggest that a) the current literature needs to be comprehensively reviewed to identify possible management methods of exotics and b) empirical research is needed to establish interactions between native and exotic species, particularly in urban waterways and wetlands, to determine the best management for exotic species. Native species that may be considered for research include (but are not limited to) *Galaxiella pusilla*, *Galaxiidae* spp., *Nannoperca* sp., *Retropinna semoni*, *Geotria australis*, *Mordacia mordax*, *Neochanna cleaveri*, *Anas* spp., *Rattus lutreolus* and *Hydromys chrysogaster*.

Other research questions

In the course of our review, we raised several hypotheses that require testing. One of the major concerns about managing stormwater treatment wetlands for biodiversity was the potential for bio-accumulation of toxicants in high-level predators. We recommend that any populations of birds such as herons, egrets and cormorants that colonize stormwater treatment wetlands be monitored for bio-accumulation and general health. We also postulated that overabundance of transient and urban-tolerant birds in wetlands and streams could contribute to eutrophication. A research study assessing the effects of birds would be warranted, particularly in places where people feed birds (e.g. the Yarra River at Warrandyte).

The future for Melbourne's streams

We have assessed what is required to conserve or restore populations of many animals that are valued by Melbourne Water, while emphasizing that effective management of these animals will require a broader management of the stream ecosystems themselves (Appendix 3). We have used evidence from available distributional data and the literature to infer that the potential ecological gains from reach-scale actions on urban streams are small. We identified value in management of urban riparian zones and wetlands, the latter in particular, can provide valuable refuge habitats for some stream dependent species that cannot maintain populations in urban streams. But for conservation and restoration of the stream ecosystems themselves, the most urgent need is for catchment-scale management, with a priority on the protection of remaining assets that are imperiled by the growing urbanization of the Melbourne Water region.

This conclusion is based on available, imperfect evidence. If future management of Melbourne's streams and rivers is to conserve our existing natural assets and to restore some of our lost assets, it is essential that management strategies be implemented adaptively. This will require integrating catchment-scale stormwater management and reach-scale stream management in an experimental framework that robustly tests that chosen management actions achieve their aims. In this review, we have attempted to identify ecological objectives that are most likely achievable and the actions required to achieve them at minimum cost. We urge Melbourne Water to adopt an adaptive management strategy that will allow the validity of our recommendations to be tested, while securing the ecological future of our streams and rivers.

Appendix 1 – Materials and methods

Species considered

Originally a list of 102 species of water-dependent animals considered to be tolerant of urban conditions was supplied by Melbourne Water. In negotiation with Melbourne water the following 26 bird species were excluded (because their ecology is not strongly linked to stream or river ecosystems in urban areas of the Melbourne region): *Anas rhynchotis* (Australasian shoveller), *Burhinus grallarius* (bush stone-curlew), *Calidris acuminata* (sharp-tailed sandpiper), *Chlidonias hybridus* (whiskered tern), *Cladorhynchus leucocephalus* (banded stilt), *Elseyornis melanops* (black-fronted dotterel), *Gallinago hardwickii* (Latham's snipe), *Gallirallus philippensis* (buff-banded rail), *Haematopus fuliginosus* (sooty oystercatcher), *Haematopus longirostris* (pied oystercatcher), *Larus novaehollandiae* (silver gull), *Megalurus gramineus* (little grassbird), *Ninox strenua* (powerful owl), *Pelecanus conspicillatus* (Australian pelican), *Platalea regia* (royal spoonbill), *Plegadis falcinellus* (glossy ibis), *Podiceps cristatus* (great crested grebe), *Poliocephalus poliocephalus* (hoary-headed grebe), *Porzana fluminea* (Australian spotted crake), *Porzana pusilla* (Baillon's crake), *Porzana tabuensis* (spotless crake), *Rallus pectoralis* (Lewin's rail), *Tachybaptus novaehollandiae* (Australasian grebe), *Threskiornis molucca* (Australian white ibis), *Threskiornis spinicollis* (straw-necked ibis), and *Vanellus miles* (masked lapwing).

During the same negotiations the following 4 invertebrate taxa were added to the list of animals to be considered: *Cherax destructor* (common yabby), *Paratya australiensis* (freshwater shrimp), Hyriidae (freshwater mussels), and Megaloptera (Corydalidae spp., dobsonfly larvae and *Stenosialis australiensis* of the family Sialidae, alderfly larvae).

The 66 species listed in table 2 and considered in detail in Appendix 2 does not include 14 species that were either a) not water dependent or b) not relevant to urban areas of the Melbourne Water region (Table A 1).

Data sources

Melbourne water provided the following faunal databases and spreadsheets with records of selected urban tolerant animals so that we could assess the distribution of animals against DCI.

- Atlas of Victorian Wildlife database, Department of Sustainability and Environment.
- Melbourne Water fish database.
- Melbourne Water macroinvertebrate database (maintained by Chris Walsh)
- Various Frog census databases (2005-2007)

These databases were used to produce maps of animal distributions for the Melbourne Water region.

Table A 1. Species not considered in Appendix 2 and the reasons they were excluded from consideration

Species name	Common name	Reason for exclusion
Anguilla reinhardti	Long-finned eel	Very few records west of Wilsons Promontory, no urban records, very similar basic ecology to the short-finned eel *Anguilla australis*
Geocrinia victoriana	Victorian smooth froglet	Not water dependent; mostly terrestrial and found in highly ephemeral water bodies
Litoria fallax	Eastern dwarf tree frog	Feral species
Litoria lesueuri	Rocky river frog (Lesueur's tree frog)	Not urban tolerant; only in Werribee Gorge.
Litoria peronii	Peron's tree frog	Not urban tolerant; only occurs in rural southeast
Litoria verreauxii	Whistling tree frog	Not urban tolerant; only occurs in rural southeast
Ardea ibis	Cattle egret	An invasive species
Miniopterus schreibersii	Common bent-wing bat	Likely a) transient through Melbourne and b) to have a seeding population in rural areas
Neobatrachus sudelli	Common spadefoot toad	Not water dependent; burrowing species
Pseudophryne semimarmorata	Southern toadlet	Not water dependent; only in highly ephemeral streams and has terrestrial eggs
Euastacus kershawi	Gippsland spiny crayfish	This species was not listed by Melbourne Water, but its common name was attributed to *E. neodiversus* (see below). *E. kershawi* is not likely to be urban tolerant; only found in western extreme of the Melbourne Water region
Engaeus sternalis	Warragul burrowing crayfish	This treatened species is only found in the extreme west of the Melbourne Water areas and is unlikely to be urban tolerant (Morey, 2004)
Euastacus neodiversus	South Gippsland spiny crayfish	The common name listed by Melbourne Water for this species was the Gippsland Spiny Crayfish, a name more commonly applied to *E. kershawi* (see above). *E. neodiversus* is only found in the Strzelecki Ranges and Wilsons Promontory, outside the Melbourne Water region (van Praagh, 2003)
Mugilogobius paludis	Pale mangrove goby	No records in Melbourne Water's fish database. Unlikely to be found in freshwater sections of streams
Pseudophryne bibroni	Bibron's toadlet	No records in Melbourne Water's frog database

Defining urban streams

Data used to estimate total and directly connected imperviousness in Melbourne remains in development. Until recently the primary source of imperviousness estimates used by Melbourne Water were derived from planning zone data (e.g. Serena and Pettigrove, 2005). While these data provide useful estimates at large scales, they are increasingly unreliable for smaller catchments. A series of projects conducted first through the CRC for Freshwater Ecology (CRCFE) and then commissioned by Melbourne Water has mapped impervious areas for parts of Melbourne, and assessed the likelihood of connection of each impervious surface to streams or drains. The first CRCFE projects used 0.25 m resolution satellite imagery to map impervious surfaces of the upper Dandenong, Cardinia, Toomuc and Bunyip catchments in the east, and the Maribyrnong, Kororoit and Skeleton catchments in the west. Subsequently, the impervious surfaces of the entire Yarra catchment to the confluence with the Maribyrnong were mapped (and assigned drainage status) using high-resolution aerial photography, providing a superior estimate of imperviousness (Projects are ongoing to extend this data to entire metropolitan area. This initial mapping work is sufficient to differentiate the urban and non-urban streams of Melbourne.

Statistical methods

Logistic regression was used where possible to predict the probability of individual species being recorded in streams with known DCI. (This analysis required reliable records of absences as well as presences: data that were missing from the Atlas of Victorian Wildlife database in the form it was supplied to us).

Contingency tables were constructed for species where associations with exotic animals were thought to be an explanatory factor in their distribution, and the probability of interspecific associations being greater or less than would be expected by chance were assessed with a χ^2 test.

Appendix 2 – Biology of water dependent native species of wildlife in the Port Phillip and Western Port Bay region

Invertebrates

Austrogammarus australis (Dandenong Amphipod)

Urban category D: urban intolerant.
Restricted to eastern Melbourne streams, absent from streams with DCI >1%

Recommended management:
1. Existing populations: retrofit of existing connected stormwater pipes; regulation of new developments including road upgrades.
2. Targeted catchments with lost or endangered populations: retrofit for in-catchment stormwater retention, and riparian vegetation and in-stream habitat restoration.

Photo: David Kerr

General notes

Austrogammarus australis is listed under the flora and fauna guarantee act as a species that is 'insufficiently known' (DSE, 2007a) although recent work on landscape scale indicators suggests its distribution has contracted as a direct result of catchment urbanization impacts. It occurs exclusively within the Dandenong Ranges and thus is particularly important for inclusion into this review.

Thought to be extinct by 1990, the rediscovery of the Dandenong Amphipod in 1996 (Doeg, Tsyrlin & van Praagh, 1996) and a subsequent survey by (Papas, Crowther & Kefford, 1999) led to the upgrading of the status from 'presumed extinct' to 'insufficiently known'.

Distribution and abundance

Austrogammarus australis was originally described by Sayce (1901) from a reach of Dandenong Creek near the suburb of Bayswater its distribution is now limited the upper reaches of a few small streams in the Dandenong Ranges (Figure A1) (Doeg & Papas, 2000; Doeg, 1997). Only two streams (Wallaby Creek draining the William Ricketts Sanctuary, and Lyrebird Creek) retain large populations of the species, and these streams had largely undisturbed forested catchments and riparian zones.

Ecology

Feeding strategy and diet

The Dandenong Amphipod is omnivorous but prefers consuming detritus originating from native vegetation and is classified in the 'shredder' feeding guild (Kerr, 2003).

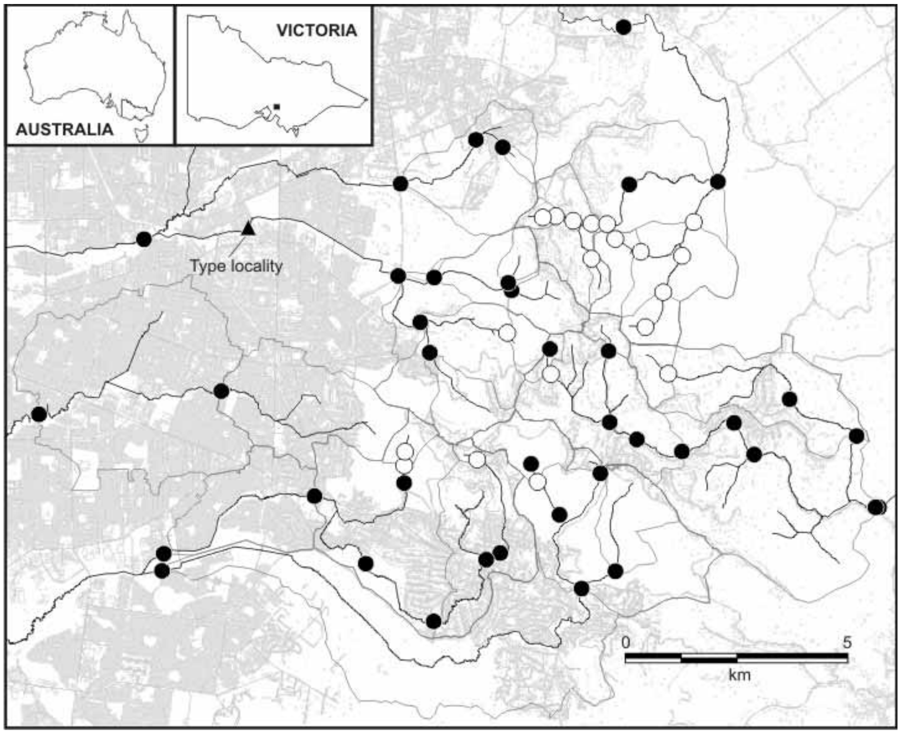


Figure A1. Sites in eastern Melbourne that have been sampled for *A. australis* during the 1990s. Open circles indicate sites where the species was present, and closed (black) circles indicate its absence. The type locality (Sayce, 1901) is also indicated. (Source: Walsh *et al.*, 2004b).

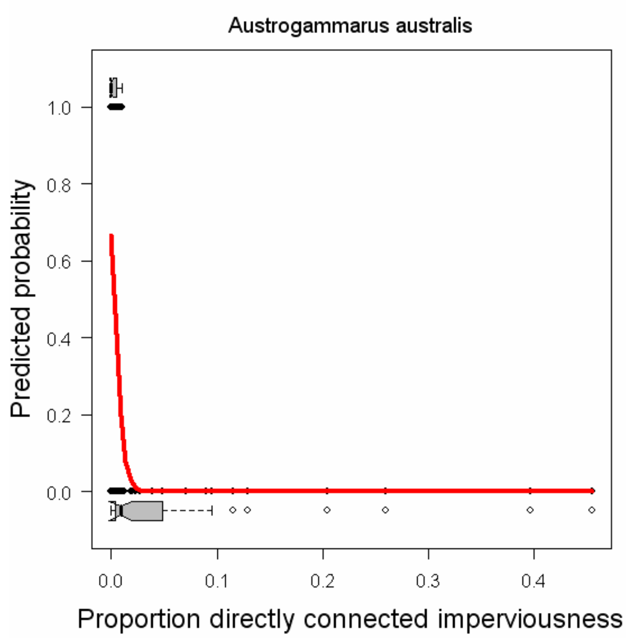


Figure A2. Presence and absence of *Austrogammarus australis* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The logistic regression predicted probability curve (red solid line) shows that the small probability of the species occurring in a site with DCI > 1% (data from Walsh *et al*. 2004).

Reproduction

Reproduction peaks during summer, with the number of berried females increasing as stream flow declines and temperatures rise (Kerr, 2003).

Habitat

Austrogammarus australis inhabits the underside of in-stream leaves and bark and likely uses these habitats both for shelter and as a food source (Richardson, 1992). Abundances of *A. australis* were positively correlated with the amount of organic matter within a reach (Kerr, 2003). *A. australis* is photosensitive and possibly competes with several other amphipod species that are not sensitive to sunlight (Kerr, 2003).

Threats

Even a small number of stormwater drains directly connected to streams constitutes a threat to *A. australis* populations. Road upgrades that involve curbing and channelling of road drainage (currently a common practice in the Shire of Yarra Ranges) and new developments in the Wallaby Creek and Lyrebird Creek catchments are a major threat to the two large remaining *A. australis* populations.

Similar activities in other catchments with smaller populations of *A. australis* are likely to lead to their complete extirpation.

At the reach scale, *A. australis* abundance is related to the abundance of in-stream organic matter (Kerr, 2003). The reduced abundance of *A. australis* downstream the directly connected, sealed carpark in the William Ricketts Sanctuary was associated with a decline in in-stream organic matter. The density of *A. australis* per g of organic matter was unchanged upstream and downstream of the carpark, suggesting that the primary threat from the car park is the increased frequency of stormwater flows washing habitat away.

Management options

In the few subcatchments where *A. australis* remain abundant (Lyrebird and Wallaby [upper Olinda] creeks), strict regulation of stormwater runoff for any new urban developments or road upgrades is required.

In conjunction with the above measures, owners of infrastructure (including that controlled by local municipalities) in surrounding catchments should be encouraged to retrofit WSUD techniques in an effort to lower stormwater delivery to streams that would otherwise support *A. australis* populations. This should be targeted, in the first instance, to catchments from which the species has been recorded recently, but in small numbers (Sassafras, Hughes, Emerald, Ferny, Ferntree Gully and Sherbrooke creeks)

While loss of habitat is likely to be the ultimate small-scale driver of the decline in *A. australis* distribution under low-levels of stormwater runoff impact, water quality impacts are likely to become increasingly important with higher levels of impact. The primary management action for the protection of this species should aim to reduce stormwater impacts, but once this is done, population recovery could be helped through the provision of bark and leaf habitat, and their ongoing supply through riparian revegetation.

Austrogammarus haasei (Sherbrooke amphipod)

Urban category D: urban intolerant. Rare, restricted to Dandenong Ranges, absent from streams with DCI >1%

Recommended management:
1. Existing population: retrofit of existing connected stormwater pipes; regulation of new developments including road upgrades.
2. Basic research on biology and distribution

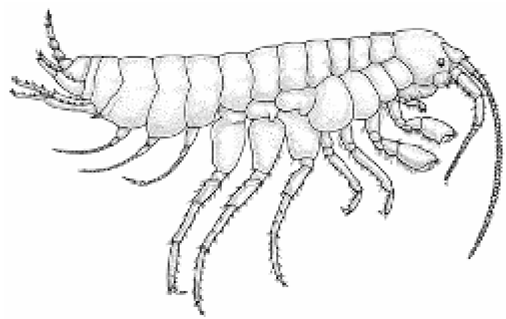


Photo: DSE Action statement

General notes

Austrogammarus haasei is listed as a threatened species under the Flora and Fauna Guarantee Act 1988 (DSE, 2007a). *A. haasei* was thought extinct until recent surveys rediscovered the species (Doeg *et al.*, 1996; Papas *et al.*, 1999). A draft of the Advisory List of Threatened Invertebrates classifies *A. haasei* as 'critically endangered' (Papas & Crowther, 2007).

Distribution and abundance

Austrogammarus haasei is restricted to the small streams of the Dandenong Ranges. It was originally described near the town of Monbulk (Sayce, 1901), presumably in Sassafras or Emerald Creeks. Recent surveys have found *A. haasei* in moderate numbers in Sherbrooke Creek, and in very small numbers in two other tributaries of Monbulk Creek (Hardy and Clematis), and in nearby Sassafras Creek (Papas & Crowther, 2007). Although the streams in which this species are found are similar to those in which *A. australis* are found, the latter species is notably absent from sites where *A. haasei* is found (only a record of a single individual *A. australis* from one of the Sherbrooke Creek sites where *A. haasei* was populous).

None of the streams in which it is found has DCI >1%, suggesting that is not urban tolerant.

Ecology

There is very little information on the ecology of *A. haasei*. It likely has many similarities with other Paramelitidae species such as *A. australis*. However, the fact that *A. haasei* has a much more limited distribution than the other Paramelitidae in the region suggests that caution should be exercised when extrapolating specific traits between these species.

Reproduction

Nothing specific known.

Feeding

Nothing specific known.

Habitat

Austrogammarus haasei resides in the upper reaches of Sherbrooke Creek with dense native vegetation and a closed canopy. This indicates that, like *A. australis*, it needs a good supply of native organic matter input (*Eucalyptus* bark and leaves) and low rates of sedimentation. It has only been found in sites with near-zero DCI.

Threats

Although much less is known about *A. haasei* because of its more restricted range, it appears to be at least as sensitive to urbanization at the catchment scale than *A. australis*. As for *A. australis*, directly connected drains from impervious surfaces constitute the major threat at the catchment (or subcatchment) scale and the quantity of in-stream organic matter is probably linked to the abundance of *A. haasei* at the reach scale. Road upgrades that involve curbing and channeling of road drainage (currently a common practice in the Shire of Yarra Ranges) are a major threat.

Management options

The catchments in which this species occur are primarily within the Dandenong Ranges National Park, but particular attention should be paid to buildings and roads in the Sherbrooke, Clematis, Hardy and Sassafras catchments, to ensure stormwater retention is standard practice for all constructions, including road upgrades.

Primary research on all aspects of basic biology, including possible interactions with *A. australis*, is necessary and the impact of specific threats such as sedimentation and nutrient enrichment from directly connected stormwater runoff and the subsequent altered hydraulic regimes need to be assessed to determine best management strategies for *A. haasei*.

Cherax destructor (Common yabby or yabbie, blue claw dam yabby)

Urban category A: urban tolerant

Recommended management:
No action required in urban streams, but could be a useful indicator organism for testing effectiveness of reach-scale actions such as point-source controls, or organic matter retention.

Photo: www.crayfishworld.com

General notes

Cherax destructor is the most common species of the diverse Australian freshwater crayfish (Reik, 1969). There is a substantial body of literature concerning the culture of *C. destructor* as it has become a species of significant commercial value (Geddes, Mills & Walker, 1988; Jerry *et al.*, 2005; Jones, Chavez & Mitchell, 2002; Verhoef & Austin, 1999)

Distribution and abundance

Cherax destructor is widespread and abundant throughout central and eastern Australia and southwestern Western Australia. It is particularly abundant in the southeast corner of the mainland but does not occur in Tasmania (Crandall *et al.*, 1999). In the Melbourne region is collected commonly from urban and rural streams, including degraded metropolitan streams such as Gardiners Creek (Figure A3). Its occurrence is not correlated with DCI (Figure A4), suggesting a tolerance for the impacts of catchment urbanization and urban stormwater runoff. However, the available distributional records are not adequate to allow an assessment of factors affecting distribution and abundance within urban streams.

Ecology

Natural predators of adult *C. destructor* include humans, diving waterbirds such as cormorants, water rats, and larger fish such as Murray cod and yellowbelly perch (Withnall, 2000). Juvenile *C. destructor* can be taken by fish, waterbirds and other larger predatory invertebrates such as dragonfly nymphs.

Feeding strategy and diet

Similar to other freshwater crayfish, *C. destructor* are generalist detritivores, and as juveniles they have the ability to hunt and capture prey items such as large zooplankton (Meakin, Qin & Mair, 2008).

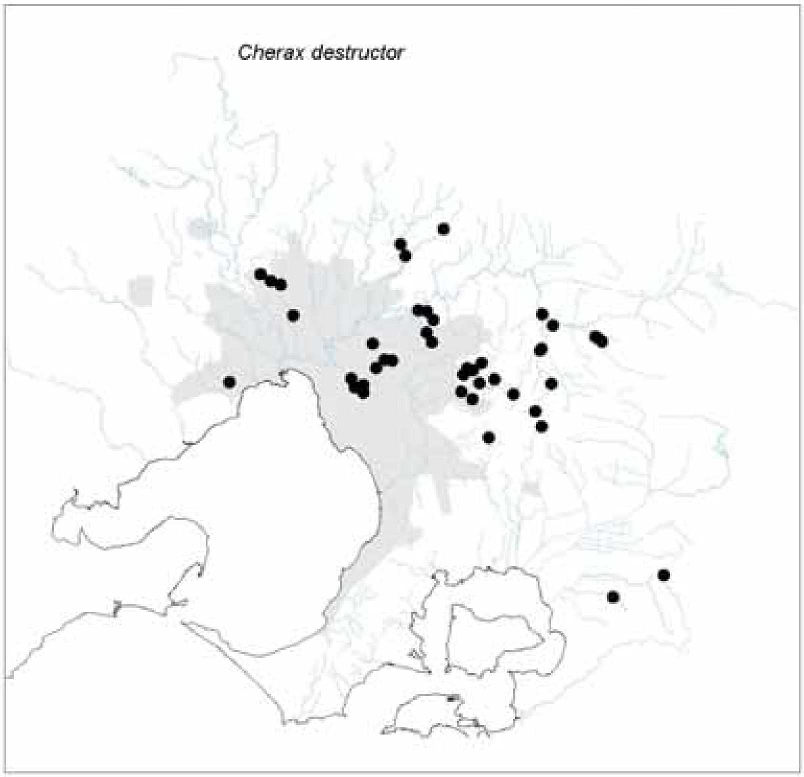


Figure A3. Records of *Cherax destructor*: *C. destructor* are found in highly urbanized streams such as Gardiners Creek; records from Melbourne Water macroinvertebrate database (earliest record in this dataset is 1993).

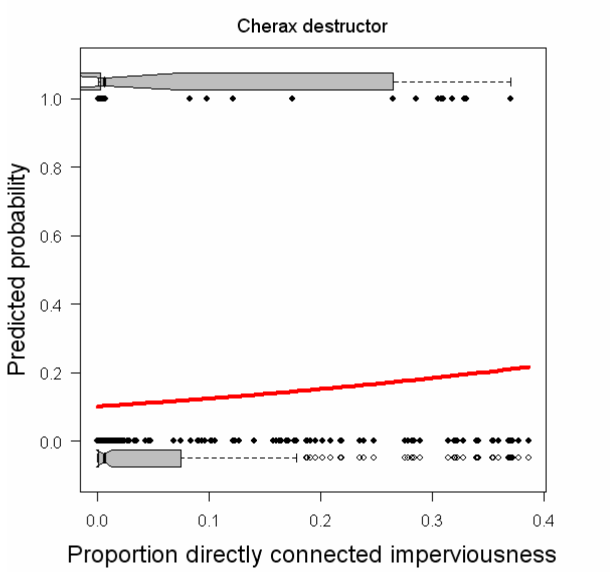


Figure A4. Presence and absence of *Cherax destructor* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The logistic regression predicted probability curve (red solid line) shows that occurrence of *C. destructor* is not correlated with catchment urbanization (data from Melbourne Water macroinvertebrate database).

Reproduction

Cherax destructor is one of the most fecund crayfish (Austin, 1998). Water temperatures over 15 ºC and increased day length are factors that trigger reproduction, and peak spawning occurs between October and January (Withnall, 2000). Females keep fertilized eggs under her tail and will actively clean, oxygenate and remove dead eggs from the brood (Withnall, 2000). If environmental conditions are favourable, *C. destructor* can spawn multiple times per year

Habitat

Cherax destructor lives in many freshwater habitats including rivers, lakes, wetlands, billabongs and farm dams (Gooderham & Tsyrlin, 2002). They prefer lightly turbid waters presumably because of the added protection from visual predators like cormorants, herons and larger fish (Withnall, 2000). Yabbies prefer waters with reasonably high dissolved oxygen (around 8 mg/l) but they are physiologically adapted to tolerate low oxygen or even hypoxic waters for short periods of time (Morris & Callaghan, 1998). *C. destructor* can survive in very cold water (reputedly as low as 1ºC) but no growth occurs at temperatures lower than 16 ºC or above 35 ºC. Optimal growth temperature in cultured *C. destructor* is around 25 ºC (Verhoef & Austin, 1999; Withnall, 2000).

Threats

Threats to *C. destructor* include overfishing by humans and waterbirds. In highly urbanized streams, heavy metal toxicity may limit the development of early life stages but Khan and Nugegoda (2007) found that *C. destructor* was relatively insensitive to copper, cadmium, nickel and iron when compared with other aquatic invertebrates. *C. destructor* also seem hardy to the effects of short term but relatively extreme pH fluctuations (Ellis & Morris, 1995).

Management options

The hardiness of *C. destructor* and its persistence in urban waterways suggests that current reach-scale management practices are sufficient for *C. destructor* to persist. However, reach-scale actions such as the targeted reduction of industrial effluents might locally increase numbers. Increased organic matter retention could also benefit *C. destructor*, however, effectiveness of reach-scale actions to achieve this is likely to be limited in reaches impacted by DCI (see Appendix 2). This species could be a useful target species for experimental assessment of the effectiveness of reach-scale actions in urban streams.

Engaeus urostrictus (Dandenong crayfish)

Urban category D: urban intolerant. Restricted to streams east of Melbourne, absent from streams with >1% DCI

Recommended management:
1. Basic distributional and ecological research required.
2. Existing populations: regulation of stormwater and wastewater from urban areas.

Photo: http://museumvictoria.com.au

General notes

Engaeus urostrictus is listed as a threatened species under the FFG act 1988 (DSE, 2007a).

Distribution and abundance

There are very few studies of *E. urostrictus*. It was originally found in the upper reaches of Dandenong Creek and its tributaries and has also been found in the Yarra Ranges near Mt Donna Buang however abundances were not reported (Horwitz, 1990; Horwitz, Richardson & Boulton, 1985; Reik, 1969). *Engaeus urostrictus* has not been recorded from any site with greater than 1% DCI (Figure A5) and is therefore considered urban intolerant.

Ecology

Engaeus urostrictus is a burrowing crayfish that spends daylight hours in underground burrows and is only active at night.

Reproduction

Crayfish mate in spring or early summer and the female broods a small number of eggs under the tail until they hatch (Horwitz, 1990). Young crayfish can live in the same burrow as the parent until large enough to burrow for themselves (Horwitz *et al.*, 1985).

Feeding strategy and diet

Engaeus urostrictus feed on decomposing organic matter such as buried leaves and dead roots. They also incidentally feed on invertebrates such as worms and insects (Horwitz *et al.*, 1985).

Habitat

Engaeus urostrictus are found in wetter parts of the Dandenong and Yarra Ranges close to creeks and wetlands in eucalypt forest. *Engaeus* spp. in general use their large claws to burrow sometimes considerable distance so that the bottom of the burrow contains water (Horwitz *et al.*, 1985). *Engaeus* spp. is known to use burrows communally but juveniles leave the burrow before sexual maturity (Reik, 1969).

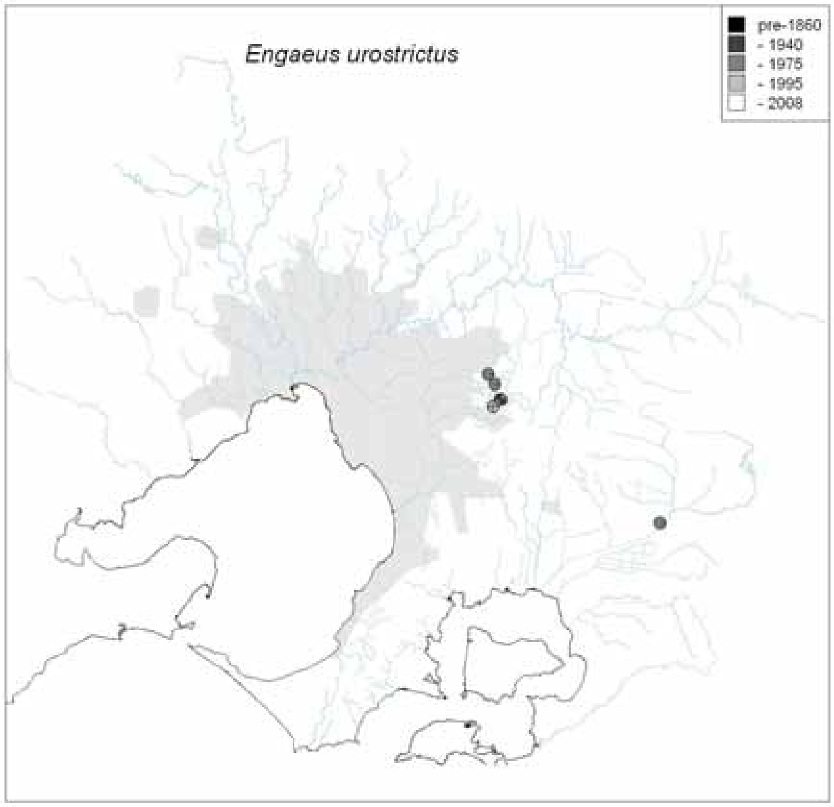


Figure A5. Records of *Engaeus urostrictus*: records in each location are represented by a pie-chart indicating period of record. *Engaeus urostrictus* has only been recorded in the upper Yarra catchments (source: Atlas of Victorian Wildlife database).

Threats

Without full knowledge of its distribution it is not possible to prioritize threats to this species. In the four Dandenong Ranges locations that it has been found (upper Dandenong, Sassafras, Sherbrooke and Hughes creeks), threats urban land use in the catchments is likely to be the greatest threat. Its reliance on subsurface riparian water suggests that lowered water tables resulting from stream incision are a threat, which could be minimized by ensuring stormwater retention in all existing and new developments, including road upgrades. In those areas, contamination of subsurface waters by sullage and septic tank leakage might also be a danger. However, further information on its current distribution are required for an informed management plan for this species.

Management options

Further information on the distribution of *Engaeus* spp. is required for eastern Melbourne streams as a basis for a management plan, and research into the interactions between water table level and condition and *E. urostrictus* would also be of benefit. It is likely that this species will also benefit from strict regulation of stormwater and wastewater management for existing and new developments in the Dandenong Ranges.

Euastacus yarraensis **(**Yarra spiny crayfish, Otway crayfish)

Urban category D: urban intolerant.
Absent from streams with >0% DCI

Recommended management:
1. For potential reintroduction to the lower Yarra: retrofit of existing stormwater system and regulation of new developments including road upgrades.
2. For remaining non-urban populations: riparian reafforestation.

Photo: www.tolweb.org

General notes

Euastacus yarraensis were originally described from the Yarra River. There is significant colour variation between the geographically isolated populations east and west of Melbourne, but they are the same species (Reik, 1969). It is not an FFG listed animal (DSE, 2007a).

Distribution and abundance

Euastacus yarraensis occurs in streams of southern central Victoria from the Tarago River in the east to the Gellibrand River in the west (Crandall, 2001; Reik, 1969). The absence of recent records in the lower Yarra River or in any site with greater than zero DCI (Figure A6), suggest that the distribution of *E. yarraensis* in Melbourne has contracted, and that this species is not tolerant of the impacts of catchment urbanization or of urban stormwater runoff.

Ecology

Euastacus yarraensis is a small crayfish, limited to low temperature streams with a good supply of organic matter. They occur in waters below 300 m elevation (Crandall, 2001). Few studies on the ecology of *E. yarraensis* have been conducted leading to the conservation status of 'insufficiently known' (DSE, 2007a). All species of *Euastacus* are considered to have similar feeding and life-cycle traits (Horwitz & Richardson, 1986) and much of the information outlined here can be extended to all *Euastacus* species.

Feeding strategy and diet

Like all *Euastacus* spp., *E. yarraensis* is omnivorous and is thought to occupy different feeding strategies at different stages of its lifecycle including shredding and predation (Gooderham & Tsyrlin, 2002).

Reproduction

Euastacus spp. is slow growing and sexual maturity can take up to 9 years in some larger species. The closely related *E. bispinosus* brood eggs over winter months and do not moult during this time (Honan & Mitchell, 1995; Reik, 1969). No information could be found on the reproduction of *E. yarraensis*.

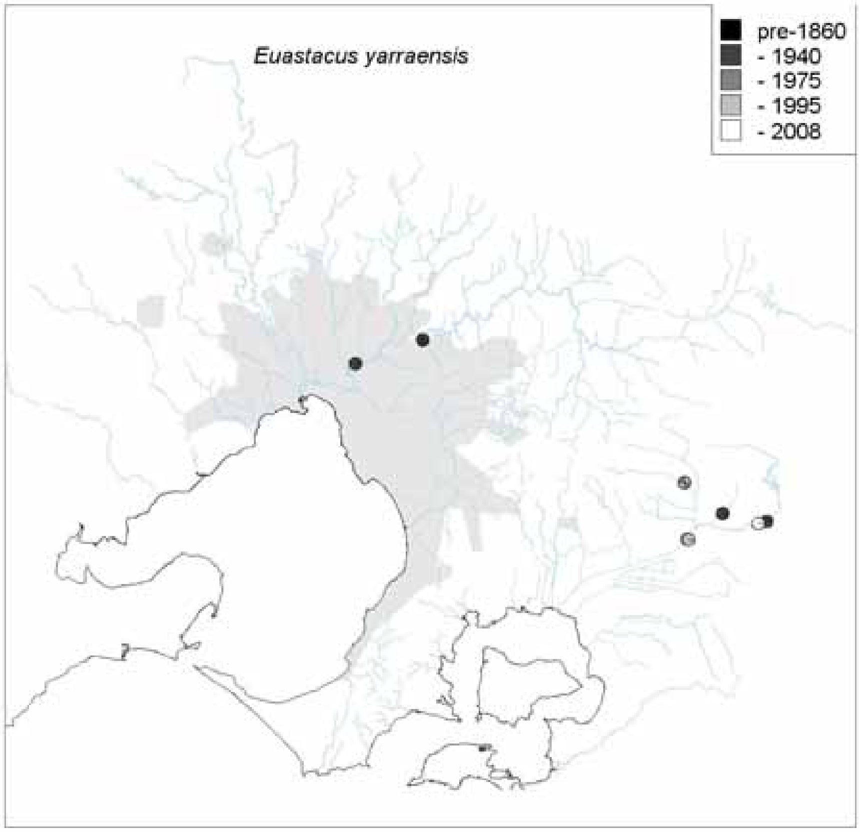


Figure A6. Records of *Euastacus yarraensis*: records in each location are represented by a pie-chart indicating period of record. There are no records in the Yarra River post-1940 (source: Atlas of Victorian Wildlife database), although Coleman and Amenta (2002) recorded the species in the (unurbanized) Little Yarra River.

Habitat

Euastacus yarraensis can be found in streams flowing through mixed, non-urban land-uses provided there is a good supply of native organic detritus from riparian vegetation (*Eucalyptus spp.*, *Acacia spp.* and tree ferns of the *Cyathea* genus (Crandall, 2001) and they commonly co-occur with several other crayfish species (Horwitz & Richardson, 1986). Coleman and Amenta (2002) found several species of *Euastacus*, including *E. yarraensis* in the fragmented landscape of the Little Yarra River.

Lieschke *et al.*, (2000) speculated that *E. yarraensis* is limited to constantly flowing streams that are fed by groundwater because a survey in the Plenty River did not find any *E. yarraensis* below Toorourrong Reservoir, the point at which the river becomes highly regulated, but did find them upstream of the reservoir.

Threats

Catchment-scale impacts of urbanization are a likely factor limiting the range of *E. yarraensis* in the Melbourne Water region. Further, flow regulation might account for the lack of *E. yarraensis* in the lower reaches of some rivers such as the Plenty River (Lieschke *et al.*, 2000).

At a reach scale, in non-urban streams, riparian vegetation removal or a change in the composition of riparian vegetation could lower the amount of food available for *E. yarraensis*.

Barriers to dispersal such as weirs and dams could prevent dispersal however *Euastacus* can survive out of water for some time and may be able to disperse over land given favorable conditions.

Management options

Reduction of DCI throughout the Yarra catchment, through retrofit of the stormwater system, is likely to be required for restoration of *E. yarraensis* populations in the Lower Yarra.

At a reach scale, remnant riparian vegetation on non-urban creeks in the non-urban streams where *E. yarraensis* is found needs to be protected. Replanting riparian vegetation along denuded banks should be encouraged and current replanting projects should be properly maintained.

Hesperilla flavescens flavescens (Altona skipper butterfly)

Urban category C_t: urban sensitive, but not relevant to stream management

Recommended management:
Parkland and wetland management, including vegetation replanting; fire management; runoff management and research into the dependent animal/plant relationship.

Photo: Melbourne Water website

General notes

The Altona Skipper Butterfly is listed as threatened (DSE, 2007a), however extensive community interest and funding from Dow Chemicals has helped to increase awareness of the plight of the butterfly (Hobsons Bay City Council, 2008). There is thought to be a critically endangered sub species, *Hesperilla flavescens flavia,* in western Victoria and south east South Australia (Relf & New, 2008).

Distribution and abundance

The Altona Skipper Butterfly occurs in native parklands around western and south-western Melbourne (Relf & New, 2008). Numbers of the butterfly are very low (at one time thought to be around 200 individuals) but due to a revegetation and controlled burn-off program initiated by Melbourne Water, the population is thought to currently be stable or increasing.

The persistence of *Hesperilla flavescens flavescens* exclusively in heavily managed parks within the urban boundary suggests that this species is urban tolerant (Figure A7). However, as this species is not dependent on stream habitats, its relevance to this review is limited.

Ecology

Very little basic ecology is known of the Altona Skipper Butterfly. The larvae construct a case from the leaves of Chaffy Saw Sedge (*Gahnia filum)*. They retreat into the case during the day, to emerge at night to feed (Braby, 2000).

Feeding strategy and diet

The Altona Skipper Butterfly consumes the *G. filum* leaves and this is reportedly its only food source. New shoots of the grass are preferred and larvae feed nocturnally (Relf & New, 2008).

Reproduction

Little is known about the reproductive cycle of *H. flavescens flavescens* other than adults lay single eggs directly upon the leaves of Chaffy Saw Sedge (Braby, 2000; Relf & New, 2008).

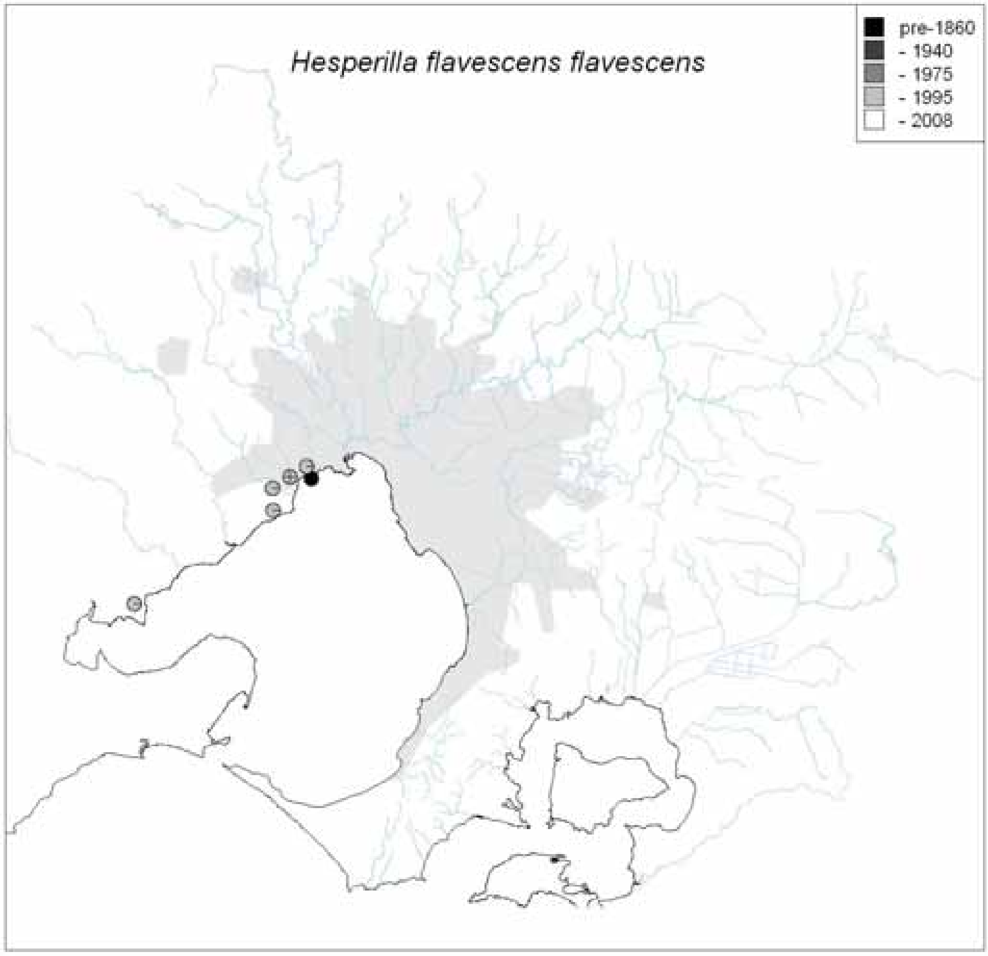


Figure A7. Records of *Hesperilla flavescens flavescens*: records in each location are represented by a pie-chart indicating period of record. No records are from stream habitats (source: Atlas of Victorian Wildlife database).

Habitat

The butterfly is mainly found in sedgeland areas in Truganina Park, the former Altona landfill tip site, Truganina Swamp and Cherry Lake in the Western Melbourne suburb of Altona (Relf & New, 2008).

Threats

Hesperilla flavescens flavescens is reliant on the protection of the parklands in which it lives and their associated wetlands. Protection of the wetlands from stormwater runoff and other effluent from the surrounding urban areas is required.

As the Altona Skipper Butterfly relies purely on *G. filum* for food, the persistence of the Butterfly is directly linked to the abundance and range of this sedge so the loss, degradation or isolation of areas where this species occurs constitutes a direct threat to *H. flavescens flavescens* (Relf & New, 2008).

Management options

Active management such as the controlled vegetation burns and also weed removal have helped increase the density of *G. filum*. Therefore continual weed removal in the parks where *H. flavescens flavescens* occurs (community and industry partnership) is necessary. Research into how to better manage *G. filum* is needed aide the survival of *H. flavescens flavescens* and formalized long term monitoring of both *H. flavescens flavescens* and *G. filum* should also be considered if no monitoring project currently exists.

Toxic spills and runoff into the parks and wetlands where *H. flavescens flavescens* is found must be prevented.

The continued engagement of community groups and industry partners in *H. flavescens flavescens* protection should ensure that the species remains of high conservational value.

Leptoperla kallistae (Kallista flightless stonefly)

Urban category D: urban intolerant. Absent from streams with DCI >1% **Recommended management:** 1. Existing populations: retrofit of existing connected stormwater pipes; regulation of new developments including road upgrades; bushfire management; protection of riparian forests. 2. Targeted catchments with lost or endangered populations: retrofit for in-catchment stormwater retention, and riparian vegetation and in-stream habitat restoration	No image available

General notes

Leptoperla kallistae is listed as threatened under the Flora and Fauna act 1988 (DSE, 2007a). Until 1987 it was considered a sub species of *L. kimminsi*, so in this report, some traits reported for *L. kimminsi kallistae* have been assumed to apply to *L. kallistae*. The Kallista flightless stonefly, as the name suggests, has greatly reduced wings and is thus flightless as an adult, unlike most other stoneflies found in the area (Tsyrlin, 2001).

Distribution and abundance

The Kallista stonefly is very limited in distribution and specimens have only been identified from a small region in the Dandenong Ranges covering the headwaters of Olinda, Monbulk and Sassafras creeks, all with DCI <1%. Like other flightless stoneflies, it is thought that *L. kallistae* has very poor dispersal abilities (Hynes & Hynes, 1975).

There were no records in the macroinvertebrate database to produce a distribution map or perform statistical analyses. Because it has such a contracted distribution, living only in areas with very low DCI, *L. kallistae* is considered urban intolerant.

Ecology

Leptoperla kallistae is not the only flightless stonefly in Australia. The other locally occurring flightless stonefly, *Riekoperla darlingtoni*, is found exclusively within a few kilomeres of the summit of Mt Donna Buang in the Yarra Valley (Hynes & Hynes, 1975; Tsyrlin, 2001). The stream-dwelling *L. kallistae* larvae are small (final instar 6-8mm) (Hynes, 1978) and the nymph undergoes metamorphosis to emerge as a flightless adult with poorly formed wings (Gooderham & Tsyrlin, 2002; Tsyrlin, 2001).

Feeding strategy and diet

Little basic biology is known of *L. kallistae*. However, like most insects that are found exclusively in headwater streams, *L. kallistae* probably rely on a good supply of organic matter for both habitat and as a food source. *L. kimminsi* is a detritivore/herbivore feeding on decaying vegetable matter and also incidentally browses on small amounts of algae and diatoms (Sephton & Hynes, 1983) so it is presumed that *L. kallistae* has extremely similar feeding habits.

Reproduction

Very little information on the reproductive behavior of *L. kallistae* is known but spent adult cases and live adults have been found throughout the year and thus it is expected that the lifespan is greater than 1 year (Hynes & Hynes, 1975).

Habitat

Leptoperla kallistae only occurs in headwater streams of the Dandenong Ranges with dense native vegetation and undisturbed flow regime. Larvae occupy patches of organic matter and utilize the resource as both food and habitat. *L. kallistae* disperses by crawling through riparian vegetation (Tsyrlin, 2001).

Threats

Directly connected drains from impervious surfaces constitute the major threat to current populations at the catchment scale. Bushfires burning portions of catchments where *L. kallistae* occurs, and the methods used to extinguish them, is also possibly a significant catchment scale threat to existing and future populations, however (Boulton, Moss & Smithyman, 2003) found little evidence to suggest that fire retardants used in Australia affected intermittent streams on King Island more than the actual fire did.

On a reach scale, the biggest threat to the Kallista stonefly is the removal of riparian vegetation. This is because *L. kallistae* is highly dependent on continuous riparian vegetation to find a suitable mating partner and for adult dispersal (Hynes & Hynes, 1975); however, more knowledge of the basic biology of this species is needed to support this assertion.

Management options

In the few subcatchments where *L. kallistae* have been recorded (Olinda, Monbulk and Sassafras creeks), strict regulation of stormwater runoff for any new urban developments or road upgrades is required.

In conjunction with the above measures, owners of infrastructure (including that controlled by local municipalities) in surrounding catchments should be encouraged to retrofit WSUD techniques in an effort to lower stormwater delivery to streams that could potentially also support *L. kallistae*.

With our current understanding of the biology of the species, there must be no removal of riparian vegetation if the species is to persist. To expand the range of *L. kallistae*, riparian corridors need to be reestablished in conjunction with the larger catchment scale conservation measures.

Further, greater knowledge of the basic biology of *L. kallistae* is necessary in order to formulate management practices that will most effectively expand the range of *L. kallistae*. Research into lifecycle details including location of emergence, adult lifespan and the timing and success of reproduction will further help establish strategic management needs and goals of this species.

Consideration of bushfire control methods may also be necessary for the conservation of the species.

Paratya australiensis (Freshwater shrimp, glass shrimp)

Urban category C: urban sensitive (in eastern metro streams), but occurs in western metro streams.

Recommended management:
1. Research into causes of regionally different responses to urbanization.
2. in-catchment stormwater retention likely required for restoration of eastern metro populations.

Photo: www.mdfrc.org.au

General notes

Paratya australiensis is the most common shrimp found in streams of the Melbourne Water region. These translucent shrimps are particularly important to the ecology of many rivers and streams in the area, partly because they are important prey for a diverse range of species including waterbirds, platypus, native rats, turtles and fish.

Distribution and abundance

Paratya australiensis is a very abundant species in south-eastern Australia. Its distribution includes coastal streams draining the entire seaboard of continental Australia, the Murray-Darling system including south-eastern South Australia and eastern Tasmania (Hancock, 1995; Walsh, 1994; Williams, 1977). Cook *et al*. (2005) showed that Australian *Paratya* is a collection of cryptic species, many of which occur together in the same locations. A single species occurs in coastal streams of Victoria and, while this species also occurs uncommonly in the Murray-Darling basin, it occurs in both freshwater and some estuaries throughout their distribution (Walsh, 1993).

It occurs in several degraded metropolitan streams in the north-west basaltic plains (e.g. Merri, Darebin, Kororoit creeks), but is less commonly found in the eastern and south-eastern metropolitan streams (Figure A8). In the northwest, its occurrence is not correlated with DCI, but in the southeast, it is negatively correlated with DCI (Figure A9). The negative correlation with DCI in southeastern streams suggests that this species is sensitive to the impacts of catchment urbanization (hence the proposed classification as category D), but its common occurrence in northwestern metropolitan streams suggests that attributes of the basalt streams can ameliorate the impacts of urbanization. The causes of this unusual distributional pattern require further research.

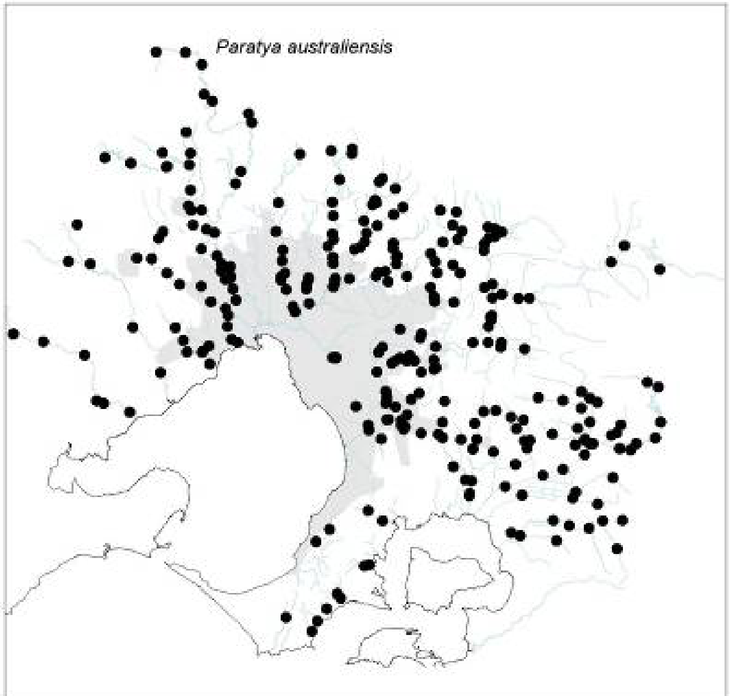


Figure A8. Records of *Paratya australiensis*: (earliest record in this dataset is 1993). Note its almost complete absence from metropolitan tributaries southeast of the Yarra River (data from Melbourne Water macroinvertebrate database)

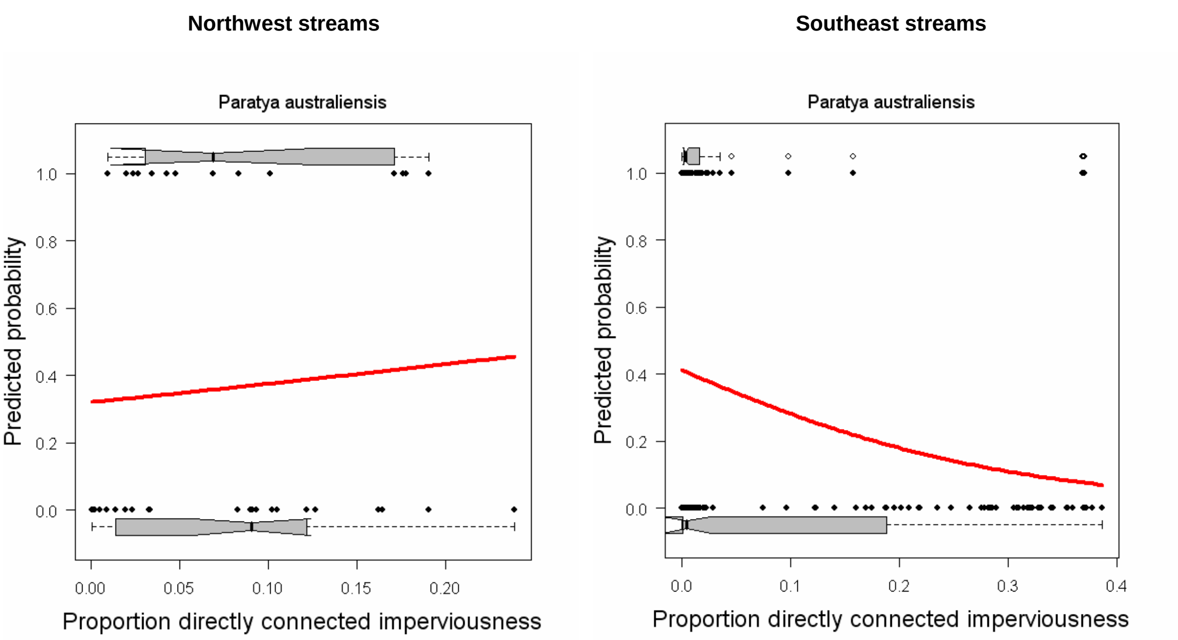


Figure A9. **Presence and absence of *Paratya australiensis* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI) in northwestern Melbourne streams and southwestern streams, according to the regionalization proposed by Walsh *et al*. (2001). The logistic regression predicted probability curves (red solid lines) show that occurrence of *P. australiensis* is not correlated with catchment urbanization in the northwest, but is in the southeast. (data from Melbourne Water macroinvertebrate database).**

Ecology

Some life stages of *P. australiensis* are sensitive to high concentrations of heavy metals (particularly copper) and Tasmanian populations were found to be depleted in streams polluted by cadmium and zinc (Thorp & Lake, 1974). Decapod crustaceans in general are sensitive to heavy metals but they may be less susceptible to heavy metal pollution in more saline waters (Bambang *et al.*, 1995). This interaction between toxicity and salinity could explain the lesser sensitivity of *P. australiensis* to urban runoff in the more saline northwestern streams of Melbourne.

Feeding strategy and diet

Paratya australiensis consumes detritus, bacteria and algae that they pick from the benthos or brush from macrophytes into their mouths using modified front legs (Gooderham & Tsyrlin, 2002; Hancock, 1995; Walsh, 1994).

Reproduction

Females over ~12mm begin brooding eggs during early spring and early summer and may have multiple broods in a given year (Williams, 1977). Larvae are planktonic and develop into juveniles in <1 week (Walsh, 1993). The lifespan is usually 2 years with females typically brooding in the second year (Williams, 1977). *P. australiensis* greatly prefer low flow conditions (drying pools for example) to reproduce (Gooderham & Tsyrlin, 2002; Williams, 1977). The need for slow-flowing refuges could in part explain the persistence of this species in the metropolitan reaches of the bedrock dominated basalt streams, which have been able to retain some of their original geomorphic integrity, in contrast to the eroded and incised channels of southeastern Melbourne (Fletcher, Breen & Pettigrove, 1997; Walsh *et al.*, 2001). *P. australiensis* cannot however tolerate desiccation (Williams, 1977).

Habitat

Paratya australiensis can be found in many and varied habitats including ponds, creeks, rivers, estuaries, farm dams, irrigation channels, shallow wetlands, billabongs and even permanent roadside ditches (Walsh, 1994; Williams, 1977).

Threats

The negative correlation between *P. australiensis* occurrence and DCI in southeastern streams suggests that catchment-scale impacts of urban stormwater runoff are a threat to this species.

Management options

Restoration of populations across the metropolitan area is likely dependent on catchment-scale retention of stormwater.

But the variation in response across Melbourne regions raises some interesting opportunities to explore the factors driving this urban response. If the persistence of *P. australiensis* in northwestern metropolitan streams is the result of low-flow refuges, then it might be possible to restore southeastern metropolitan streams by provision of low-flow refuges. If, on the other hand, it is because of the toxicity-salinity interaction, then local scale habitat restoration is unlikely to be effective. These hypotheses require experimental assessment.

Megaloptera (Alderflies *Stenosialis australiensis* and dobsonflies, *Corydalidae* spp.)

Urban category D: urban intolerant.
absent from streams with
DCI >0% and DCI >2%, respectively

Recommended management:
1. Expansion into metro streams will require widespread in-catchment stormwater retention and riparian replanting.
2. In streams with up to 2% DCI, riffle restoration can promote Corydalidae

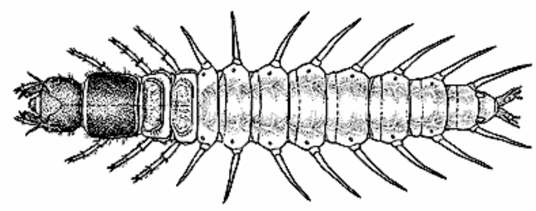


Photo: www.ento.csiro.au

General notes

Although this is a small group of invertebrates, containing just 9 species in temperate Australia, megalopterans are some of the physically largest aquatic insect larvae (Gooderham and Tsyrlin, 2002).

Distribution and abundance

Found over southern Australia. In the Melbourne Water region, megalopterans are restricted to streams with little or no urban impact. Corydalidae occur in riffles of the lower Yarra to Ivanhoe, where DCI = 2% (Figure A10; Figure A11).

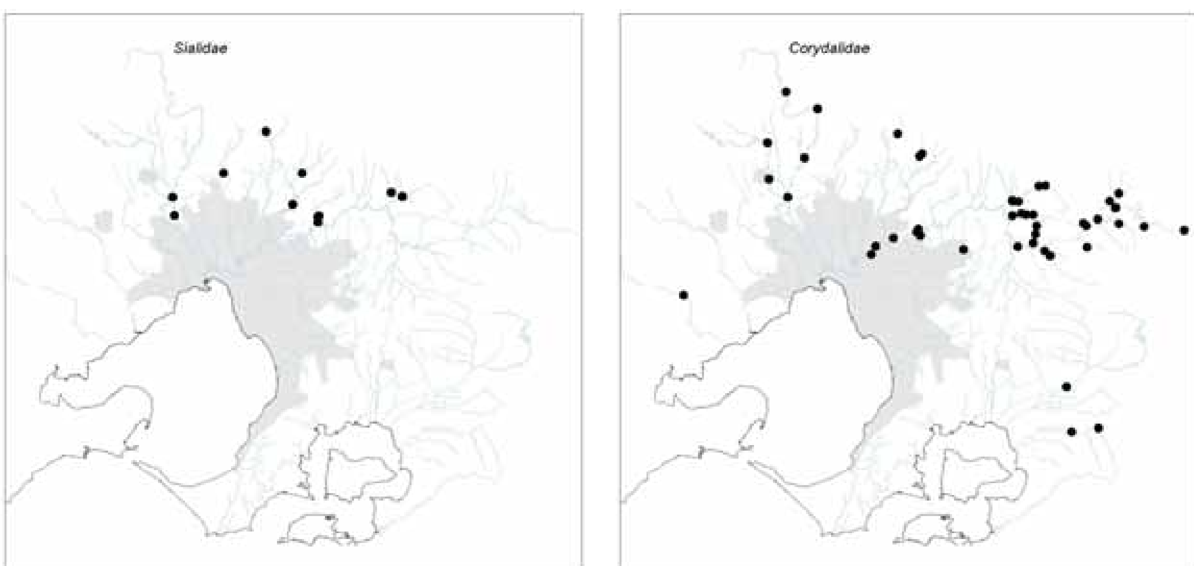


Figure A10. Records of two megalopteran families from Melbourne Water macroinvertebrate database (earliest record in this dataset is 1993). Sialidae are completely absent from the metropolitan area, while Corydalidae occur in the mainstem Yarra up to DCI of ~2% (data from Melbourne Water macroinvertebrate database).

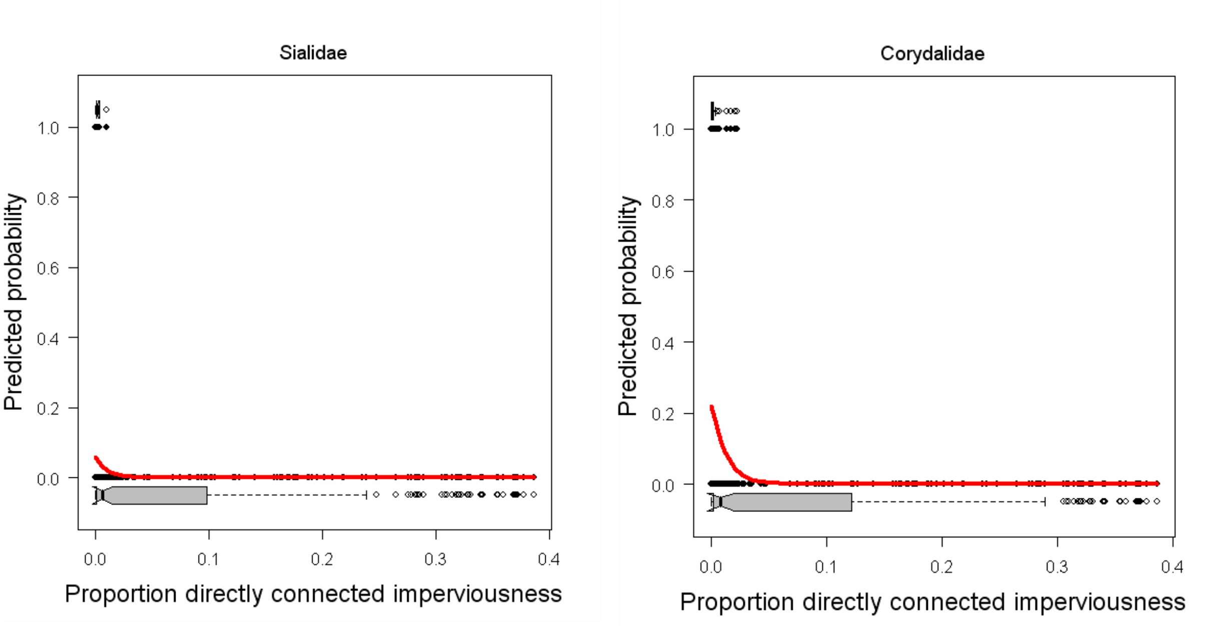


Figure A11. **Presence and absence of the two megalopteran families (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The logistic regression predicted probability curves (red solid line) show a low probability of occurrence for Sialidae > 0% DCI, and > 1-2% DCI for Corydalidae (data from Melbourne Water macroinvertebrate database).**

Ecology

While the taxonomy status is good, ecological aspects of Megaloptera in Australia are relatively poorly studied. All larvae are aquatic and reported to be quite sensitive to human disturbance (Gage, Spivak & Paradise, 2004; Rasmussen & Pescador, 2002). Adults are considered nocturnal and can be readily captured using light traps (Reik, 1954).

Feeding strategy and diet

Megalopterans are predators that feed on small invertebrates but they have also been observed to cannibalize and scavenge dead organisms (Cover & Resh, 2008; Rasmussen & Pescador, 2002).

Reproduction

The lifecycle of most Megaloptera lasts between one and 2 years, however, in particularly cold or ephemeral streams larvae may take as many as 5 years to pupate (Cover & Resh, 2008). Final instar larvae leave the stream and build chambers in moist leaf litter or soil. Adult Megaloptera are poor fliers and after pupation live in riparian vegetation close to the source stream. Adult lifespan is ~1 week. Females lay up to 3000 eggs on vegetation that overhang the stream so first instar larvae fall directly into water (Cover & Resh, 2008; Rasmussen & Pescador, 2002).

Habitat

Corydalidae are found under gravel, rocks and woody debris in riffle sections of swiftly flowing streams whereas sialids (*S. australiensis*) are usually collected from slower flowing stream reaches (Theischinger, 2000).

Threats

Catchment urbanization, most likely urban stormwater runoff, is the primary threat to urban populations of Megaloptera, and loss of riparian vegetation is likely to be a secondary threat. This is because females typically lay their eggs on riparian vegetation, so megalopterans may be especially sensitive to land use practices involving removal of riparian vegetation.

Management options

Expansion of the distribution of megalopterans into metropolitan streams will require widespread stormwater retention in metropolitan catchments and also extensive riparian replanting.

An artificial riffle constructed in the Yarra River at Heidelberg (DCI 2%) was colonized by large numbers of Corydalidae (V. Pettigrove pers. comm.), suggesting that habitat enhancement in streams with little urban impact can promote corydalid populations.

Synemon plana (Golden sun moth)

Urban category C_t: urban sensitive, but not relevant to stream management

Recommended management: Protection of selected grasslands; reduce habitat fragmentation; active grass management.

Photos: http://www.ento.csiro.au/gallery/moths/Synemonplana

General notes

Synemon plana is listed as critically endangered under the federal Environmental Protection and Biodiversity Act 1999 (DEH, 2007) and is subsequently listed as threatened under the state or territory acts within the moths diminishing range (Gibson & New, 2007; O'Dwyer & Attiwill, 2000).

Distribution and abundance

Golden Sun Moths were distributed over much of southeastern Australia (excluding Tasmania) but extensive development of the native grassland that the moth inhabits for agricultural and urban land-use, has reduced the moth's range (O'Dwyer & Attiwill, 2000). Habitat fragmentation has been suggested as the major cause of the population reduction. Recent population surveys have found the moth on remnant grasslands in Melbourne (near Craigieburn, Figure A12) that are designated for urban development (Gibson & New, 2007).

The moths are abundant in habitat patches where they persist. Of concern with this species is the number of habitat patches that are under development pressure either from agriculture or urban development. Because of these pressures and also because its range is significantly smaller that it was historically, *Synemon plana* cannot be considered an urban tolerant species. However, its management is not strongly relevant to stream management.

Ecology

Males and females of the Golden sun moth are small (3-4cm wingspan) and only males have been observed flying; typically each flight lasts for <20m duration. Females crawl along the ground only taking to short flights to avoid predation and thus are described as 'semi-flightless'. Because of the poor ability of females to fly, dispersion is thought highly limited (Gibson & New, 2007; O'Dwyer & Attiwill, 2000).

Reproduction

Females lay ~200 eggs at the base of the native grass *Austrodanthonia* spp. (Wallaby grass) and when larvae hatch they immediately burrow into the ground. Estimates on reproductive lifecycle vary between one and three years with the pupa lying under the surface for six weeks before emergence (DEWHA, 2008). Further, very specific climatic conditions (dry, >20 degrees, bright sunshine and little wind) need to be met before adults become active and males actively search for mates. The short adult lifespan combined with cryptic behaviour brings difficulty in accurately determining population range and size (Gibson & New, 2007).

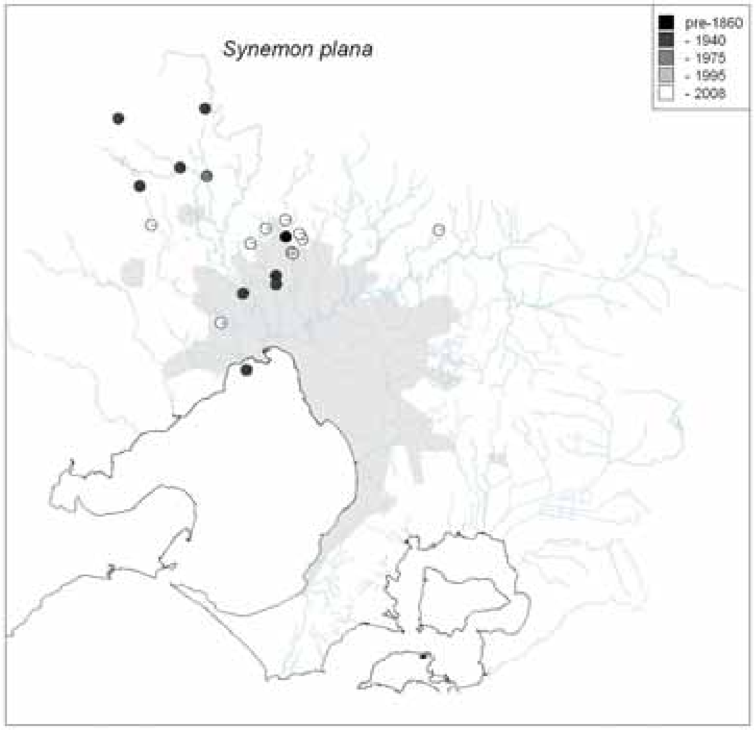


Figure A12. Records of *Synemon plana*: records in each location are represented by a pie-chart indicating period of record. No records are from stream habitats (source: Atlas of Victorian Wildlife database).

Feeding

Adult moths have no functional mouthparts and live on fat reserves for a maximum of 3-4 days (Gibson & New, 2007).

Habitat

Golden Sun Moths are found in native open woodlands and grasslands <720m above sea level(DEWHA, 2008). Larvae are thought to consume the roots of *Austrodanthonia spp.*, in particular *Austrodanthonia carphoides* and other closely related species such as *A. setacea, A. eriantha* and *A. auriculata* (Gibson & New, 2007; O'Dwyer & Attiwill, 2000).

Threats

The biggest threat to the Golden sun moth is the destruction of grassland habitat caused by urban development and agriculture.

Management options

O' Dwyer and Attiwill (2000), suggested that grasslands with a >40% cover of *Austrodanthonia spp.* (mainly *A. carphoides*) is preferred by Golden sun moths so grasslands approaching this level of *Austrodanthonia* spp. cover should be considered for priority protection. Continued active management and protection of the grasslands where *S. plana* occurs is necessary and formalized long term monitoring of both *S. plana* and *Austrodanthonia* spp. should also be considered if no project currently exists. Habitat connectivity between sites is important to establish or preserve in cases where connectivity still exists.

Hyriidae (Freshwater mussels)

Urban category D: urban intolerant.
Absent from streams with DCI >1%

Recommended management

1. For potential reintroduction to metro streams: retrofit of existing stormwater system and regulation of new developments including road upgrades.
2. For non-urban populations: adaptive management of land use, riparian vegetation and flow regimes.

Photo: http://clade.acnatsci.org

General notes

Hyriid mussels, most commonly represented by *Velesunio* spp. in the Melbourne Water region, are some of the largest invertebrates found in freshwaters, growing up to 120 mm in length.

There is growing global concern about the declining abundances of all freshwater mussel species, particularly given their ecological role as filter feeders (Poole & Downing, 2004; Vaughn & Hakenkamp, 2001; Vaughn & Taylor, 1999).

Distribution and abundance

Hyriidae are widespread and locally abundant throughout south-eastern Australia. In the Melbourne Water region, they occur mainly in the lower sections of streams with soft substrates. They have not been reported from any stream with DCI > 1% (Figure A13; Figure A14), suggesting an intolerance to the impacts of catchment urbanization.

Ecology

Freshwater mussels have a strong muscular foot and can move relatively quickly through sediments. They can withstand desiccation with a combination of behavioural (burying themselves in mud) and physiological (closing their shells and lowering metabolism until water returns) adaptations (Gooderham & Tsyrlin, 2002).

Small- to medium-sized mussels are readily consumed by animals like water rats, platypus and rarely by some bird species, and thus have the potential to form an important link in the food chain (Gooderham & Tsyrlin, 2002).

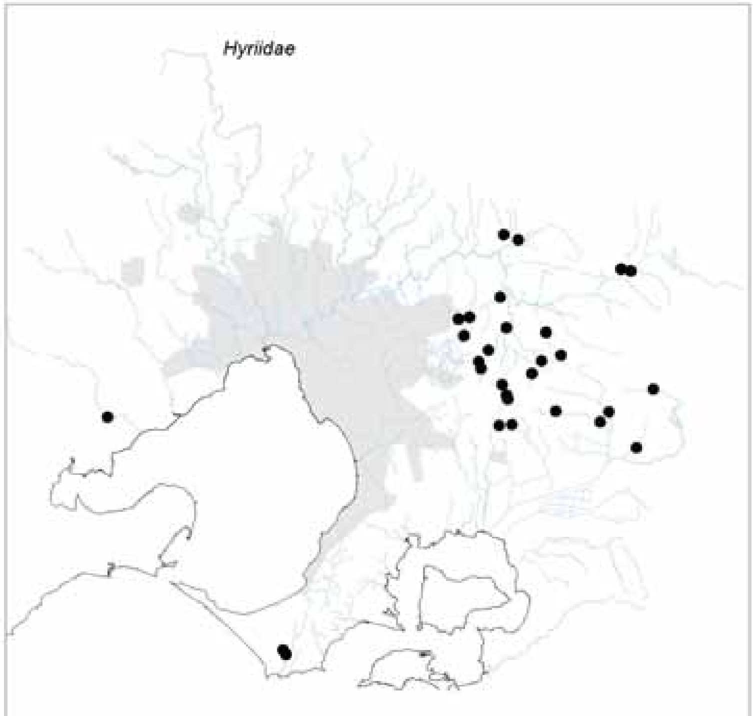


Figure A13. Records of Hyriidae mussels from Melbourne Water macroinvertebrate database (earliest record in this dataset is 1993). They occur in the outer eastern parts of the city but are completely absent from the metropolitan area (data from Melbourne Water macroinvertebrate database)

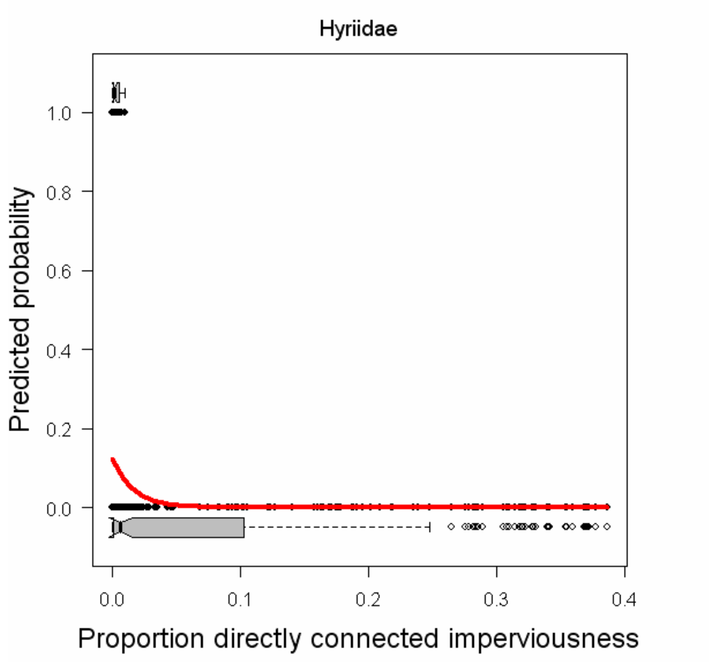


Figure A14. Presence and absence of Hyriidae (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The logistic regression predicted probability curve (red solid line) show a low probability of occurrence at sites with >1% DCI (data from Melbourne Water macroinvertebrate database).

Feeding strategy and diet

Hyriidae are filter feeders. When buried in sediments they extend muscular syphons above the substrate and pump large volumes of water through their bodies. The gills of the mussel act as both the breathing apparatus and as filters for digestible materials (Gooderham & Tsyrlin, 2002).

Reproduction

Mussels have a considerably complex lifecycle that can involve a parasitic phase as larval and small juveniles on the gills of native fish. Mature mussels then drop to the benthos with fully developed syphons and begin filter feeding (Gooderham & Tsyrlin, 2002).

Habitat

Hyriidae bury themselves into the soft sediments (sand and mud) of slow flowing, lowland rivers and streams (Gooderham & Tsyrlin, 2002).

They seem to be tolerant to moderately poor water quality and can live for short periods in low oxygen waters.

Threats

A range of threats that could be attributed to catchment urban impacts are potentially implicated in the absence of hyriid mussels from streams of the metropolitan area. Stormwater runoff can scour sediments from streams reducing suitable habitat, as well as diminish water quality. Introduced species may prey on smaller individuals and distributions may be impacted if native fish numbers (dispersal vectors) are depressed.

In wetlands, the accumulation of toxic sediments and a reduction in overbank flood events (caused by flood mitigation or drought conditions) could potentially disrupt mussel lifecycles. Riparian deforestation as a result of either urbanization or intensive agriculture is strongly suspected to contribute to a decline in mussel abundance in many rivers worldwide (Brainwood, Burgin & Byrne, 2006; Poole & Downing, 2004).

Altered river flow (regulation) is often attributed to the decline of mussel species (Di Maio & Corkum, 1997; Howard & Cuffey, 2003) but some authors have found no relationship between river hydraulics and mussel distribution (Brainwood *et al.*, 2006; Hardison & Layzer, 2001).

Management options

Re-introduction of Hyriidae into Melbourne metropolitan streams will require in-catchment stormwater retention, and perhaps remedial treatment of sediment quality to address legacy effects. Outside the metropolitan area, research into the effects of agricultural land use, river regulation and riparian deforestation on hyriid populations would help guide management strategies.

Fish

Anguilla australis (Short-finned eel, silver eel, yellow eel)

Urban category A: urban tolerant. Common in metropolitan streams

Recommended management: no action required in urban areas.

http://www.nativefish.asn.au/sfeel.html

General notes

Anguilla australis is one of 15 species of eel. It is of significant commercial value in regional Victoria, particularly in the Gippsland region where natural stocks are fished on a large scale. Elver license conditions require 10% of elver catch to be returned into watercourses of the region and the Gippsland wild eel license holders have a self imposed minimum size of 500g in lieu of an official size limit (Fisher, 2008). Aborigines of southern states were known to trap large numbers of eel and trade preserved (smoked) eel with tribes from other areas. They have few natural predators in freshwater as adults but herons and egrets have been observed consuming large number of elvers (Fisher, 2008).

Distribution and abundance

Anguilla australis is widespread and abundant in perennial, coastal streams of southern and eastern Australia (Shen & Tzeng, 2007; Silberschneider, Pease & Booth, 2004). They are abundant in almost all streams of the Melbourne Water region (Figure A15), and tend to be collected more commonly in streams with higher DCI (Figure A16).

Ecology

Anguilla australis can grow very large, but typically they grow to around 90cm and can be in excess of 25 years old before they reach maturity. They are most active during warmer months and they migrate in autumn and are mainly nocturnal (Fisher, 2008).

Feeding strategy and diet

Mature short-finned eels are generalist carnivores. Frogs, fish, crustaceans and even smaller eels have been found in eel stomachs (Fisher, 2008; Robinson, 2008).

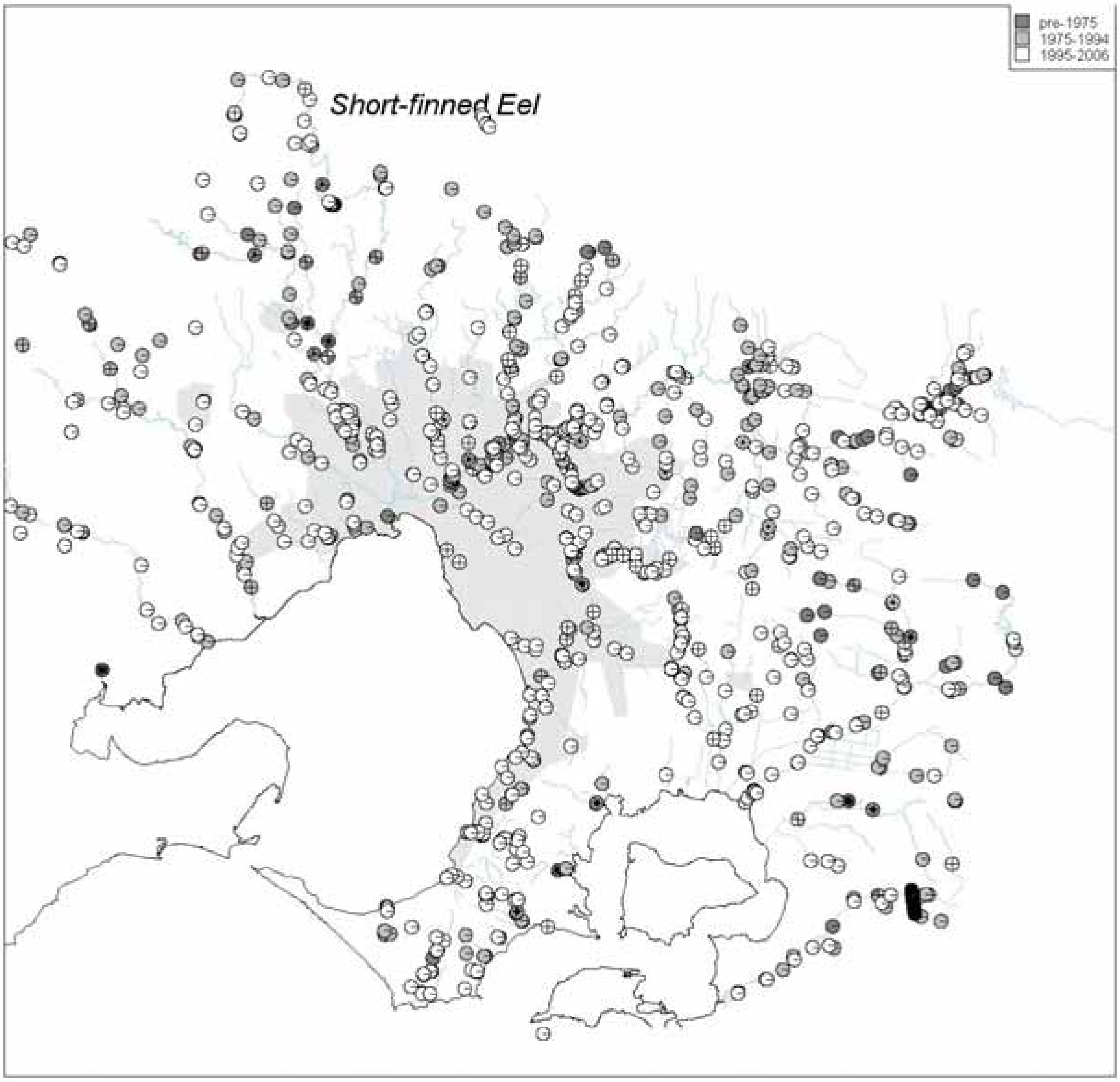


Figure A15. Records of *Anguilla australis*: represented by a pie-chart for each location indicating period of record. *Anguilla australis* are frequently recorded in all waterways across Melbourne (source: Melbourne Water fish database).

Reproduction

Reproductive details of *A. australis* remain unknown. Adults make their way to the ocean where they are thought to migrate to the Coral Sea where they spawn. Larvae are carried on ocean currents and develop into elvers (glass eels) and on a suitable queue, migrate up a freshwater creek or stream where they develop and mature.

Habitat

Anguilla australis can be found in many different habitats from fast flowing streams and creeks with cobbled beds, to ponds with little dissolved oxygen, and farm dams lakes and backwaters with a wide range of salinities. Koehn *et al.*(1994) suggested that eels preferred reaches of waterways that contained a large number of log jams and snags.

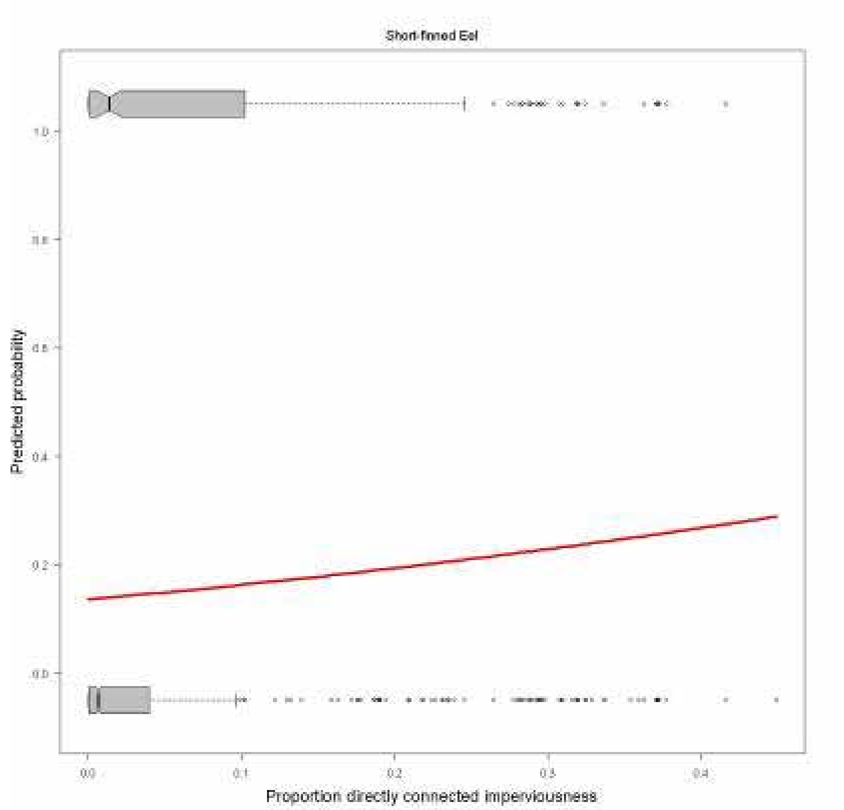


Figure A16. Presence and absence of *Anguilla australis* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The logistic regression predicted probability curve (red solid line) shows a significant correlation with DCI (P < 0.001; Data from Melbourne Water fish database, restricted to records post-1994, in the Yarra catchment).

Silberschneider *et al.* (2004) found that small eels preferred medium sized cobbles as habitat over silt and sandy substrates.

Threats

Eels can cope with very poor water quality in the short term (days to weeks) but it has been noted that bacterial infections can occur if eels are subjected to poor water quality for extended periods (weeks to months). Barriers to migration of juvenile and mature eels include natural (closed estuary mouths) and artificial (weirs, dams etc.) barriers, however eels do have the ability to absorb oxygen through the skin and can often skirt barriers by leaving the water and moving across damp grass and vegetation.

Management options

It would seem that no management action is needed to conserve eel stocks in urban streams.

Gadopsis marmoratus (River blackfish, freshwater blackfish, slippery, slimy, marbled river cod, greasy, taylor, Australian smelt)

Urban category E: urban intolerant.
Absent from streams with >1% DCI

Recommended management:
1. Isolated populations on urban fringe require urgent protection through in-catchment stormwater retention, and habitat management (refuge & spawning sites);
2. In-catchment stormwater retention required more widely before restoration of lower Yarra populations possible;
3. In reaches without stormwater impacts, habitat management is appropriate.

Photo: http://www.dpi.nsw.gov.au

General notes

Gadopsis marmoratus are a common target for recreational fishers. The southern form grows to a maximum of 600mm (rarely) but the distinctly smaller northern form grows to ~300mm and are tolerant of salinity concentrations < 10 parts per thousand (Koster & Crook, 2008).

Distribution and abundance

Gadopsis marmoratus occurred commonly throughout southern Australia and Tasmania but its range and abundance has been in decline since European settlement. They are tolerant of low salinities, and can be found in the upper limits of estuaries.

In the Melbourne Water region, there are historical records of *G. marmoratus* from the lower Yarra and Gardiners Creek (Figure A17), but since 1994, there have been no records from any sites with > 2% DCI, with a very low probability of occurrence in sites with DCI > 1% (Figure A18). It thus appears that *G. marmoratus* is intolerant of catchment urban impacts, and its distribution has contracted as a result of the urbanization of Melbourne.

Ecology

Blackfish are well studied compared to many Australian fish species. Despite their name, they are variable in colour ranging from yellow to dark olive, brown and black and are a solitary fish (Khan, Khan & Wilson, 2004).

Reproduction

G. marmoratus spawns in warmer water temperatures over summer and spring with sticky eggs laid onto woody debris and the male guards the eggs. This strategy is consistent with fish that are not diadromous (i.e. do not need or have a saltwater lifecycle phase) (Jackson, 1978).

Feeding strategy and diet

G. marmoratus feed from the benthos where they consume insect larvae, crustaceans, other fish and molluscs. Feeding occurs at night (Jackson, 1978; Khan *et al.*, 2004).

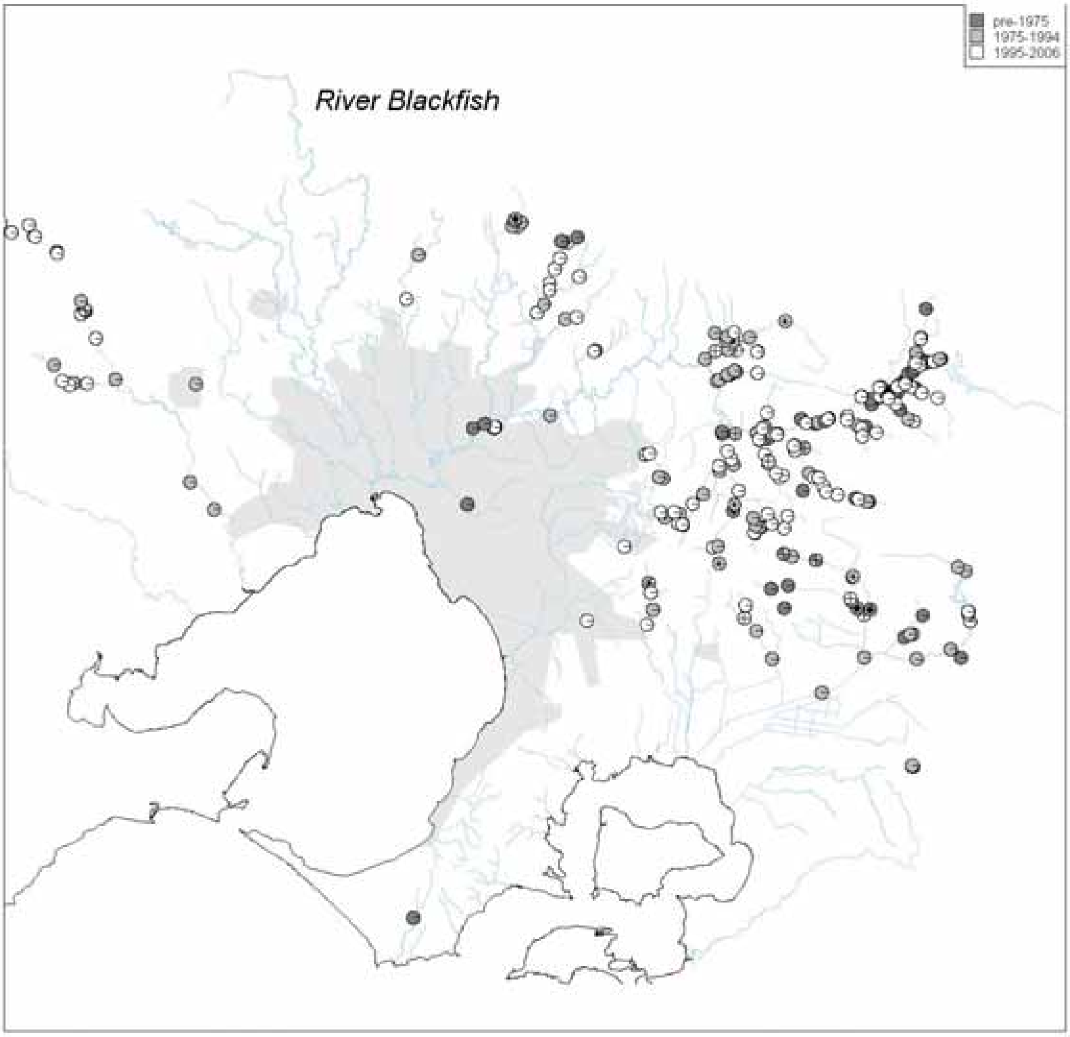


Figure A17. Records of *Gadopsis marmoratus*: represented by a pie-chart for each location indicating period of record. *G. marmoratus* occur almost exclusively in streams that are not degraded by urbanization (source: Melbourne Water fish database).

Habitat

G. marmoratus prefer clear water streams with slow water velocities. They need a complex habitat with plentiful woody debris, boulders, undercut banks and aquatic vegetation. They are more active at night and retreat to individual hideouts during daylight hours (Koster & Crook, 2008). Translocation experiments have determined that fish will return daily to the same retreat and will also quickly return if moved 10^2 m from the retreat (Khan *et al.*, 2004).

Threats

The almost complete absence of blackfish from streams with >1% DCI suggests the importance of urban stormwater impacts in limiting the distribution of this species. Ongoing urban development and road upgrades on the urban fringes of Melbourne, particularly in the Dandenongs (Monbulk, Emerald, and Olinda catchments) and upper Merri Creek, are primary threats to isolated populations.

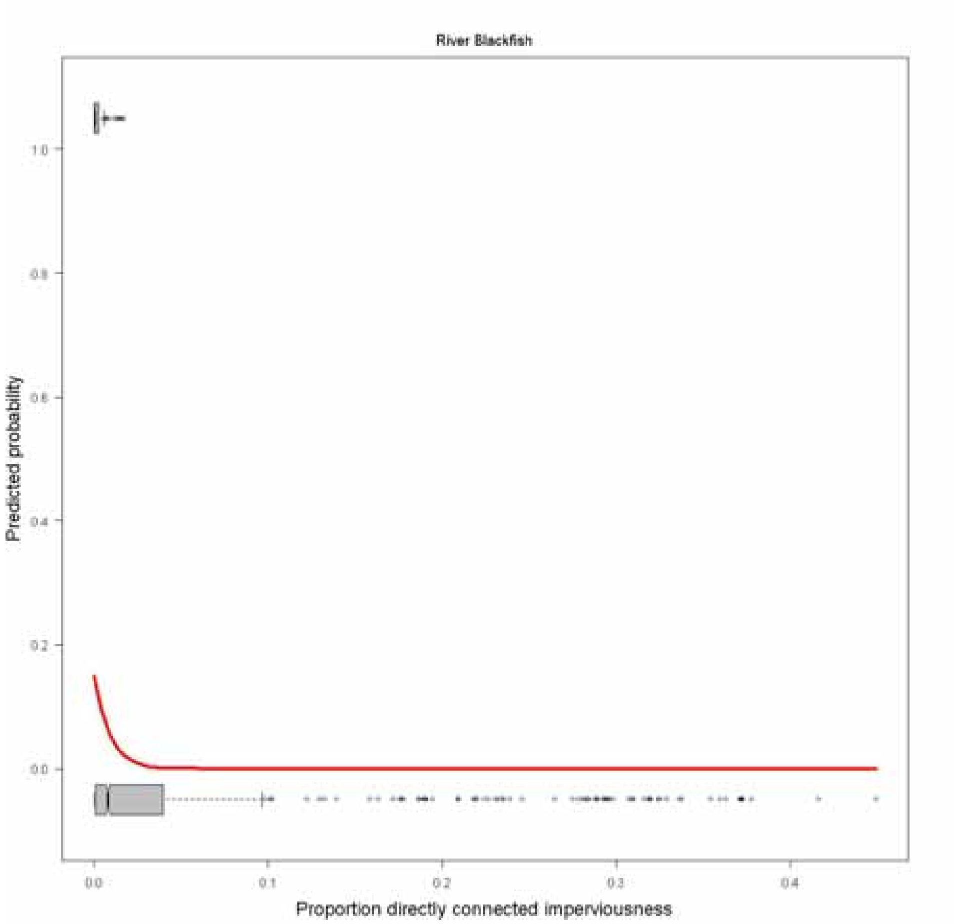


Figure A18. **Presence and absence of *Gadopsis marmoratus* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The logistic regression predicted probability curve (red solid line) shows a low probability of occurrence in streams with > 1% DCI (Data from Melbourne Water fish database, restricted to records post-1994, in the Yarra catchment).**

Habitat destruction such as de-snagging, riparian vegetation removal, siltation and bank slumping all contribute to reduce the physical habitat available for *G. marmoratus*, and these small scale threats are likely to be worsened by the water quality and hydrologic impacts of stormwater. Predation by introduced trout and over fishing further adds stress on populations of *G. marmoratus*.

Management options

Reduction of DCI throughout the Yarra catchment, through retrofit of the stormwater system, is likely to be required for restoration of *G. marmoratus* populations in the Lower Yarra. Isolated populations in the Monbulk, Emerald, Olinda and Merri catchments should be high-priority catchments for stormwater management, and reach-scale management of habitat.

On a reach scale, once catchment-scale impacts have been controlled, reintroduction of in-stream habitat such as woody debris to increase spawning sites and large boulders for residing under would benefit *G. marmoratus*. This needs to be targeted in and near streams where *G. marmoratus* currently occurs in order to expand the now restricted range.

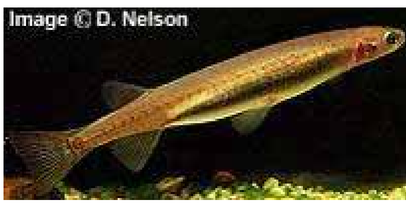
Galaxias maculatus (Common galaxias, common jollytail)

Galaxias truttaceus (Spotted galaxias, spotted mountain trout, trout minnow)

Galaxias brevipinnis (Climbing galaxias, Short-finned galaxias, broad-finned galaxias, Cox's mountain galaxias, Pieman galaxias)

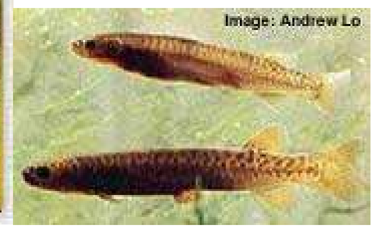
Urban category A: urban tolerant. All occur in metropolitan streams

Recommended management: 1. In urban streams: possibly (for *G. maculatus* and *G. truttaceus*) restoration/modification of fish-ways; 2. To expand populations outside metropolitan area: control of exotic species (trout)



Common Galaxias;
www.austmus.gov.au;

Spotted Galaxias;
www.nativefish.asn.au;



Climbing Galaxias
www.austmus.gov.au

General notes

Galaxiids are generally small elongate fish with no scales. Adults were recreationally fished before the introduction of brown trout. They are not highly targeted today, but juveniles migrating upstream from the ocean are taken in commercial quantities as whitebait in Tasmania and New Zealand.

Distribution and abundance

Galaxias maculatus is a cosmopolitan species found in South America, New Zealand and Australia. *G. maculatus* is abundant in coastal streams of southern states in Australia, north to S.E. Queensland and south to Tasmania. *G. maculatus* is not common in streams of the upper Yarra catchment, but is commonly collected from degraded metropolitan streams (Figure A19). Its occurrence is positively correlated with DCI (Figure A20), but it co-occurs with brown or rainbow trout less frequently than would be expected by chance (Table A2). *G. maculatus* is thus urban tolerant, and possibly uses degraded urban streams as a refuge from competition and predation by trout.

Table A2. Cross tabulation of records of *Galaxias maculatus* and rainbow or brown trout. Co-occurrence is less frequent than would be expected by chance ($\chi^2 = 21.7$, df = 1, $P < 0.001$).

		Galaxias maculatus	
		Absent	Present
Trout	Absent	435	242
	Present	164	44

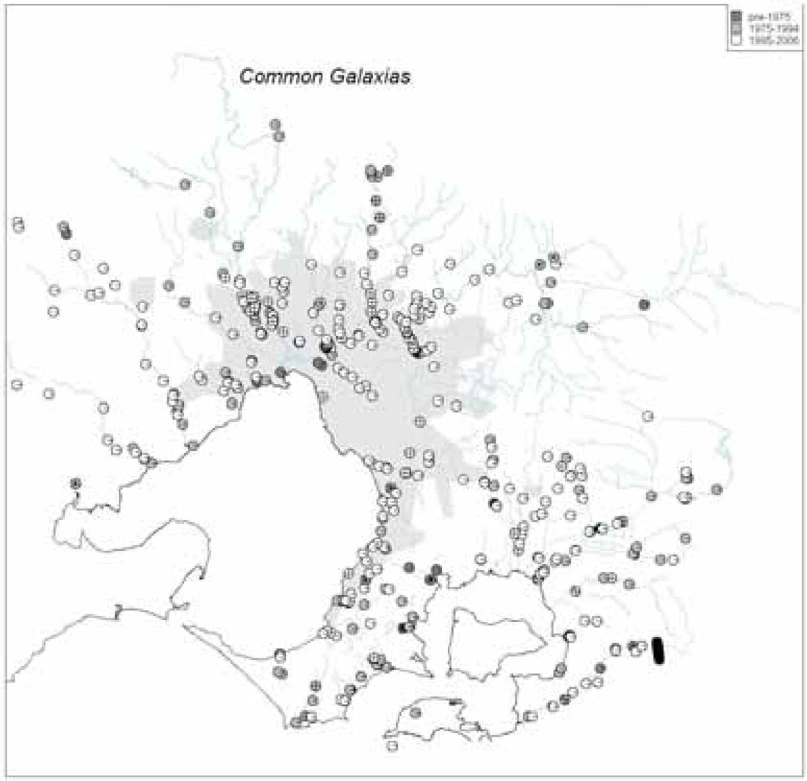


Figure A19. **Records of *Galaxias maculatus*: represented by a pie-chart for each location indicating period of record. *Galaxias maculatus* are very frequently recorded throughout metropolitan Melbourne (source: Melbourne Water fish database).**

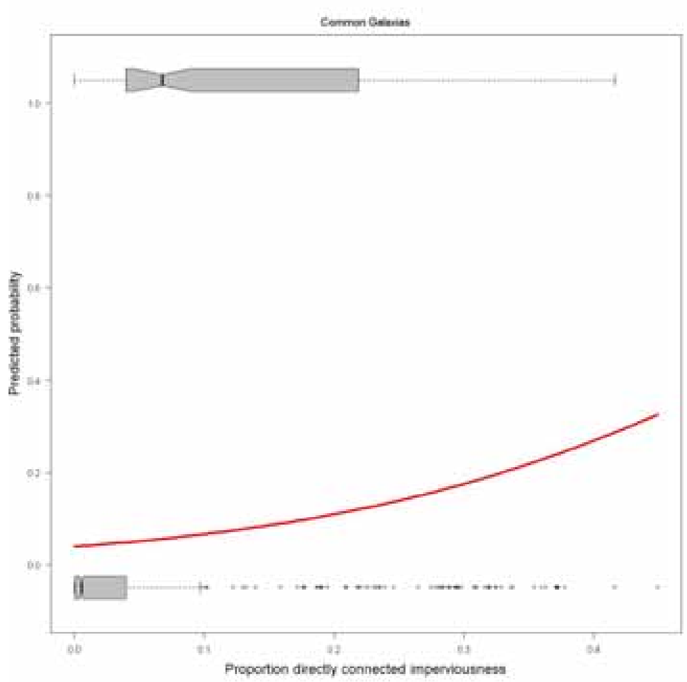


Figure A20. **Presence and absence of *Galaxias maculatus* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The logistic regression predicted probability curve (red solid line) shows a positive correlation with DCI (P < 0.05; Data from Melbourne Water fish database, restricted to records post-1994, in the Yarra catchment).**

Galaxias truttaceus is found over a similar range in Australia but the species occurs in fewer streams than *G. maculatus*. In the Melbourne Water region, *G. truttaceus* is recorded in lower reaches of a few urban waterways of the Yarra catchment, but it is also found in streams with low levels of catchment urbanization, such as those draining the Mornington Peninsula and Westernport (Figure A21). Its occurrence is not correlated with DCI (Figure A22), suggesting urban tolerance. Unlike *G. maculatus*, its frequency of co-occurrence with trout is not different from what would be expected by chance (Table A3).

Table A3. Cross tabulation of records of *Galaxias truttaceus* and rainbow or brown trout. Co-occurrence is no different than would be expected by chance (χ^2 = 1.19, df = 1, P = 0.28).

		Galaxias truttaceus	
		Absent	Present
Trout	Absent	609	68
	Present	193	15

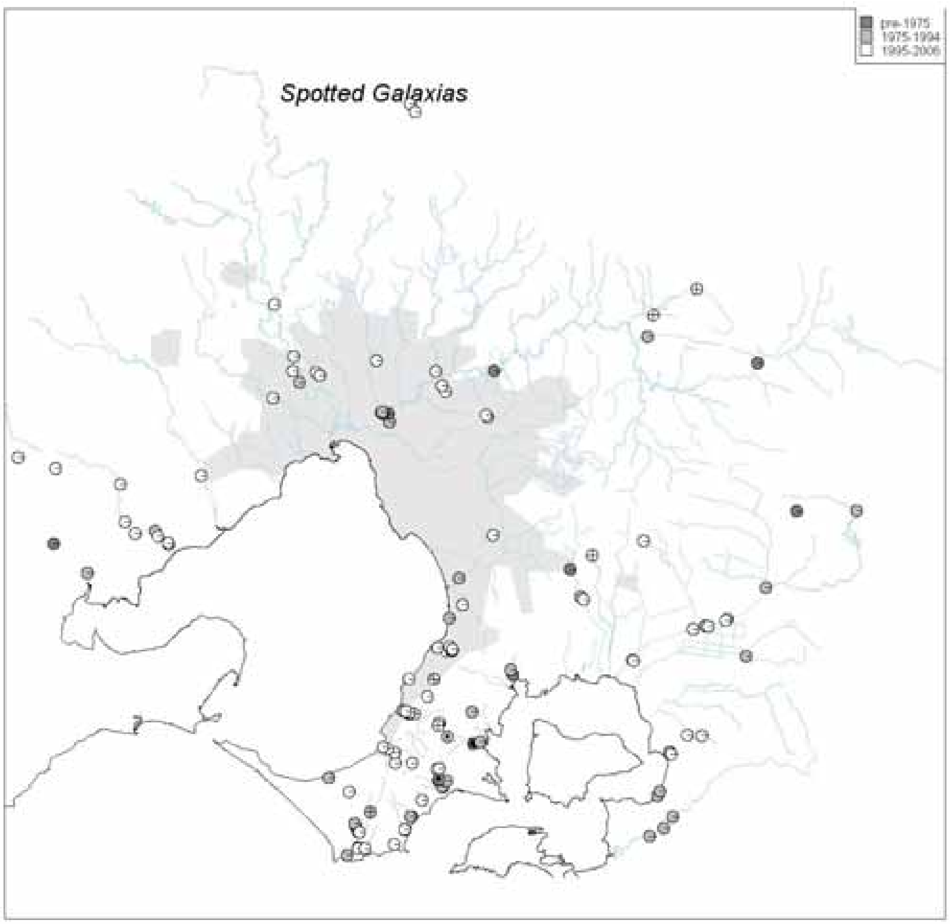


Figure A21. Records of *Galaxias truttaceus*: represented by a pie-chart for each location indicating period of record. *Galaxias truttaceus* are found in the Yarra and Maribyrnong rivers in metropolitan Melbourne as well as short estuaries of the Mornington Peninsula (source: Melbourne Water fish database).

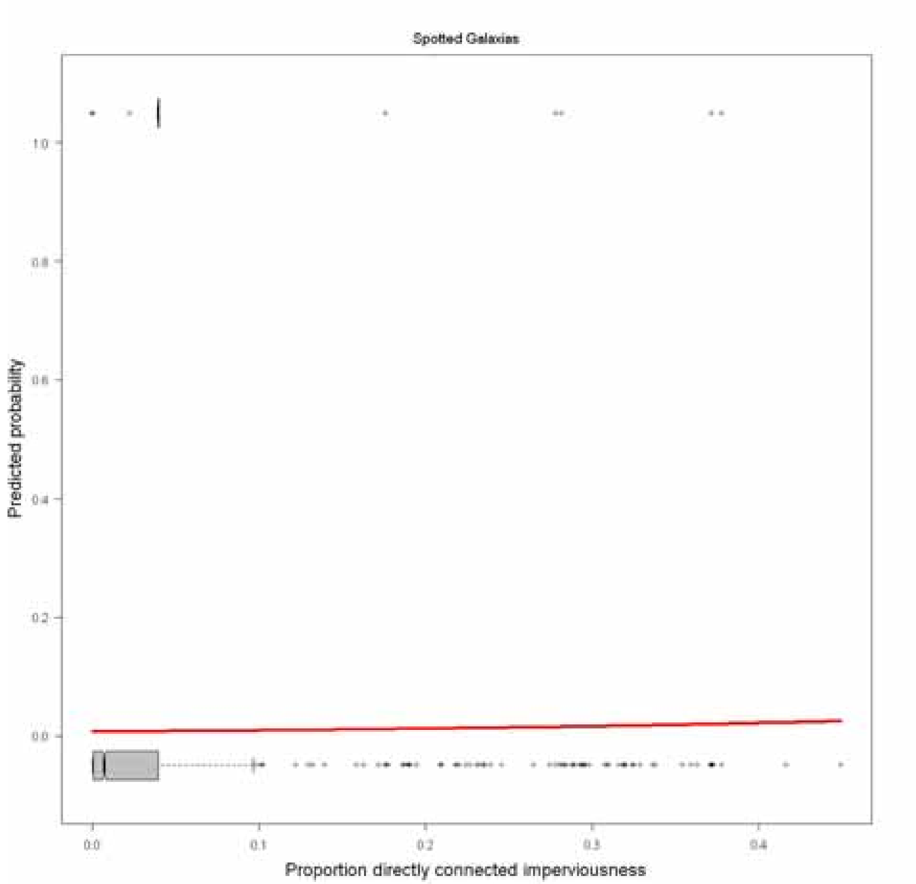


Figure A22. Presence and absence of *Galaxias truttaceus* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The logistic regression predicted probability curve (red solid line) shows no correlation with DCI (NS); Data from Melbourne Water fish database, restricted to records post-1994, in the Yarra catchment).

Galaxias brevipinnis can be found in cool, coastal streams of south eastern states on mainland Australia and also Tasmania and New Zealand. *G. brevipinnis* is more likely to be found in higher reaches of streams that contain other galaxiid species. This is not the case in Melbourne streams; the population is mainly restricted to low-lying reaches and tributaries of the Yarra and some short streams on the Mornington peninsula (Figure A23). Its occurrence is positively correlated with DCI (Figure A24), and its frequency of co-occurrence with trout is not different from what would be expected by chance (Table A4). They are most common in the Yarra River and some highly urban southern Yarra River tributaries such as Koonung and Gardiners creeks and are common on the Mornington Peninsula (Figure A23).

Table A4. Cross tabulation of records of *Galaxias brevipinnis* and rainbow or brown trout. Co-occurrence is no different than would be expected by chance ($\chi^2 = 0.27$, df = 1, P = 0.61).

		Galaxias brevipinnis Absent	*Galaxias brevipinnis* Present
Trout	Absent	637	40
	Present	193	15

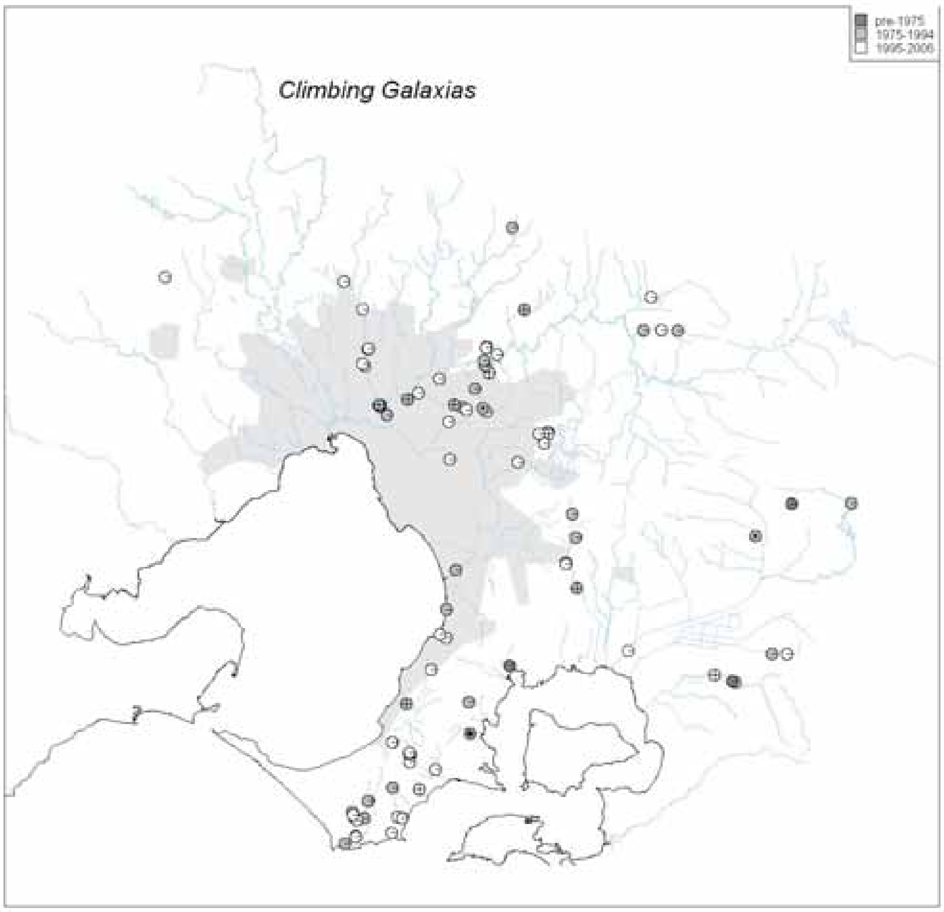


Figure A23. Records of *Galaxias brevipinnis*: represented by a pie-chart for each location indicating period of record. *Galaxias brevipinnis* occur frequently in the Yarra River and some highly urban southern tributaries such as Koonung and Gardiners creeks and are common on the Mornington Peninsula (source: Melbourne Water fish database).

Ecology

Galaxias maculatus and *G. brevipinnis* can be found breeding in landlocked populations in some Western Victorian lakes (Lake Purrumbete, Lake Bullen Merri, Lake Murdeduke and Lake Corangamite) (McDowall & Eldon, 1980) but they are unlikely to adopt such a lifecycle in flowing waterways or water storages around Melbourne.

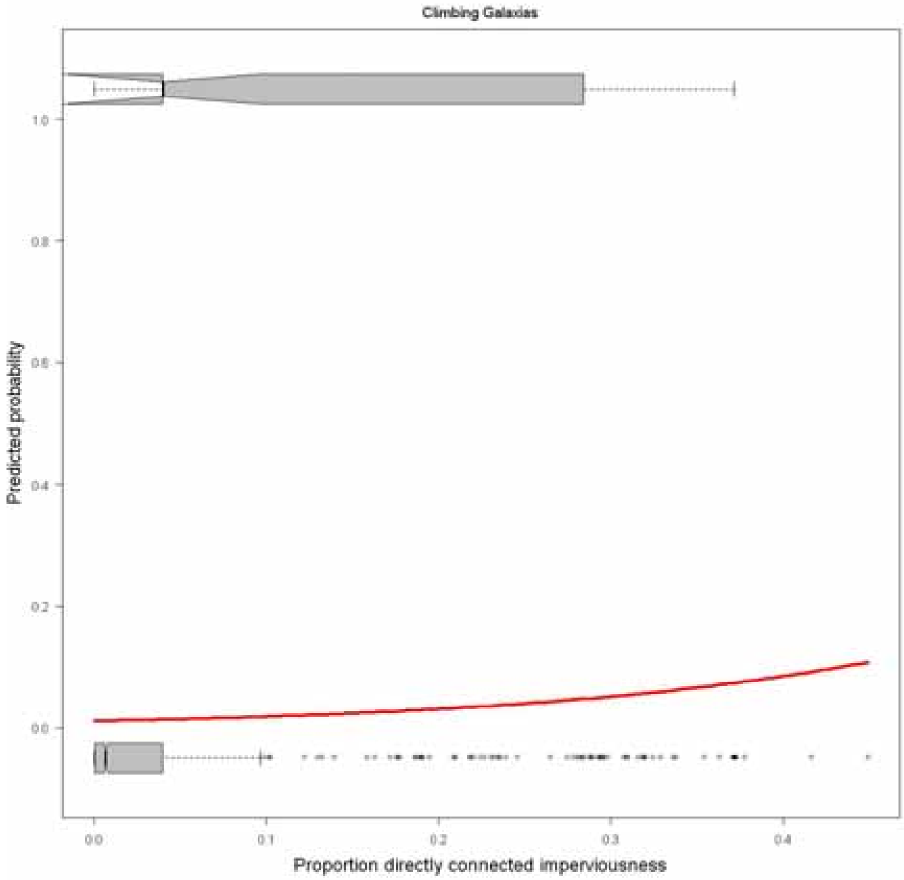


Figure A24. Presence and absence of *Galaxias brevipinnis* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The logistic regression predicted probability curve (red solid line) shows a positive correlation with DCI (P < 0.001; Data from Melbourne Water fish database, restricted to records post-1994, in the Yarra catchment).

Feeding strategy and diet

Larvae and juveniles of *Galaxias* spp. eat copepods and other small zooplankton and adults eat aquatic and terrestrial insects throughout the entire water column (Morgan, 2003). They are a cold-water species that exhibit little or no growth over summer months (Morgan, 2003).

Reproduction

In Melbourne these species migrate to the upper reaches of estuaries to spawn at the end of summer (Allen, Midgley & Allen, 2002). When larvae hatch they are swept or move out to sea for up to 6 months. They re-enter streams as juveniles or 'whitebait' and do not migrate again (Hale and Swearer, 2008). Further, all three of these species are thought to have persistent landlocked populations where they either migrate into feeder streams or use hard substrates in the shallow littoral zone to spawn on (Allen *et al.*, 2002).

Most of these species do not mature until they are > 1 year old and populations may not necessarily have synchronous spawning times throughout the populated range (Humphries, 1989).

Habitat

Galaxias truttaceus and *G. brevipinnis* prefer cool flowing waters, usually with good habitat complexity (e.g. log jams, rocks and boulders, gravel and abundant vegetation) (McDowall, 2006). *G. maculatus* have been found to tolerate much higher water temperatures than other galaxiids (McDowall & Eldon, 1980). Landlocked populations can persist in lakes but often migrate upstream (where possible) after spawning in the lake (Barriga, Battini & Cussac, 2007).

G. brevipinnis prefers faster flowing water and can be found above waterfalls and dam walls where the other species cannot physically access. *G. brevipinnis* lives closer to the stream-bed than the other two species which may help avoid predators (http://www.nativefish.asn.au).

Threats

The loss of habitat through deforestation (and subsequent siltation) or urban encroachment can reduce available habitat for these *Galaxias* species.

Jackson and Williams (1980) found a negative association between abundance of *G. maculatus* and brown trout (*S. trutta*) in the Yarra catchment and higher numbers of *G. maculatus* and *G. truttaceus* in streams in Wilsons Promontory where there are no brown trout. They also found a strong negative association between *G. brevipinnis* and trout. This is consistent with our finding of a negative association between trout and *G. maculatus* (Table A2). Our finding of a lack of strong association between the other two *Galaxias* species and trout could be an artifact of our analyses using presence-absence data rather than abundance data.

Gambusia holbrooki were not found to be a competitive threat to *G. maculatus* until *G. holbrooki* were in ratios above 3:1 (Becker *et al*., 2005).

Finally, water impoundment and abstraction can have deleterious affects on *Galaxias* populations although *G. brevipinnis* seems to be well adapted to navigate over introduced obstacles like dam walls.

Management options

The broad distribution of *G. maculatus* across Melbourne suggests that there is probably little need to alter current management strategies for this species, however, they do not occur in high numbers in the upper Yarra catchment where brown trout are common. Tasks like removing barriers to fish movement and increased stream flows to ensure healthy estuaries may be important, but the control of brown trout numbers will benefit *G. maculatus* in the broader Yarra catchment.

G. truttaceus is mainly restricted to streams draining the Mornington Peninsula and also those streams in the north and west that have few barriers to dispersal. There are only three recent records of *G. truttaceus* above Dights Falls so there is a strong possibility that the current fish passage is not working to the intended design or that predation pressure (trout and waterbirds) is too high.

The distribution and biology of *G. brevipinnis* does not readily identify additional management actions to help this species.

Galaxiella pusilla **(**Dwarf galaxias, eastern little galaxias)

Urban category C: urban sensitive.
Rare in urban streams, but occur in urban wetlands

Recommended management:
1. Protection of urban wetland refuge habitats (revegetate and prevent draining), creation of new refuge wetlands
2. Re-establishment of urban stream populations: in-catchment stormwater retention
3. Control exotic fish populations
4. Basic distributional and ecological research

Photo: R. Kuiter

General notes

Galaxiella pusilla is a small, sexually dimorphic fish with males having a unique longitudinal orange stripe. It is listed as threatened under the FFG Act of 1988 (DSE, 2007a). There is a considerable community following for this species resulting from the actions of the Australia-New Guinea Fishes Association to conserve *Galaxiella pusilla* near Narre Warren (Agg, date unknown; Bolling, 2008; Tucceri, 2005)

Distribution and abundance

Galaxiella pusilla are limited to coastal streams from Bairnsdale in eastern Victoria to the South Australian boarder. It is also found on Flinders Island and northern Tasmania (Allen *et al.*, 2002; Koster, 2003). It can be locally abundant but is patchy within its range (Koster, 2003; Tucceri, 2005).

In the Melbourne Water region, almost all of the in-stream records of *G. pusilla* have been outside the metropolitan area, with DCI < 1% (Figure A25). It has been recorded from several urban locations in the south-eastern suburbs, but almost all of these records have been from small wetlands or roadside drains in areas without stormwater drainage (including ponds at LaTrobe University and several locations in the south-eastern suburbs). Two records in the Melbourne Water database suggest at least some ability to survive in streams suffering urban stormwater impacts are a) a 1985 record from Dandenong Creek 'at Police Road, Mulgrave' (although it is not clear if the record was from the creek or an associated wetland), and b) a 2006 record from Little Boggy Creek, Langwarrin, which certainly has DCI >1%. The relative scarcity of urban stream records compared to rural stream records suggests that the ability of *G. pusilla* to inhabit stream habitats is limited by urban stormwater impacts. Its more common occurrences in small wetlands in urban areas suggest that management of urban wetlands could provide urban refuges for this species.

Although it has been posited that a major threat to *G. pusilla* is competitive exclusion by *Gambusia* (McDowall, 2006, Tucceri, 2005), a contingency analysis suggests that it co-occurs more frequently with *Gambusia* than would be expected by chance (Table A5). If this analysis is restricted to urban sites, the same pattern holds. However, it should be noted that this analysis is based on presence-absence, and would not detect an effect of suppressed populations numbers rather than exclusion.

Table A5. Cross tabulation of records of *Galaxiella pusilla* and *Gambusia holbrooki*. Co-occurrence is more frequent than would be expected by chance (χ^2 = 9.23, df = 1, P = 0.002).

		Galaxiella pusilla	
		Absent	Present
Gambusia holbrooki	Absent	592	23
	Present	244	26

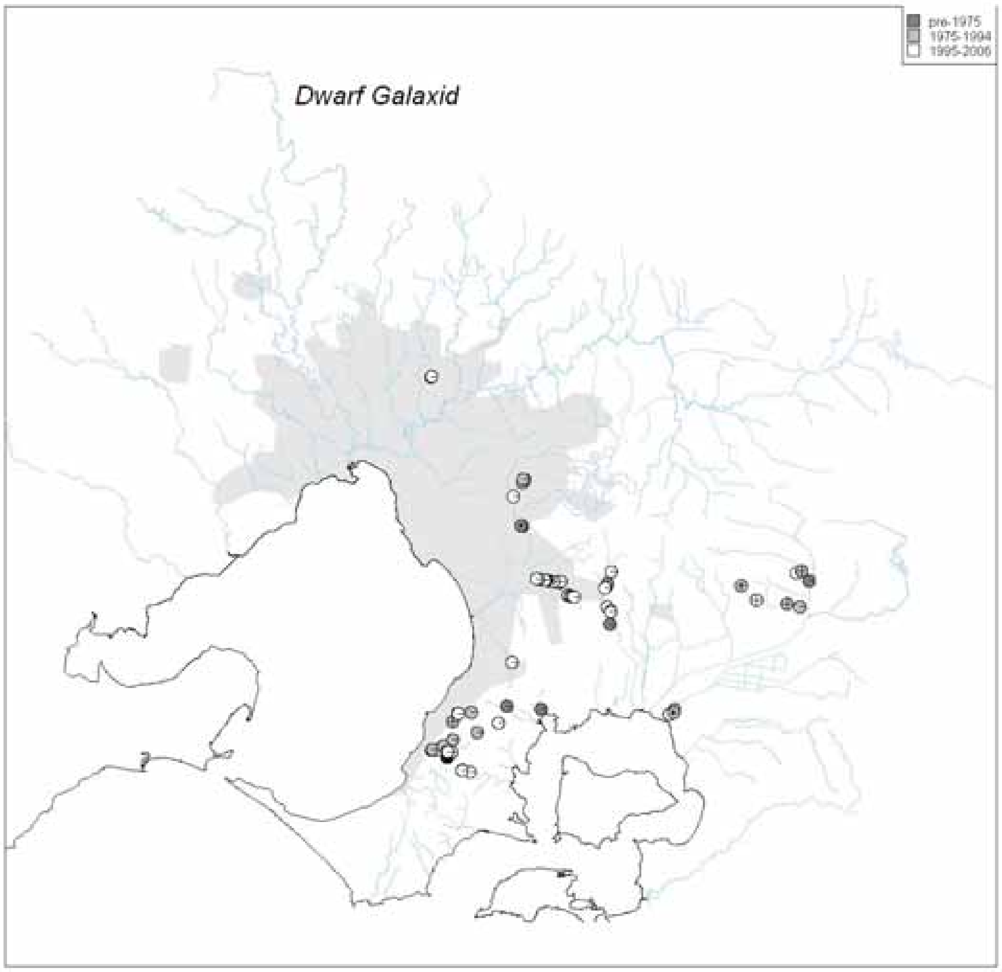


Figure A25: Records of *Galaxiella pusilla*: represented by a pie-chart for each location indicating period of record. *Galaxiella pusilla* occur frequently in the east around developing suburbs such as Hallam and Narre Warren. It also occurs on the Mornington Peninsula (source: Melbourne Water fish database).

Ecology

Galaxiella pusilla benefit from low water temperatures that their main introduced competitor, *Gambusia holbrooki*, cannot cope with (McDowall, 2006). Female *Galaxiella pusilla* grow to around 40mm and males to around 30mm. They have a solitary lifestyle but loose shoals have been witnessed at the juvenile stage (Backhouse & Vanner, 1978). Individuals sometimes live for 2 years but they more commonly die after spawning after their first year (Koster, 2003). *G. pusilla* are tolerant of lower water temperatures than many of their competitors either native or introduced (McDowall, 2006).

Feeding strategy and diet

Galaxiella pusilla are generalists feeding on aquatic insect larvae and crustaceans in the mid water column. They can also consume aquatic plants such as *Lemna* spp. and filamentous algae (Backhouse & Vanner, 1978).

Reproduction

Fecundity is low and up to 240 small eggs, with an adhesive coating, are laid individually on stones, emergent macrophytes and submerged aquatic vegetation (Humphries, 1983; McDowall, 2006). They can spawn multiple times over spring-winter (Koster, 2003).

Habitat

Galaxiella pusilla survive in shallow wetlands and slow flowing streams. They have been known to aestivate in ephemeral water bodies. The exact site of aestivation is unknown but speculated to be in crayfish burrows or mud. Adults were found shortly after the refilling of wetlands ruling out a desiccation resistant life stage (McDowall, 2006).

Threats

Urban stormwater runoff is likely to be the major threat excluding *G. pusilla* from urban stream habitats. However, within urban areas, *G. pusilla* is able to survive in small wetlands and even table drains along roads. The drainage of wetlands and curbing and channeling of roads is therefore a threat to urban refuges for this species. Deforestation, habitat fragmentation and competition with introduced pest species (*Gambusia holbrooki*) are also important factors likely to threaten the survival of both urban and rural populations of *G. pusilla* (Koster, 2003; McDowall, 2006; Tucceri, 2005).

Management options

If the records of *G. pusilla* in the Melbourne Water database are reliable, the re-establishment of sustainable populations of this species into urban streams will require widespread in-catchment stormwater retention and treatment. The priority catchments for this species would be those in which populations persist in riparian wetland refuges: Boggy Creek, Langwarrin, Cardinia Creek, below Beaconsfield, and Hallam main drain and its tributaries. More systematic distributional surveys of *G. pusilla* in streams and wetlands are required to confirm the validity of these priorities.

In the short-term, protection of populations in urban wetland refuges should be a management priority. Riparian vegetation replanting and fencing off would compliment measures to secure habitat by firstly reducing water temperatures to reduce the advantage of *Gambusia holbrooki* and secondly by providing habitat structure for food sources.

In the long term, constructed wetlands could potentially secure populations throughout south-eastern Melbourne by acting as re-seeding stocks for rehabilitated streams and wetlands (J. McGuckin pers. comm., R Coleman pers. comm.), as long as their primary purpose is not the treatment and retention of urban stormwater runoff. Continued research into the basic biology of the species, particularly reproductive timing, diet and the adult aestivation ability is also required.

Geotria australis (Pouched lamprey)

Urban category B: transient

Recommended management:
1. Confirmation of distribution
2. To increase populations in urban streams: in-catchment stormwater retention, and possibly remedial sediment management

Photo: www.brisbanetimes.com.au

General notes

Lamprey, along with hagfish, are primitive jawless fishes growing to a maximum of around 40 cm. They are not a fish of commercial interest but lamprey anatomy is commonly studied in an effort to advance human medicines. They are also thought to have a high vulnerability to anthropogenic stressors as they have a long lifecycle and juveniles live within the sediments (Macey, 1981).

The reliability of taxonomic identifications of *G. australis* in existing records in the Melbourne Water fish database has been questioned (J. McGuckin, pers. comm.), so the following assessment of distribution must be considered tentative.

Distribution and abundance

Pouched lampreys are widely distributed along the coastal margins of south-eastern Australia and also New Zealand, and southern South America (Allen *et al.*, 2002). They are common in many coastal Victorian streams including those in and around Melbourne. Adults are thought to be more active during the night. Potter *et al.* (1986) observed larval *G. australis* in abundances as high as 128 m^{-2} in a Western Australian stream.

The distribution of *G. australis* in the Melbourne Water region suggests some occurrence in urban streams, but the record is sparse and most recordings are from streams with low DCI (Figure A26). This suggests that *G. australis* use urban streams as a passageway to healthy streams higher in the catchment but are unlikely to reside permanently in urban waterways.

Ecology

Geotria australis are anadromous (adults move into freshwater to spawn). *G. australis* can survive out of water for some time because they can adsorb oxygen through their thin skin, especially in cooler environments (Potter *et al.*, 1996).

Reproduction

The lifecycle is complex with larvae burrowing into medium to coarse sediments where they can spend up to six years maturing (Potter *et al.*, 1986). They then go through metamorphosis and migrate out to sea as mature fish. The site of breeding is unknown but females return to the headwaters of streams to spawn. Females produce a vast number of eggs (estimated to be ~58,000) (http://www.fishbase.org).

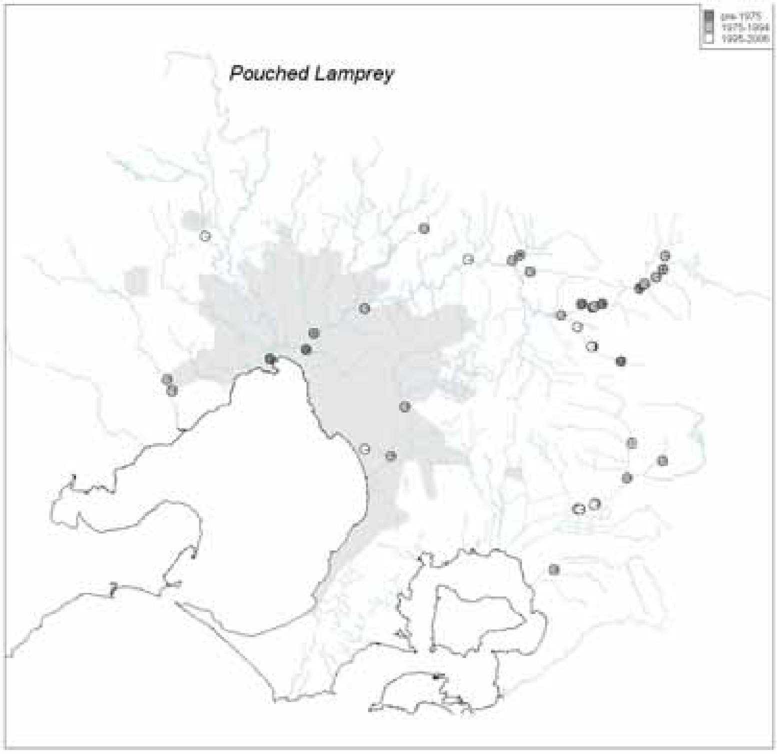


Figure A26. Records of *Geotria australis*: represented by a pie-chart for each location indicating period of record. (source: Melbourne Water fish database). The frequent records in the Yarra estuary are likely to be migrating individuals.

Feeding strategy and diet

Feeding strategies change as the individual fish goes through the series of morphological changes associated with this species. Larvae filter unicellular freshwater algae, detritus and microorganisms from the water column (Potter *et al.*, 1986).

Habitat

The larval phase of the pouched lamprey inhabits freshwater where they burrow into soft sediments. Adults spend only a short time in freshwater (Allen *et al.*, 2002).

Threats

The likelihood that the few records from urban streams represent migrating individuals (or are erroneous records) suggests that the impacts of catchment urbanization are a threat to this species. As they live in sediments, poor sediment quality arising from urban stormwater impacts could be a proximate stressor that could persist as a legacy effect after any potential removal of stormwater impacts. The Melbourne distributional record suggests that barriers to migration are not a limiting factor for *G. australis*, a conclusion supported by the observation that *G. australis* can climb wet vertical walls (http://www.fishbase.org) (Allen *et al.*, 2002).

Management options

Before firm management recommendations can be made, the distributional records of this species need to be confirmed. Based on available information, it is likely that an increase in urban stream populations will require reduction of DCI in targeted catchments, possibly in concert with remediation of sediment quality.

Mordacia mordax **(**Short headed lamprey, Australian lamprey, Southern pouched lamprey, Murray lamprey).

Urban category B: transient

Recommended management:
To increase populations in urban streams: in-catchment stormwater retention, and possibly remedial sediment management

Photo: http://www2.mdbc.gov.au

General notes

Lamprey, along with hagfish, are primitive jawless fishes growing to a typical maximum of around 40 cm. They are not a fish of commercial interest but lamprey anatomy is commonly studied in an effort to advance human medicines. They are also thought to have a high vulnerability to anthropogenic stressors as they have a reasonably slow lifecycle and juveniles live within the sediments (Macey, 1981).

Distribution and abundance

Mordacia mordax is found in the Murray River and small coastal rivers of Victoria, Tasmania, South Australia and southern New South Wales (Macey, 1981).

Similar to *G. australis*, the distribution of *M. mordax* in the Melbourne Water region suggests occurrences sites such as the Yarra estuary (with DCI = 4%: Figure A27), are likely to be migrating individuals which are unlikely to reside permanently in urban waterways. Even including records from the Yarra estuary, the occurrence of *M. mordax* is negatively correlated with DCI (Figure A28).

Ecology

The larvae are found in slow-flowing reaches of both small and larger streams and rivers where they burrow into soft sediments. Juveniles found in muddy reaches of the same streams (Allen *et al.*, 2002).

Feeding strategy and diet

Feeding strategies change as the individual fish goes through the series of morphological changes associated with this species. Larvae filter unicellular freshwater algae, detritus and microorganisms from the water column (http://www2.mdbc.gov.au).

Reproduction

Few details are known but juveniles migrate out to sea to mature and then re-enter freshwaters to breed (Potter *et al.*, 1998). Females are reported to produce between 5000 and 13000 eggs and spawning occurs from June to August (Potter *et al.*, 1998) (http://www.dpi.vic.gov.au).

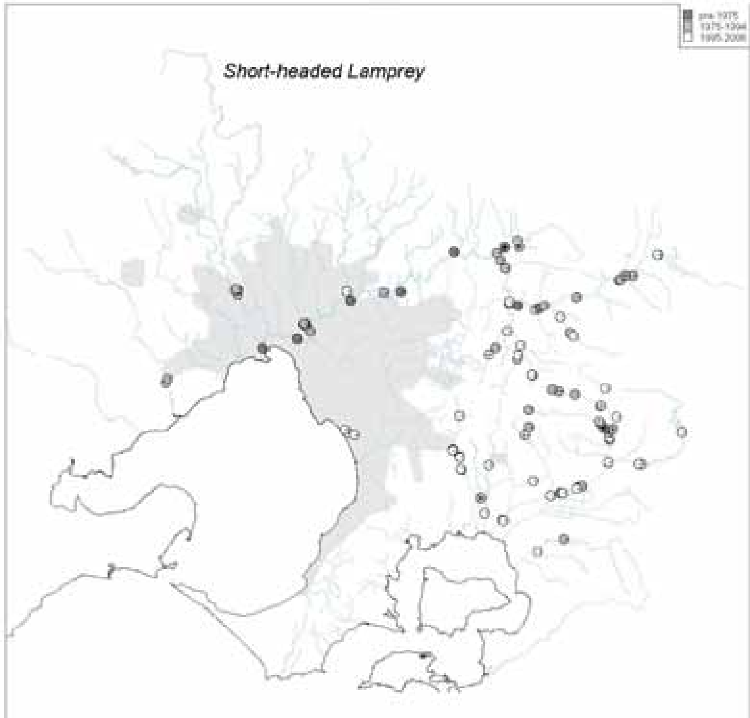


Figure A27. Records of *Mordacia mordax*: represented by a pie-chart for each location indicating period of record. The frequent records in the Yarra estuary are likely to be migrating individuals but few have been recorded in recent years (source: Melbourne Water fish database).

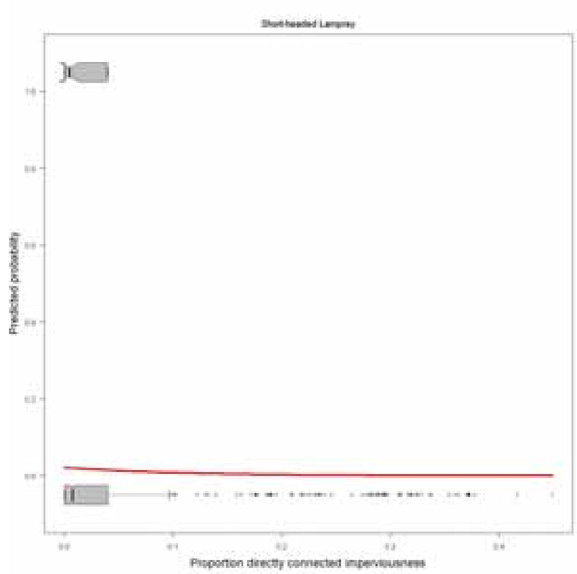


Figure A28. Presence and absence of *Mordacia mordax* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The predicted probability curve (red solid line) shows a low probability of occurrence in sites with DCI > 4% (Data from Melbourne Water fish database, restricted to records post-1994, in the Yarra catchment).

Habitat

Small streams and larger rivers of coastal southern Australia; ammocoetes live in slow flowing streams but adults prefer estuaries or the sea (Allen *et al.*, 2002). Juveniles burry themselves in the soft sediments and filter feed for an indeterminate time before maturity (Potter *et al.*, 1998).

Threats

The impacts of catchment urbanization are a likely major threat to this species. As they live in sediments, poor sediment quality arising from urban stormwater impacts could be a proximate stressor that could persist as a legacy effect after any potential removal of stormwater impacts. The Melbourne distributional record suggests that barriers to migration are not a limiting factor for *M. mordax.*

Management options

An increase in urban stream populations of *M. mordax* will require reduction of DCI in targeted catchments, possibly in concert with remediation of sediment quality.

Nannoperca australis (Southern pygmy perch, Swamp perch)

Urban category C: urban sensitive

Recommended management:
1. Protection of urban wetland refuge habitats (revegetate and prevent draining), creation of new refuge wetlands
2. Re-establishment of urban stream populations: in-catchment stormwater retention
3. Research on interactions with exotic species

Photo: www.mdbc.gov.au

General notes

Nannoperca australis is a small fish typically between 65 and 85mm and is of no commercial or recreational fishing value. It is closely related to the Yarra (*Nannoperca obscura*) and Ewens (*Nannoperca variegata*) pygmy perch but each of these species has a more restricted range than *N. australis*. *N. australis* is not considered to be a threatened species in Victoria (DSE, 2007a).

Distribution and abundance

Nannoperca australis was widely distributed over much of southern Australia. Populations in NSW and SA are threatened but Southern pygmy perch are common throughout coastal Victoria and are also found in many inland river basins (Humphries, 1995). They are strong swimmers and can move freely patches of suitable habitat when necessary.

In the Melbourne Water region, *N. Australis* is most common outside the metropolitan area (Figure A29). In the Yarra catchment, it is not found in any sites with > 1% DCI (Figure A30). While the Yarra distribution of this species suggests it is sensitive to the impacts of catchment urbanization, its presence in urban sections of Dandenong Creek suggests some degree of urban tolerance. *N. australis* was collected in 1998 from Dandenong Creek at Police Road and Greens Road both ~20% DCI), and in 2001 from Cardinia Creek below Beaconsfield (~5.5% DCI). All other recent urban records of *N. australis* are from floodplain wetlands (such as on Corhanwarrabul and Cardinia creeks, and Jells Park and Rowville wetlands on Dandenong Creek). It is therefore likely that *N. australis* is sensitive to urban stormwater impacts, and that its rare occurrences in urban streams might arise from populations surviving in riparian wetland refuges.

Nannoperca australis is thought to compete with the exotic *Gambusia holbrooki* (King & Warburton, 2007), however, in the Melbourne Water region, these two species tend to co-occur more frequently than would be expected by chance (Table A6). If this analysis is restricted to just urban sites, the same pattern holds, although not significant, because of the few records of *N. australis* in urban streams.

Ecology

Feeding strategy and diet

Nannoperca australis is carnivorous, hunting small aquatic crustaceans and insects (Humphries, 1995). Larvae prey on plankton but as they grow, larger benthic prey items can be taken (http://www.fisheries.nsw.gov.au).

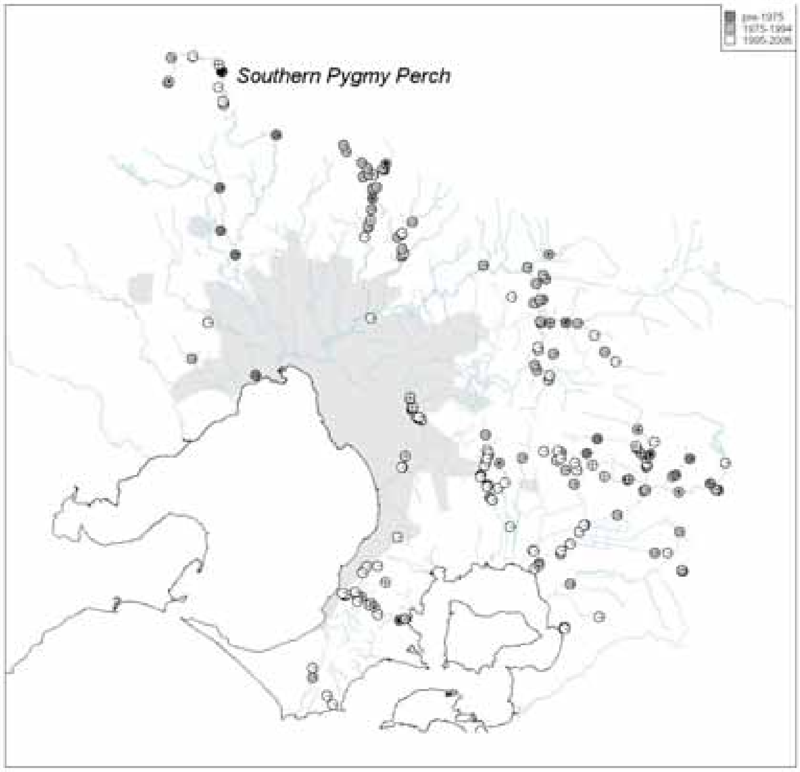


Figure A29. Records of *Nannoperca australis*: represented by a pie-chart for each location indicating period of record. Other than a few records from Dandenong Creek, *N. australis* has not been recorded from metropolitan streams (source: Melbourne Water fish database).

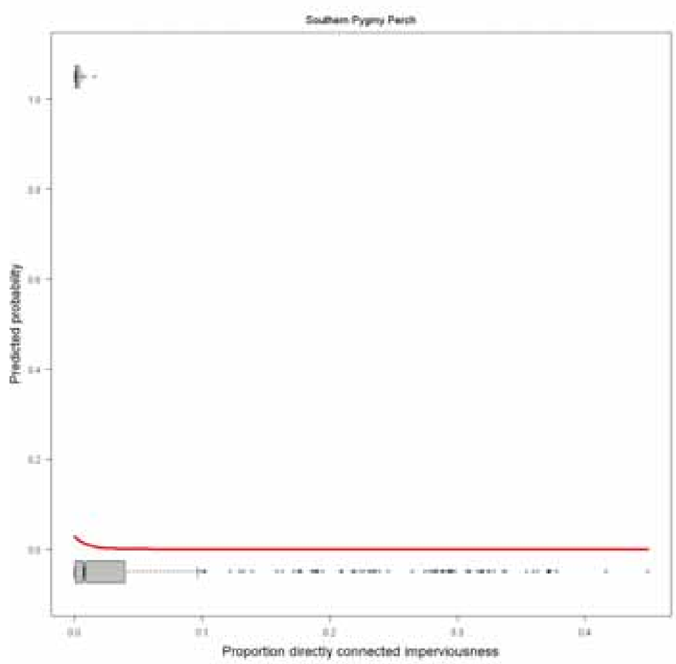


Figure A30. Presence and absence of *Nannoperca australis* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The predicted probability curve (red solid line) shows a low probability of occurrence in sites with DCI > 1%, but this excludes data from Dandenong Creek (Fig. A30) (Data from Melbourne Water fish database, restricted to records post-1994, in the Yarra catchment).

Table A6. Cross tabulation of records of *Nannoperca australis* and *Gambusia holbrooki*. Co-occurrence is more frequent than would be expected by chance (χ^2 = 9.23, df = 1, P = 0.002).

		Nannoperca australis	
		Absent	Present
Gambusia holbrooki	Absent	547	68
	Present	219	51

Reproduction

Nannoperca australis has the ability to spawn multiple times during the warmer months when water temperatures are above 16 degrees. Females > 1 year old can produce >650 eggs which they scatter over aquatic vegetation or sediments (Humphries, 1995; Llewellyn, 1974). Eggs hatch within 4 days and larvae are 3-4mm long (http://www.fisheries.nsw.gov.au).

Habitat

Nannoperca australis is found in streams with low flow, billabongs and lakes with healthy stands of macrophytes where it can shelter from predators and hunt for food (Humphries, 1995).

Threats

The distribution of *N. australis* in the Melbourne region suggests that the catchment impacts of urbanization are likely to be a primary threat. However, the presence of this species in urban reaches of Dandenong creek suggests that it can persist in urban streams.

Urban stormwater runoff is likely to be the major threat reducing the abundance of *N. australis* in urban stream habitats. However, N. australis remain relatively common in floodplain wetlands of urban streams, which are likely to form an important source of recruits to urban streams. Loss or degradation of these refuges is therefore an important threat in urban areas. The importance of competitive exclusion or suppression by exotic species such as *Gambusia* requires further investigation in urban areas.

Management options

Most likely the re-establishment of sustainable populations of *N. australis* into urban streams will require widespread in-catchment stormwater retention and treatment. The priority catchments for this species would be those in which populations persist in riparian wetland refuges: Dandenong and Cardinia creeks. More systematic distributional surveys of *N. australis* in streams and wetlands are required to confirm the validity of these priorities.

In the short-term, protection of populations in urban wetland refuges should be a management priority. Riparian vegetation replanting and fencing off would compliment measures to secure habitat by firstly reducing water temperatures to reduce any potential advantage of *Gambusia holbrooki* (King & Warburton, 2007) and secondly by providing habitat structure for food sources.

In the long term, constructed wetlands could potentially secure populations throughout south-eastern Melbourne by acting as re-seeding stocks for rehabilitated streams and wetlands.

Nannoperca obscura (Yarra Pigmy Perch)

Urban category D E: urban intolerant.
No recent records from streams with DCI > 0%

Recommended management:
Further research required for a management plan, but recovery unlikely in streams with DCI >1%

Photo: www.mdbc.gov.au

General notes

Nannoperca obscura was formerly found in central and western Victorian coastal streams from Melbourne through to the South Australian boarder. The conservation status of *N. obscura* is vulnerable (DSE, 2007a).

Distribution and abundance

The range of *N. obscura* has greatly reduced and now cannot be found in streams in urban Melbourne; however, there is a population in Waurn Ponds Creek and lower reaches of the Barwon River near Geelong (Close, Webb & Koster, 2002).

In the Melbourne Water region, there are several historic records from the Yarra River and Dandenong Creek catchments, but there are no recent records (Figure A31). While it has been recorded in recent years in the upper Maribyrnong catchment, the most recent metropolitan record was from 1982.

Ecology

Nannoperca obscura is typically found in small shoals, often with *N. obscura* which share many similar physical and ecological traits (Close *et al.*, 2002).

Feeding

Nannoperca obscura are carnivorous feeding on small crustaceans and insect larvae. *N. obscura* larvae presumably feed on smaller plankton similar to *N. australis* (Allen *et al.*, 2002).

Reproduction

Similar to *N. australis*, little is known about the reproductive cycles of *N. obscura*. Spawning occurs during spring and *N. obscura* probably take one year to sexually mature, evidenced by the detection of two distinct size cohorts in Waurn Ponds Creek (Close *et al.*, 2002).

Habitat

Nannoperca obscura typically prefers slow flowing coastal creeks and lakes with dense macrophyte stands. It is tolerant of brackish waters and low oxygen conditions (Zampatti, 2001).

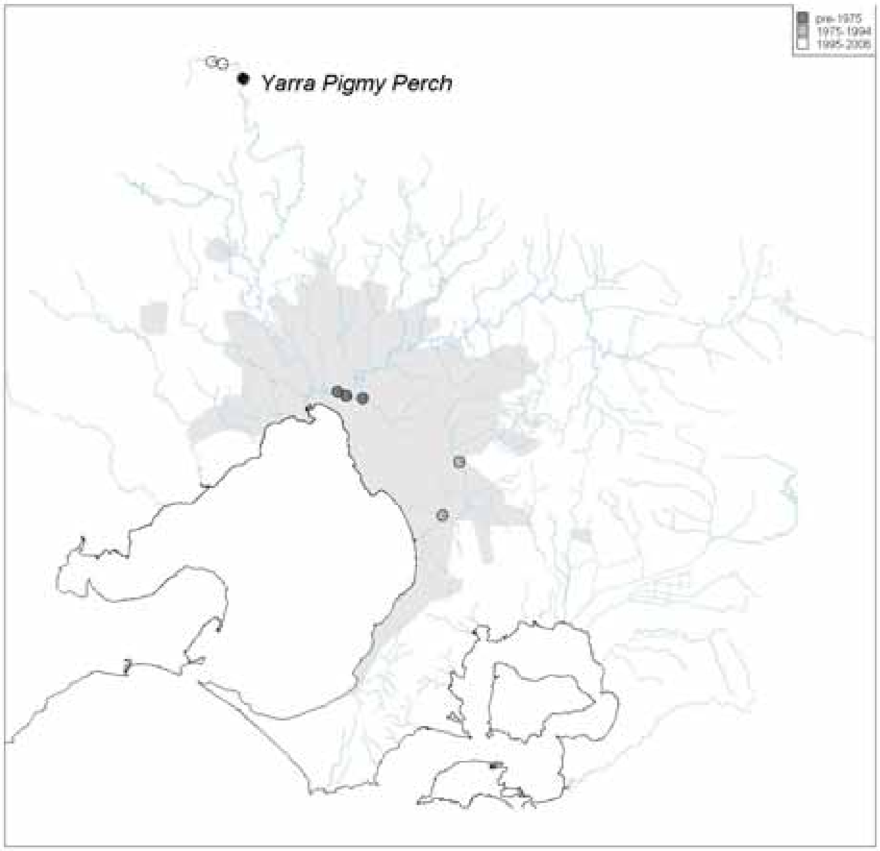


Figure A31. Records of *Nannoperca obscura*: represented by a pie-chart for each location indicating period of record. Other than a few records from Dandenong Creek, *N. australis* has not been recorded from metropolitan streams for over 25 years (source: Atlas of Victorian Wildlife database).

Threats

There is insufficient information to conclude the causes of the decline in *N. obscura* in the Melbourne metropolitan area, given its similar decline in non-urban habitats. However, it would appear unlikely that restoration of Melbourne populations of this species would be possible without catchment-wide reduction of DCI.

Further research is required into the primary threats causing the decline of this species, including the effects of exotic fish and small-scale habitat structure.

Management options

Further research is required before a management plan could be developed for this species.

Neochanna cleaveri (Australian mudfish)

Urban category B C: transient.
A single record from the Yarra estuary

Recommended management:
1. Basic distributional and ecological research
2. Barrier removal

Photo: Tarmo Raadik

General notes

Neochanna cleaveri is a small, scaleless fish growing to ~14cm. The body is long and thin, much like other members of the Galixiidae. It is listed as threatened under the Flora and Fauna Guarantee Act (DSE, 2007a).

Distribution and abundance

Neochanna cleaveri is found only in low elevation waterways in Tasmania and Victoria but close relatives are common in New Zealand (McDowall, 2006). The Victorian population is limited to a few coastal streams from Wilsons Promontory to the Aire River. It has been found in a drain the Barwon River but more commonly in coastal Otway streams (Koehn & Raadik, 1991; Skene *et al.*, 2003).

In the Melbourne Water region a single juvenile has been collected from below Dights Falls on the Yarra River in 1991, likely to be migrating.

Ecology

Neochanna cleaveri are diadromous and can survive periods out of water (aestivate) by burrowing into mud or sheltering under rocks (McDowall, 2006).

Reproduction

Neochanna cleaveri spawn over winter in the lower reaches of rivers and creeks where eggs and larvae are washed into the marine environment where they stay for an undetermined time. They make their way back into freshwater streams as juveniles where they remain until mature (McDowall, 2006).

Feeding strategy and diet

Neochanna cleaveri forage during the night but it is not known what they feed on (Koehn & Raadik, 1991).

Habitat

Neochanna cleaveri has the potential to live in many habitats including permanent and ephemeral creeks and wetlands, estuaries and the main stems of larger rivers like the Yarra and Barwon Rivers. *N. cleaveri* live in dense aquatic macrophytes and snags (McDowall, 2006). They are known to survive in ‘dry’ habitats (aestivation) for several weeks and possibly months by a combination of cutaneous breathing and avoiding total desiccation with careful microhabitat selection (McDowall, 2006).

Threats

Habitat loss by draining wetlands and channeling streams has been identified as major threats to Tasmanian and Victorian populations (Allen *et al.*, 2002; McDowall, 2006), so habitat destruction by riparian removal, cattle pugging and increasing urbanization should also constitute significant threat to *N*. *cleaveri* populations. Competitive or predator interactions between *N. cleaveri* and introduced species such as mosquito fish, redfin and trout may also be important depending on fish age and population location.

Management options

The single record of this species in Melbourne is insufficient basis to recommend a management plan for its conservation, beyond the recommendations of Skene *et al*. (2003). Further research is required into its distribution and basic biology. On the basis of its single record being below Dights falls, barrier management is likely to be an important management action for the Melbourne Water region.

Prototroctes maraena (Australian grayling, cucumber mullet, cucumber herring, Yarra herring)

Urban category B: transient. Many urban estuarine records, no freshwater records with DCI >1%

Recommended management:
1. Barrier removal and management
2. To expand into urban streams: In-catchment stormwater retention
3. Environmental flow management

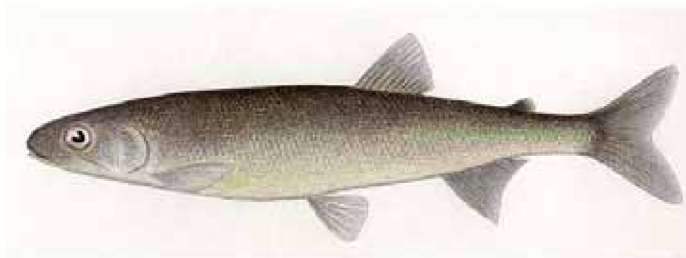


Photo: http://www.dpi.nsw.gov.au

General notes

Prototroctes maraena is considered a threatened species in Victoria under the Flora and Fauna Guarantee Act (1988) (DSE, 2007a). It was historically targeted as a recreational fishing species but this is no longer the case (Crook *et al.*, 2006).

Distribution and abundance

Prototroctes maraena is widespread throughout Victoria and Tasmania and also occurs from central NSW and eastern South Australia. There are numerous records of this species below barriers to migration in the Yarra and Maribyrnong Rivers, and following the construction of fish ladders on those rivers, there have been several records in non-urban reaches of both rivers (Figure A32). They are more common in streams flowing into Westernport. This distribution suggests that while barriers to migration are a primary limitation to its distribution, their presence in streams suffering from catchment urbanization is at best transient. Certainly, other than records from below barriers, this species has not been found in sites with >0% DCI (Figure A33).

Ecology

When in sufficient numbers, *P. maraena* form small shoals in the mid water column (Allen *et al.*, 2002).

Feeding strategy and diet

Prototroctes maraena are omnivores feeding on a mixed diet of freshwater zooplankton, benthic algae and aquatic insect larvae (Bishop & Bell, 1978; McDowall, 2006).

Reproduction

Prototroctes maraena spawn on gravel in the middle and lower reaches of a stream and the large number of eggs produced are non-adhesive and settle on the benthos before hatching. When larvae hatch they quickly swim to the surface where they are swept downstream to the ocean. They remain in the marine environment for about six months before migrating upstream to mature and reproduce (McDowall, 2006).

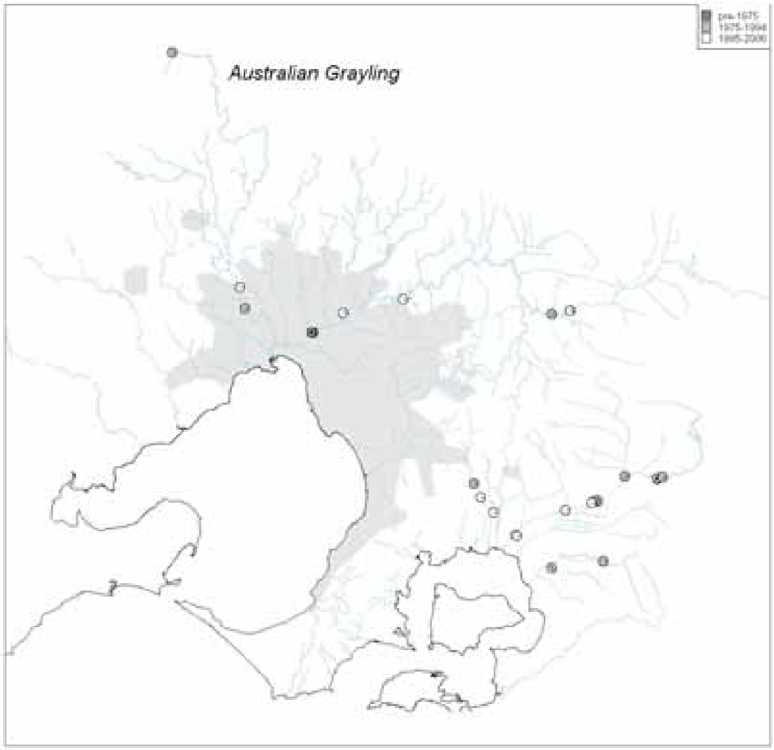


Figure A32. Records of *Prototroctes maraena*: represented by a pie-chart for each location indicating period of record. Other than a few records in the Yarra and Maribyrnong rivers, grayling are not found in urban streams (source: Atlas of Victorian Wildlife database).

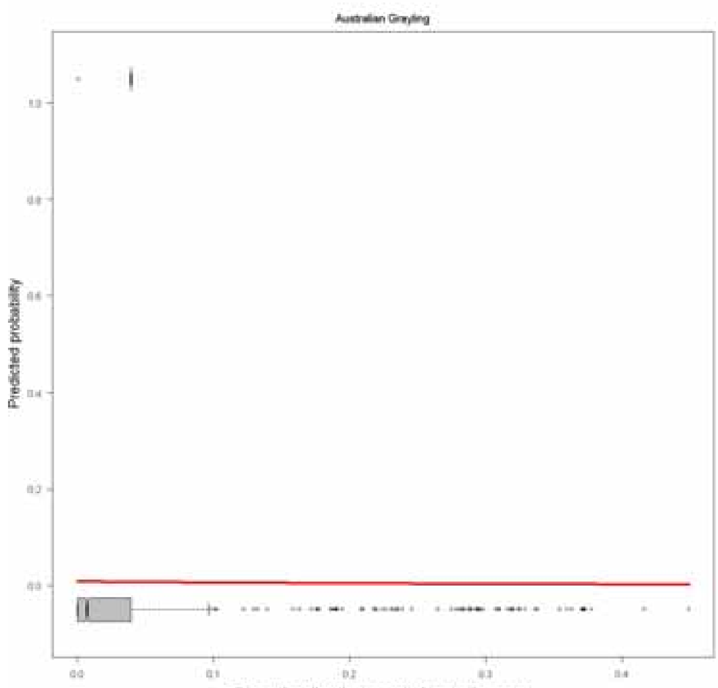


Figure A33. Presence and absence of *Prototroctes maraena*: (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The records with ~5% DCI was from below Dights Falls (Data from Melbourne Water fish database, restricted to records post-1994, in the Yarra catchment).

The timing of spawning seems to be variable between populations along the Victorian coastline with east Gippsland Grayling spawning during late summer but a population in the Barwon River spawning during early winter when water levels rise (Berra, 1982; O'Connor & Mahoney, 2004).

Habitat

Adult *P. maraena* usually reside in the water column of the middle reaches of sluggish rivers and creeks. They are diadromous and move between fresh and marine waters during larval and juvenile phases of their life cycle (Crook *et al.*, 2006).

Threats

It is possible that the poor condition of the urban lower Yarra River might itself be acting as a barrier to more substantial migration to non-urban reaches of the upper Yarra.

McDowall (2006) suggests a multitude of threats to populations of *P. maraena*. The ones particularly pertinent to streams around Melbourne are a) barriers such as dams and the subsequent flow regulation of streams leading to reproductive cycles being upset as mature fish cannot reach suitable spawning grounds and b) predation/competition by exotic fish. There has been no causative link between the presence of trout (and redfin) and a decline in *P. maraena* numbers but regardless, the stocking of trout in streams where *P. maraena* occur should not be encouraged and the presence of other exotics such as redfin should be considered deleterious until proven otherwise (Jackson & Koehn, 1988; McDowall, 2006).

Management options

Barrier management is the primary action for expansion of *P. maraena* populations. For this species to expand its distribution into metropolitan streams, and possibly increase population numbers upstream of the metropolitan area, catchment-wide reduction of DCI will be required.

Rural populations could be increased by reducing trout stocking to streams where *P. maraena* are present.

Measures to restore stream flow regimes in the Yarra and Maribyrnong rivers will likely help recruitment and migration of *P. maraena*.

Retropinna semoni (Australian Smelt)

Urban category C: urban sensitive.
A single occurrence >4% DCI

Recommended management:
1. For expansion into urban streams: In-catchment stormwater retention
2. Basic ecological research

Photo: http://www.nativefish.asn.au

General notes

Retropinna semoni is a small fish growing to a maximum of 100mm and are of neither commercial nor recreational value. In the past there was another recognized species, *Retropinna victoriae*, although recent research suggests that there are up to four species on mainland Australia and a fifth in Tasmania (Hammer *et al.*, 2007).

Distribution and abundance

Retropinna semoni is widespread throughout Victoria and abundant throughout its range. In the Melbourne Water region, it has been collected commonly in the Maribyrnong and Yarra rivers (Figure A34). It is more common in semi-rural and rural streams (Figure A34), and all of its metropolitan records are either from rivers with connection to non-urban reaches or near estuaries (Figure A35).

Ecology

Retropinna semoni are a freshwater species, however the Tasmanian species is thought to be diadromous (Hammer *et al.*, 2007) and Allen (2002) suggests they can tolerate brackish estuaries and inland salt lakes. Records in the Melbourne Water database show its presence in Melbourne estuaries (Fig. A35).

Feeding strategy and diet

Retropinna semoni feed mainly on Cladocera and calanoid copepods in the mid-water column and, when confined to lakes, they will track their preferred zooplankton prey over regular diurnal movements (Lieschke & Closs, 1999). *R. semoni* in flowing water will also regularly consume terrestrial and aquatic insects (http://www.mdbc.gov.au).

Reproduction

A study in southern Queensland suggests that *R. semoni* spawn over winter prior to high flow events that aid larval dispersal (Milton & Arthington, 1985). Water temperature seems to play an important role with more southern populations spawning over the spring-summer period when water temperatures are between 11 and 15 degrees (Tonkin, King & Robertson, 2008). Females lay small batches of eggs every 3-4 days that stick to aquatic vegetation. Eggs hatch after 9-10 days and larvae are <5mm long (Allen *et al.*, 2002).

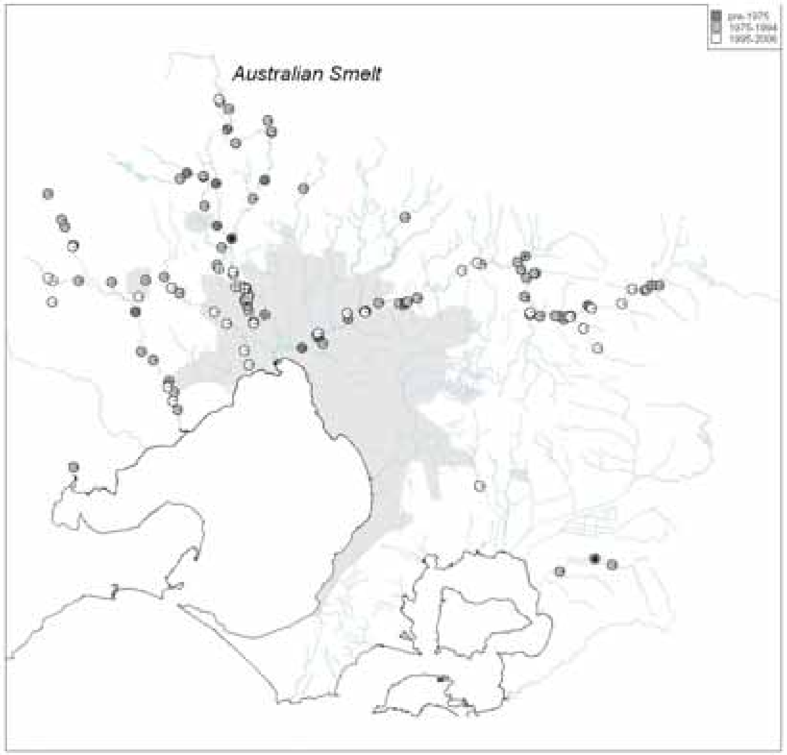


Figure A34. Records of *Retropinna semoni*: represented by a pie-chart for each location indicating period of record. In the metropolitan area, it is largely restricted to rivers with connection to non-urban reaches, (source: Melbourne Water fish database).

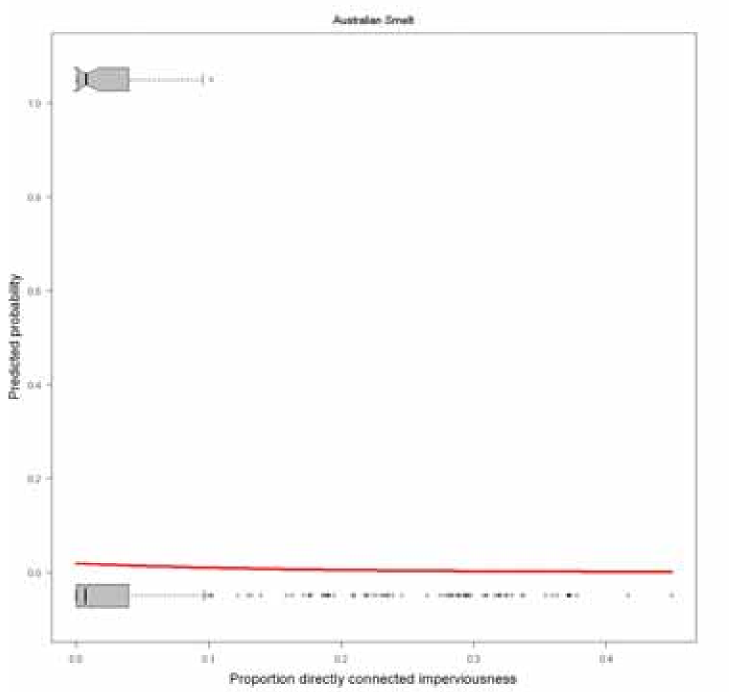


Figure A35. Presence and absence of *Retropinna semoni*: (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The predicted probability curve (red solid line) shows a greater probability of occurrence in less urban streams (Data from Melbourne Water fish database, restricted to records post-1994, in the Yarra catchment).

Habitat

Retropinna semoni are a pelagic (mid-water) species and prefer slower or still waters in the lower reaches of rivers, creeks and streams and are also commonly found in large numbers in billabongs, dams and lakes.

Threats

The absence of this species from metropolitan tributaries with DCI > 10%, suggest that its expansion will require catchment-wide reduction of DCI.

Melbourne estuarine records conflicts with some claims of this species being entirely freshwater (Hammer *et al.*, 2007), so further research is required into the life history of this species in Melbourne.

Management options

In-catchment stormwater retention and further research into life history are required for this species.

Philypnodon grandiceps (Flat-headed gudgeon)

Urban category A: urban tolerant

Recommended management:
1. In urban streams: no action identified;
2. Research into factors affecting distribution in urban streams

Photo: www.vic.waterwatch.org.au

General notes

Philypnodon grandiceps can be found in large numbers in freshwater and estuarine environments (Becker & Laurenson, 2007).

Distribution and abundance

Philypnodon grandiceps is common in rivers and estuaries of southeastern Australia. Its distribution ranges from the mouth of the Murray River in South Australia, through the Murray-Darling basin and in coastal streams of the mainland to central Queensland and also northern Tasmania (Allen *et al.*, 2002).

In Melbourne, *P. grandiceps* commonly occurs in northwestern streams with low to moderate DCI but is found in high DCI streams (Gardiners, Mullum Mullum and Dandenong creeks) in eastern catchments suggesting that it is urban tolerant (Figure A36; Figure A37). It does not occur in rural streams east and south of the city.

Ecology

Feeding strategy and diet

Philypnodon grandiceps consumes a wide range of prey including aquatic crustaceans, insect larvae, molluscs and fish, in both estuarine and freshwater environments with the relative abundance of prey items varying seasonally (Becker & Laurenson, 2007). The body shape and bottom-dwelling habit of *P. grandiceps* suggests they are ambush predators.

Reproduction

Philypnodon grandiceps spawn annually in the highly regulated Campaspe River (inland Victoria) when water temperatures being to rise (Humphries, Serafini & King, 2002). *P. grandiceps* is sensitive to high stream flows and thus may benefit from river regulation in some areas. They do not need to migrate to the estuary to spawn (Humphries *et al.*, 2002).

Habitat

Philypnodon grandiceps can be found living on the soft bottom and within aquatic vegetation of estuaries, slow flowing streams, lakes and reservoirs (Allen *et al.*, 2002). They are particularly abundant in the flooded margins of estuaries (Becker & Laurenson, 2008).

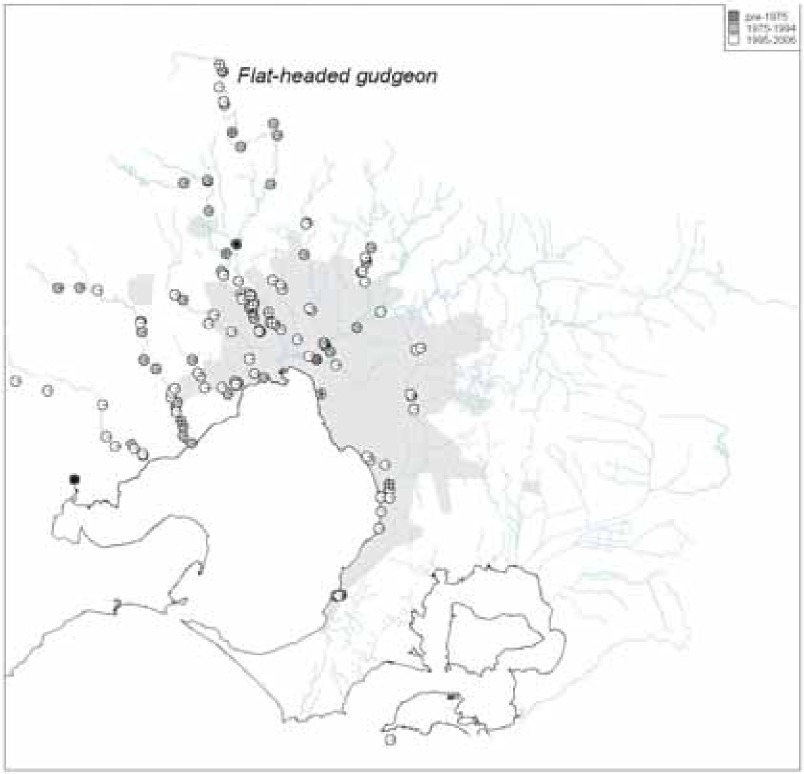


Figure A36. Records of *Philypnodon grandiceps*: represented by a pie-chart for each location indicating period of record. *Philypnodon grandiceps* is common to streams draining northwestern catchments and it also occurs in some eastern streams with high DCI (source: Melbourne Water fish database).

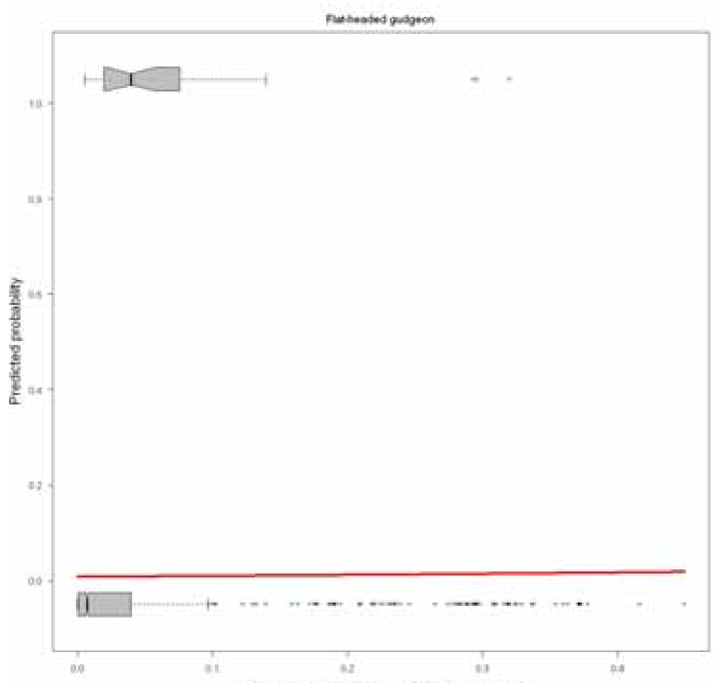


Figure A37. Presence and absence of *Philypnodon grandiceps*: (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI). The predicted probability curve (red solid line) shows a greater probability of occurrence in less urban streams (Data from Melbourne Water fish database, restricted to records post-1994, in the Yarra catchment).

Threats

The distribution of *P. grandiceps* suggests it is tolerant of conditions in urban streams, and the effects of urban stormwater might allow the colonization of streams that it would not normally occur in (i.e. eastern Melbourne streams). Further assessment of abundances across metropolitan streams and distributions within reaches would help to assess possible threats to this species.

Management options

We are unable to identify a management action to conserve or promote populations of this species in urban streams. The unusual distribution of this species presents an interesting research question as to the factors associated with urbanization that promote its occurrence in eastern metropolitan streams. Urban stormwater runoff raises salinity of the eastern streams and dilutes the salinity of the northwestern streams, resulting in the baseflow EC of metropolitan streams typically 350-400 µS/cm (Walsh *et al.*, 2001). It is possible that the salinizing effect of stormwater on Dandenong, Gardiners, and Mullum Mullum is promoting colonization of *P. grandiceps*.

Pseudaphritis urvilli (Tupong, sandy trout, freshwater flathead, sandies, congolli, sanding, sand whiting, blennie, sand trout, marble fish) congolli

Urban category B: transient in urban streams, but inhabit urban estuaries

Recommended management:
1. Barrier removal and management
2. To expand into urban streams: In-catchment stormwater retention
3. Ecological research

http://www2.mdbc.gov.au

General notes

Pseudaphritis urvilli grow to around 240mm but are neither commercially nor recreationally fished. Their conservation status is considered secure.

Distribution and abundance

Pseudaphritis urvilli occur across south-eastern Australia from western South Australia to central NSW and also Tasmania (Allen *et al.*, 2002; Hortle & White, 1980).

In the Melbourne Water region, *P. urvilli* occur most commonly in non-urban streams and estuaries. They are relatively common in urban estuaries, but records in urban streams are rare, and are usually near the head of the estuaries (Figure A38). The only non-estuarine records in the metropolitan area are: two records from below Dights Falls (~300 m upstream of the head of the estuary); two from (1995 and 2005) from Moonee Ponds Creek in the concrete channel ~1km upstream of estuary; and one from Kororoit Creek at Deer Park ~2 km upstream of estuary (1994 before the construction of Caroline Springs, when this reach of stream would have been at most ~3% DCI). There are many records from the Maribyrnong River for many km upstream of the estuary (but the catchment urban impacts there are minor—<2% DCI).

As females are thought to be migratory (see below), we class this species as transient through urban streams, but unlikely to be able to inhabit urban streams. As there are very few records from the Yarra catchment, an analysis of occurrence in relation to DCI was not possible.

Ecology

They are closely related to a clade of sub-antartic fish and so can tolerate extremely low temperatures (Eastman, 2006).

Feeding strategy and diet

Pseudaphritis urvilli is an ambush predator. It buries itself in soft sediment or loose detritus in estuaries or fresh waters, where they wait until suitable prey ventures close enough to mount an attack. Aquatic insects and crustaceans constitute the largest components of *P. urvilli* prey, as well as small fish, mollusks and worms (Hortle & White, 1980).

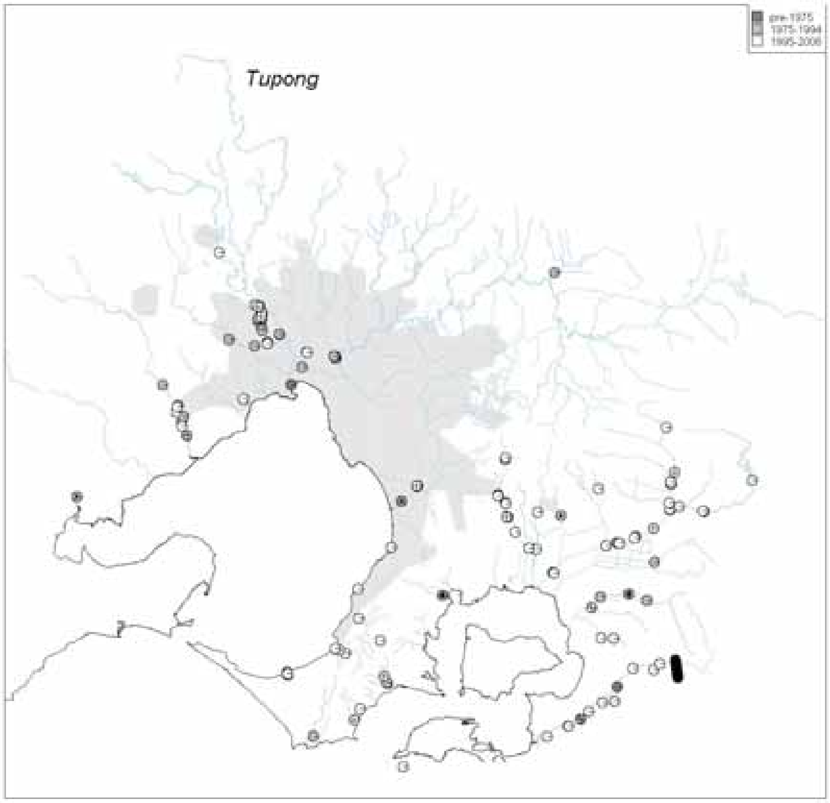


Figure A38. Records of *Pseudaphritis urvilli*: represented by a pie-chart for each location indicating period of record. *Pseudaphritis urvilli* is common to streams in Melbourne's rural southeast and some western streams with low DCI such as the Werribee and Maribyrnong rivers (source: Melbourne Water fish database).

Reproduction

Females *P. urvilli* are suspected to inhabit freshwater streams and migrate to estuaries to spawn when flows are high (Allen *et al.*, 2002). Larvae and males are estuarine or marine. Females can take up to five years to reach sexual maturity (Allen *et al.*, 2002).

Habitat

Tupong are osmoregulators and are able to withstand a wide range of salinities. They are most abundant in slow-flowing water among leaf litter and benthic debris such as under logs, overhanging banks or buried in sand (Allen *et al.*, 2002; Hortle & White, 1980).

Threats

DCI likely limits the distribution of *P. urvilli*. Loss of habitat in estuaries and barriers to migration will also prevent fish from dispersing to new habitat patches. As they are a bottom dwelling species, they may be sensitive to the poor sediment quality found in some of Melbourne's estuaries (Arundel & Barton, 2007).

Management options

In-catchment stormwater retention and barrier removal will benefit *P. urvilli*. Basic biological and ecological research into life history patterns such as migration timing and spawning location is needed to determine a management plan for *P. urvilli*.

Frogs

Overview

Frogs are sensitive to changes in environmental variables (Pechmann & Wilbur, 1994). Dissolved salts, heavy metals, pesticides and other complex compounds are readily absorbed through frogs' permeable skin and can quickly decimate populations (Tyler & Watson, 2000).

Despite the apparent obviousness that human impacts are the primary cause of amphibian species richness and distribution decline over the past 40 years, few studies have been able to separate the effects of anthropogenic causes from natural population fluctuations (Pechmann & Wilbur, 1994; Wake, 1991).

No frogs in the Melbourne Water area are solely dependent on in-stream habitat for part of their life-cycle. All are able to reproduce and survive in wetland habitats that may or may not be associated with streams. Some species, such as *Litoria raniformis*, or *Lymnodynastes* spp. might use stream ecosystems for larval habitat, but there has been little research on in-stream requirements and limitations for frog habitat.

Some excellent research has been conducted on the effects of urbanization on the ecology of frogs in the Melbourne Water region (e.g. Parris, 2006), demonstrating that a major threat resulting from urbanization is the fragmentation and isolation of habitat. However, Parris (2006) deliberately restricted her study to non-riparian ponds and wetlands, because she considered wetlands associated with streams to be more likely connected through riparian corridors. This assumption remains to be tested, and the question of the importance of riparian connectivity in the distribution and abundance of frogs in Melbourne remains an important research area to be explored. The extent to which frogs use in-stream habitats is also a knowledge gap.

In the absence of knowledge on the importance of in-stream habitat to frog populations in the Melbourne area, we assume that most of the management actions required to protect and increase frog populations in the Melbourne area will be associated with direct management of wetlands and ponds. Only riparian wetlands are likely to be directly influenced by in-stream hydrological and chemical condition, and even then, disturbances will likely be much less frequent than those experienced by in-stream biota, because flow disturbances affecting riparian wetlands will be limited to large flow events. We thus expect that in-catchment stormwater retention that we advocate for the protection of urban sensitive and intolerant stream fauna are likely to have indirect benefits to frog populations. However, the primary management priority for frogs remains direct management of their pond and wetland habitats.

We thus make some general management recommendations that are applicable to all frog species considered.

Management options for frogs

The conservation of existing frog habitats requires: maintenance of natural hydrology, protection of existing riparian vegetation from disturbance and revegetation of lost riparian forests around wetlands; fencing to prevent disturbance, and exclusion of predators such as cats and dogs; stormwater retention in the catchments of wetlands.

Reconnecting fragmented habitats with vegetated corridors will likely have benefits for frogs, and riparian corridors are an important landscape feature to achieve this in Melbourne. These works need to be combined with other methods of removing barriers to migration such as installing earthen lined tunnels under roads.

The strategic control of exotic pest species like *Gambusia* in permanent wetlands will be of benefit to all frogs with aquatic eggs. This needs to be combined with ensuring that permanent wetland habitats do not dry up and that the hydroperiod of ephemeral wetlands is not significantly altered.

Surveys of frogs are needed before any weed control works are performed along substantial lengths of waterways as they are sensitive to habitat disturbance by physical removal, and chemical herbicides.

The creation of artificial wetlands with suitable frog habitat is also a possible management option, although the potential conflicts between stormwater treatment and biodiversity protection need consideration.

Litoria raniformis (Growling grass frog, southern bell frog, green and golden frog, warty frog, warty bell frog, green and warty swamp frog)

Litoria ewingi (Brown tree frog, Ewing's tree frog, whistling tree frog)

L. raniformis **Urban category:** E_r, urban intolerant (in riparian wetlands), also occurs in non-riparian wetland

L. ewingi **Urban category:** A_r, urban tolerant (common in metropolitan riparian and non-riparian wetlands)

Recommended management:
1. Protection of existing habitat (riparian vegetation, fencing, hydrology, stormwater control)
2. Reconnection of fragmented habitats
3. Exotic predator control
4. creation of new wetland habitats

L. raniformis

L. ewingi

(images: http://frogs.org.au)

Distribution and abundance

The growling grass frog, *L. raniformis*, occurs in southern central NSW, eastern South Australia, northern Tasmania and Victoria, but its distribution has contracted since records began (www.environment.gov.au). In the Melbourne Water region its distribution is restricted to a small number of wetlands mainly outside the metropolitan area, including riparian wetlands on Merri Creek upstream of Craigieburn (Figure A39). None of the riparian wetlands that it occurs in are on reaches with >1% DCI.

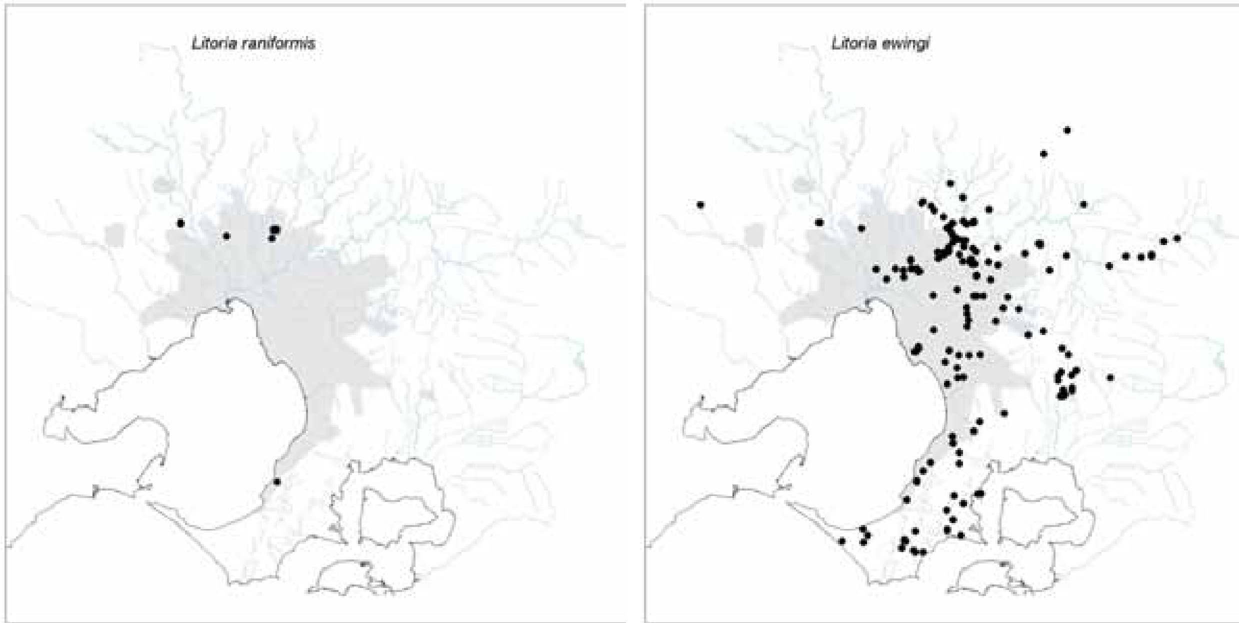


Figure A39. Records of *Litoria raniformis* and *Litoria ewingi* from Atlas of Victorian Wildlife database (earliest record in this dataset is 1993).

Litoria ewingi is distributed over much of south-eastern Australia including Tasmania and can be locally abundant (Barker, Grigg & Tyler, 1995; Lauck, Swain & Barmuta, 2005). In the Melbourne Water region, it occurs most commonly in wetlands of the eastern metropolitan area, both riparian and non-riparian (Figure A39).

Ecology

Feeding strategy and diet

Litoria are usually insectivorous feeding on both aquatic and terrestrial invertebrates but the larger *L. raniformis* will often prey on small vertebrates like lizards, snakes and fish and are sometimes cannibalistic (DEC, 2005).

L. raniformis is a sit-and-wait predator but *L. ewingi* will actively hunt and often jump to capture prey items (ARC, 2008).

The diet of *Litoria* spp. tadpoles is relatively poorly known, but similar to many species of tadpole, larvae of both species are suspected to browse or graze on benthic algae (filamentous green algae and diatoms) attached to aquatic macrophytes, submerged leaf litter or rocks (Gillespie, 2002).

Reproduction

L. raniformis breeding usually occurs after flood events in the warmer months of the year (November-March). They have the ability to breed in slow-flowing or still water and females spawn up to 4000 eggs that sink to the bottom (DEC, 2005).

L. ewingi breed predominantly in spring and summer in still water bodies of various sizes. They can lay up to 500 eggs which are attached to aquatic vegetation (Lauck *et al.*, 2005).

Both species have the potential to breed in either permanent or ephemeral water bodies but larval maturation times depend largely on environmental conditions and can range between 3 and 12 months for *L. raniformis* (DEC, 2005) and between <1 month and 7 months in *L. ewingi* (Lauck *et al.*, 2005).

Habitat

L. raniformis can be found in all freshwater wetland types and can readily disperse away from unsuitable habitat such as drying ephemeral ponds. They are often found in highly modified landscapes such as irrigated pastures, vegetated canals and urban areas (DEC, 2005; Wassens *et al.*, 2008).

L. ewingi is a tree dwelling species. *L. ewingi* is also restricted to freshwater habitats as even low salinities can adversely affect larval growth rates and survival (Chinathamby *et al.*, 2006)

Threats

The loss of connectivity between habitats caused by habitat fragmentation is significant to frogs (Parris, 2008; Wassens *et al.*, 2008). The ability of individual frogs to safely navigate a passage between fragmented habitat patches is greatly reduced in urban areas. This is due to the increased likelihood of encountering predators (domestic pets, foxes etc) and other potentially fatal barriers such as roads.

Urban impacts on water quality such as elevated, low dissolved oxygen, and altered pH and salinity also have the potential to reduce frog distributions within urban Melbourne (Chinathamby *et al.*, 2006). Sedimentation from urban stormwater runoff might also have impacts on *Litoria* spp. through the smothering of food sources such as benthic algae (Gillespie, 2002)

Wetland draining reduces available habitat for *Litoria* spp. This affects both larval and adult frogs and may be of particularly significant local concern if wetlands remain dry for several consecutive years.

Predation on native frog eggs by *Gambusia* is yet another example of how exotic species introduction can have a negative impact on native species. A study of a closely related species (*Litoria aurea*) showed that the presence of *Gambusia* can 1) reduce the amount of a larva that survive to maturity and 2) force adults to spawn in more ephemeral wetlands that are more risky for survival but generally contain fewer *Gambusia* (Hamer, Lane & Mahony, 2002).

Management options

See overview section on frogs.

Crinia signifera (Common froglet)

Urban category A_r: urban tolerant, common in metropolitan wetlands, not strongly associated with streams

Recommended management:
1. Minimize habitat (wetland) loss, maximize habitat connectivity
2. Exotic predator control
3. local in-catchment stormwater retention

http://frogs.org.au

General notes

Crinia signifera is not listed as a threatened species and, unlike many frog species, appears somewhat resilient to human disturbance (Baker & Lauck, 2006). Adults grow to ~35mm in length (Baker & Lauck, 2006; Barker *et al.*, 1995) and are highly variable in colour, markings and skin texture (Barker *et al.*, 1995).

Distribution and abundance

Crinia signifera is common throughout south-eastern Australia including Tasmania (Baker & Lauck, 2006). They occur commonly throughout Melbourne but are not strongly associated with streams or riparian wetlands (Figure A40).

Figure A40. Records of *Crinia signifera*: It is a common and widespread species in Melbourne but not strongly associated with urban streams or riparian wetlands (data from the spring 2007 Melbourne Water frog census).

Ecology

Feeding strategy and diet

Tadpoles of *C. signifera* have the ability to consume mosquito larvae (Mokany & Shine, 2002) and other small aquatic insects and they also graze on vegetative matter (Lane & Mahony, 2002). Adults forage in terrestrial leaf litter and mainly consume insects (Baker & Lauck, 2006).

Reproduction

Reproduction can occur in many habitats including ephemeral water bodies such as roadside ditches and even wheel ruts and footprints surrounding wetlands (Lane & Mahony, 2002; Mokany & Shine, 2002). *C. signifera* produce a large number of eggs for a small frog and this is assumed to offset the low survivorship of tadpoles (Lane & Mahony, 2002). The peak breeding season is during winter (Mokany & Shine, 2002) and tadpole metamorphosis is usually in early to mid-summer (Baker & Lauck, 2006).

Habitat

Crinia signifera adults are terrestrial and live on the ground amongst abscised leaf litter (Baker & Lauck, 2006), but eggs are laid in both permanent and ephemeral water bodies (Lane & Mahony, 2002). Tadpoles have been shown to tolerate considerable levels of habitat disturbance such as elevated nutrient concentrations (Hamer et al., 2004) and adults were more abundant at the edges of recently disturbed forest patches (Baker & Lauck, 2006).

Threats

Crinia signifera are a hardy species that can tolerate substantial disturbances to habitat as is associated with urban environments. Thus there appears to be few specific threats to *C. signifera*. However, there are some common themes that threaten frog assemblages (see overview section on frogs)

Management options

See overview section on frogs.

Limnodynastes peroni (or *peronii*) (Striped marsh frog, brown-striped frog)

Limnodynastes dumerilii (Pobblebonk frog; eastern banjo frog; southern bullfrog)

Limnodynastes tasmaniensis (Spotted marsh frog)

Urban category A_r: urban tolerant

Recommended management: Distribution surveys for adults and tadpoles; Minimise habitat loss; maximise habitat connectivity; exotic predator control.

Striped Marsh Frog

Pobblebonk Frog

Spotted Marsh Frog

http://frogs.org.au

General notes

Adults of all species are only strongly associated with streams and riparian wetlands during their respective breeding seasons.

Distribution and abundance

Limnodynastes spp. are common in south-eastern mainland Australia and the northern half of Tasmania. *L. tasmaniensis* has the broadest distribution of the three species on mainland Australia, recorded throughout the Murray-Darling basin and along the eastern seaboard (ARC, 2008; Schäuble, 2004); *L. dumerilii* is restricted to eastern South Australia, Victoria, coastal NSW and southeast Queensland (ARC, 2008); and *L. peroni* is found along the south-eastern coast of mainland Australia from south-western South Australia to northern Queensland but its distribution does not extend to the Cape York Peninsula (ARC, 2008; Schäuble, 2004). Schäuble (2004) however, suggested that *L. peroni* is found across a larger (and drier) range than *L. tasmaniensis*.

All three species of *Limnodynastes* occur frequently around Melbourne (Figure A41, 42, 43). Distributional studies have been conducted for *Limnodynastes* spp. in the Maribyrnong (Brown & Smith, 2007), Werribee (Smith & Brown, 2005) and Mornington Peninsula (Aboltins & Organ, 2007) catchments.

Ecology

Feeding strategy and diet

Literature on the diet of *Limnodynastes* spp. is scarce but like other frogs with similar life strategies, tadpoles are thought to graze benthic algae and other vegetable matter and adults consume terrestrial invertebrates.

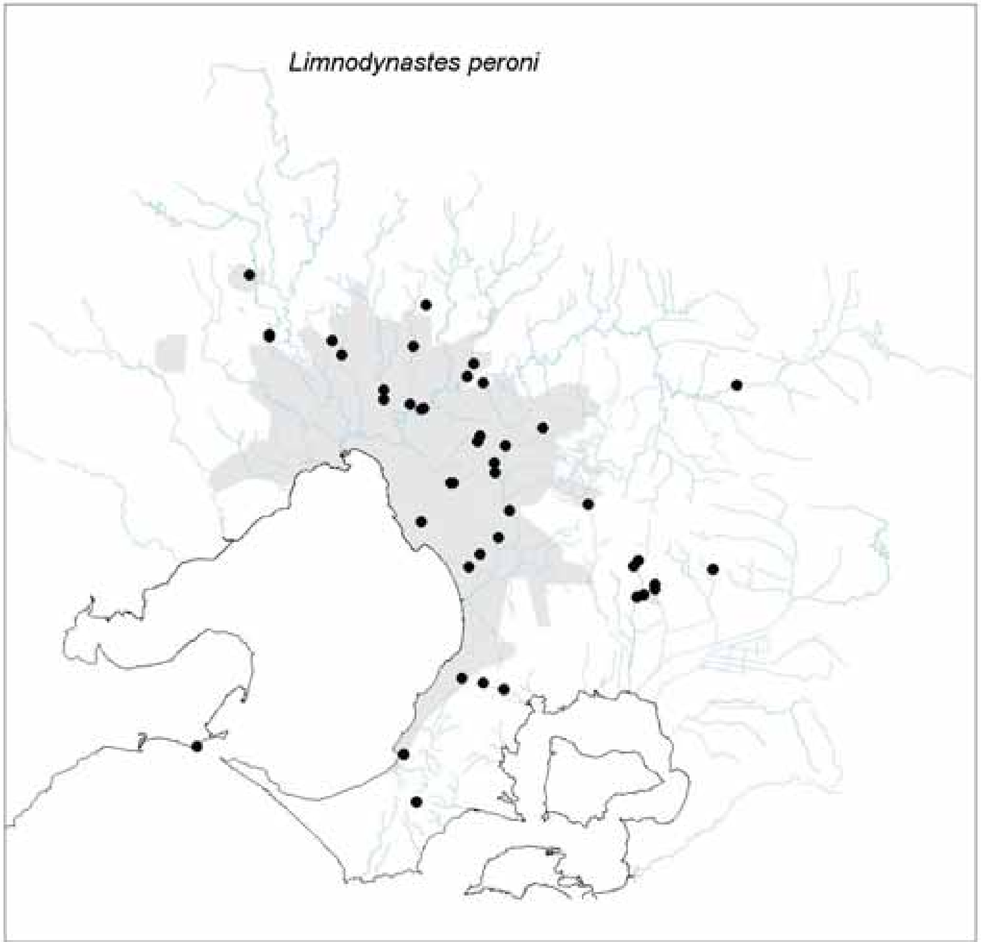


Figure A41. Distribution of *Limnodynastes peroni* in the Melbourne Water region (data from the Melbourne Water frog census: 2004-2007).

Reproduction

Limnodynastes spp. are very similar in their breeding characteristics with peak breeding activity during the warmer months between late spring and early autumn but with some seasonal plasticity (Barker *et al.*, 1995). They all produce foamy masses of eggs that raft on the surface of water bodies such as wetlands, ponds and slow flowing streams (Aboltins & Organ, 2007; Brown & Smith, 2007; Smith & Brown, 2005). Tadpole development is dependent on water temperature with tadpoles in low water temperatures developing slower (Barker *et al.*, 1995).

Habitat

Adult *L. tasmaniensis* were equally associated with a variety of microhabitats in a rural setting including grass, emergent rushes and sedges (Healey, Thompson & Robertson, 1997). It can colonize ephemeral or permanent water bodies including those in urban environments (Brown & Smith, 2007; Smith & Brown, 2005). *L. peroni* can reportedly tolerate slightly dryer conditions than *L. tasmaniensis* (Schäuble, 2004) so can presumably select from a slightly larger range of microhabitats. All three species are tolerant of poor water quality.

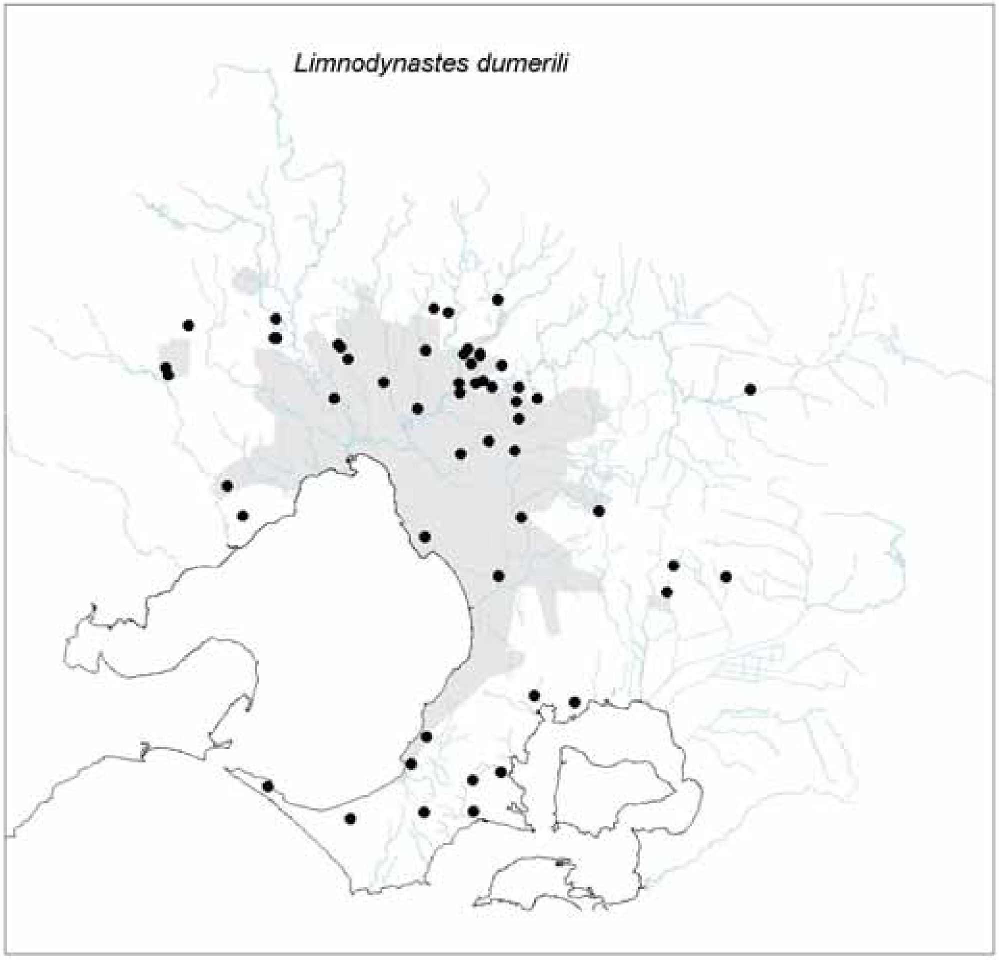


Figure A42. Distribution of *Limnodynastes dumerilii* in the Melbourne Water region (data from the Melbourne Water frog census: 2004-2007).

When breeding, *Limnodynastes* are mainly associated with streams and wetlands with intact riparian vegetation (Barker *et al.*, 1995) but can be found in wooded (forests, shrublands etc.) and open (grassland) areas around Melbourne when not breeding (Aboltins & Organ, 2007; Brown & Smith, 2007; Smith & Brown, 2005) and some *Limnodynastes* are adapted to burrow to escape sub-optimal conditions (Brown & Smith, 2007; Smith & Brown, 2005).

Threats

Several reports to Melbourne Water list and discuss threats to *Limnodynastes* spp. (Aboltins & Organ, 2007; Brown & Smith, 2007; Smith & Brown, 2005; Tyler & Watson, 2000). An overview of threats identified in these reports is outlined below.

Habitat loss through wetland drainage and other associated works has the potential to reduce *Limnodynastes* abundance. Changes to water quality and hydrology associated with urbanization may also negatively impact on frog populations and this may also increase the infection rate of the introduced chytrid fungus which is listed under the Environment Protection and Biodiversity Conservation Act (1999) (DEH, 2007).

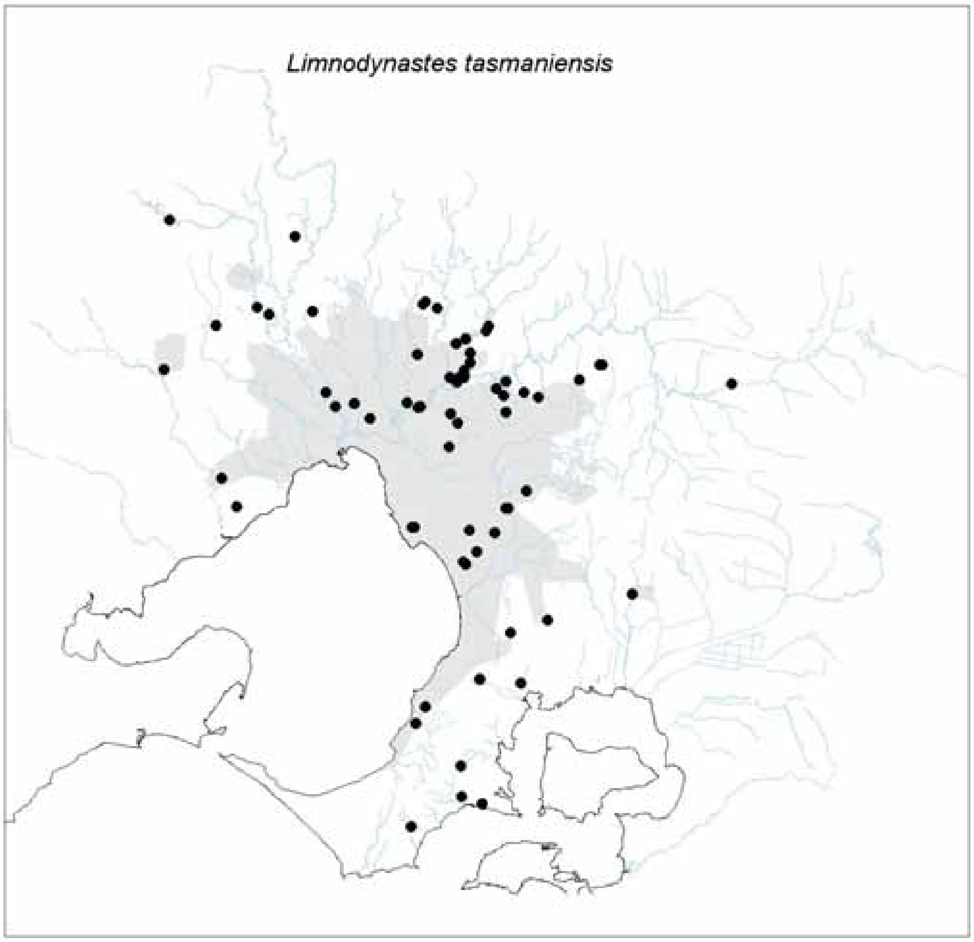


Figure A43. Distribution of *Limnodynastes tasmaniensis* in the Melbourne Water region (data from the Melbourne Water frog census: 2004-2007).

Predation impacts on frog eggs and tadpoles by introduced predators are now well documented with several authors finding that *Gambusia holbrooki* can reduce tadpole survival (Komak & Crossland, 2000; Lane & Mahony, 2002). As the abundance of exotic predators is high in urban streams, frog numbers may be suffering as a result. Feral and domestic cats are also likely to impact frog populations through predation.

Habitat fragmentation and barriers to dispersal (e.g. roads) may prevent individuals from dispersing to suitable habitats. As *Limnodynastes* are mainly terrestrial as adults, and eggs are usually laid in confined water bodies (ponds, wetlands etc.), in-stream barriers are unlikely to hinder dispersal.

Management options

See overview section on frogs.

Reptiles

Chelodina longicollis (Eastern long-necked turtle, eastern snake-necked turtle, common snake-necked turtle, eastern long neck tortoise)

Urban category A: urban tolerant

Recommended management:
1. Reduce habitat fragmentation
2. Migration barrier management
3. Distributional research

Photo: www.anbg.gov.au

General notes

Chelodina longicollis is not listed as a threatened species (DSE, 2007a).

Distribution and abundance

Chelodina longicollis is abundant in the eastern states of mainland Australia but its range does not extend to Tasmania. In the Melbourne Water region, it is recorded from degraded urban streams as well as rural streams (Figure A44). The lack of absence data makes formal statistical analysis of *C. longicollis* distributions against DCI impossible. The distribution of records in Melbourne Water's faunal database suggests that *C. longicollis* has been collected less frequently in the last decade than in the previous decade, but without records of unsuccessful capture attempts or of sampling methods, it is impossible to assess if this is a real trend or a sampling artifact.

Ecology

C. longicollis is the largest freshwater turtle in Australia. They are well adapted to Australia's variable climate and can spend a considerable amount of time in terrestrial aestivation if necessary (Roe & Georges, 2006).

Feeding strategy and diet

C. longicollis is an opportunistic carnivore feeding on small fish, yabbies, shrimp, larger aquatic insects and even zooplankton like Cladocera where fish are not abundant. There is little difference in the diet of mature and juvenile turtles (Chessman, 1984).

Reproduction

Females nest in spring and early summer and there is evidence to suggest that females can have multiple clutches in years with favorable conditions. Up to 13 eggs can be laid in any one clutch, and males and females reach sexual maturity at variable ages (Kennett & Georges, 1990). Nesting sites can be vulnerable to terrestrial predation from foxes, feral pigs, some birds and are also affected by human activity.

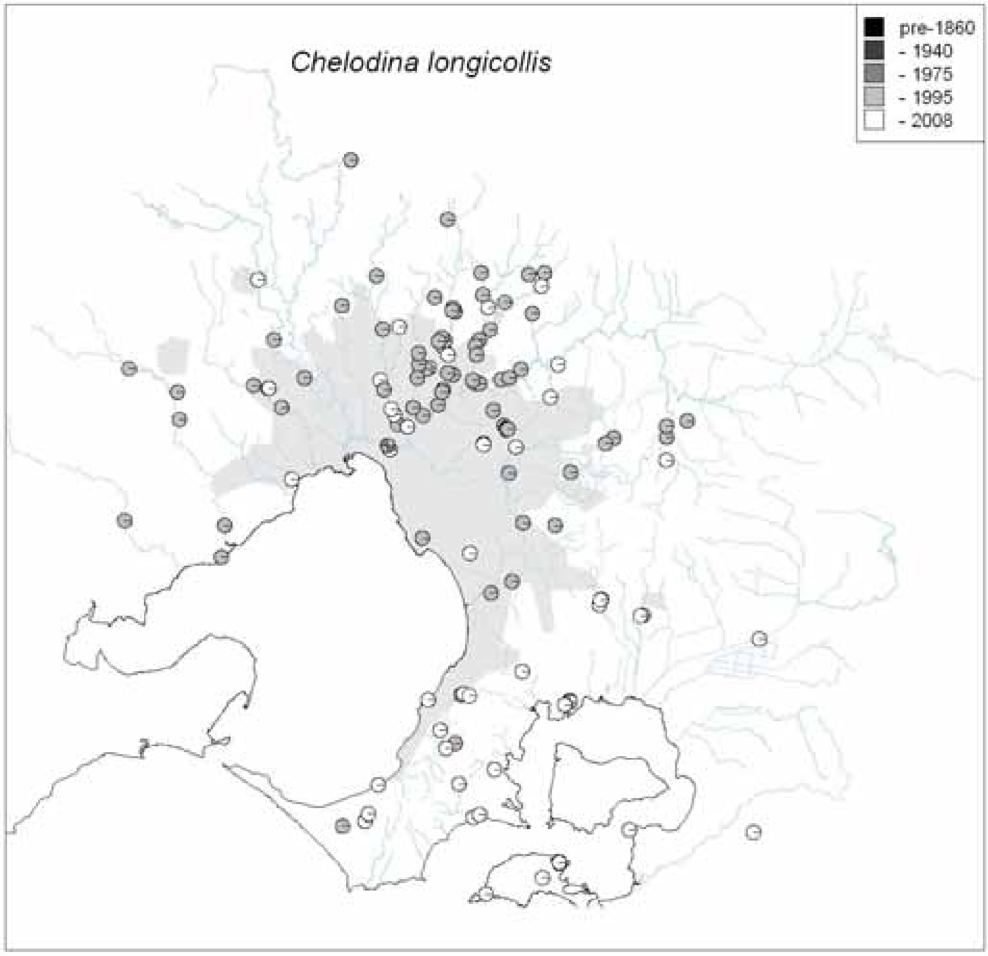


Figure A44. Records of *Chelodina longicollis*: represented by a pie-chart for each location indicating period of record. (source: Atlas of Victorian Wildlife database).

Habitat

C. longicollis is found in both permanent and ephemeral freshwater wetlands. They readily move between suitable habitat and several studies have shown that their movement patterns are very direct and frequent (Roe & Georges, 2006; Ryan & Burgin, 2007).

Threats

Threats to *C. longicollis* include the loss of suitable habitat through wetland draining and changing climate patterns. In the urban environment, movement of turtles between suitable habitats constitutes a major risk due to necessarily navigating roads, domestic pets and physical obstacles impeding migration.

Management options

As *C. longicollis* is highly mobile, fragmented habitats (streams and wetlands) need to identified and be reconnected with riparian corridors. Vegetated corridors are preferable, however, passages like earthen lined under road tunnels (such as those used for frogs) should also be considered. Further study of temporal and spatial distribution of *C. longicollis* would allow a more informed management strategy.

Egernia coventryi (Swamp skink)

Urban category D_r: urban intolerant

Recommended management:
1. Re-establishment in urban areas unlikely
2. Protection, restoration and connection of existing habitats
3. Exotic predator control

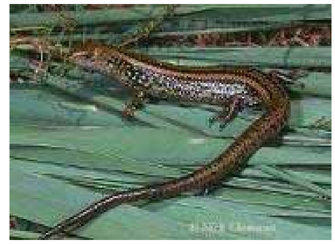


Photo: Clemann (2006)

General notes

Egernia coventryi is listed as vulnerable under the FFG Act 1988 (DSE, 2007a). It is one of five species in this genus, two of which are listed as critically endangered.

Distribution and abundance

Egernia coventryi are found in swampy regions of coastal south eastern Australia but populations persist as far inland as the Grampians in western Victoria. Abundance has been in decline since European settlement to the extent that *E. coventryi* now has a very patchy distribution and is mainly limited to National Parks and other protected reserves (Clemann, 2006).

Disjunct populations in densely-vegetated freshwater swamps, wet heaths, sedgelands and along watercourses, across the Melbourne Water region, but only two populations are known from the metropolitan area: the Liverpool Road retarding Basin on upper Dandenong Creek, and a nearby roadside ditch on Swansea Road (Clemann, 2006). Neither of these sites is highly urban (DCI of Dandenong Creek = 1.2% at Liverpool Rd). Clemann (2006) speculated that undetected populations of *E. coventryi* are likely to exist in the Melbourne Water region, because they are so cryptic. However, the complete absence of records in the more urbanized metropolitan area compared to the frequent records outside (Figure A45), suggest that this species is intolerant of urban conditions. As it is not an aquatic animal, terrestrial impacts of urbanization are probably at least as important as the impacts of stormwater runoff.

Ecology

Egernia coventryi has the ability to drop its tail when attacked by predators such as birds or foxes but also when avoiding other lizards.

Feeding strategy and diet

Egernia coventryi are omnivorous with adults feeding on a diet comprised mainly of fruits and seeds and juveniles preferring spiders, terrestrial and aquatic insects and crustaceans. The tails of same-species competitors were found in some adult stomachs suggesting that there is some overlap in the diet of the age classes (Clemann, Chapple & Wainer, 2004).

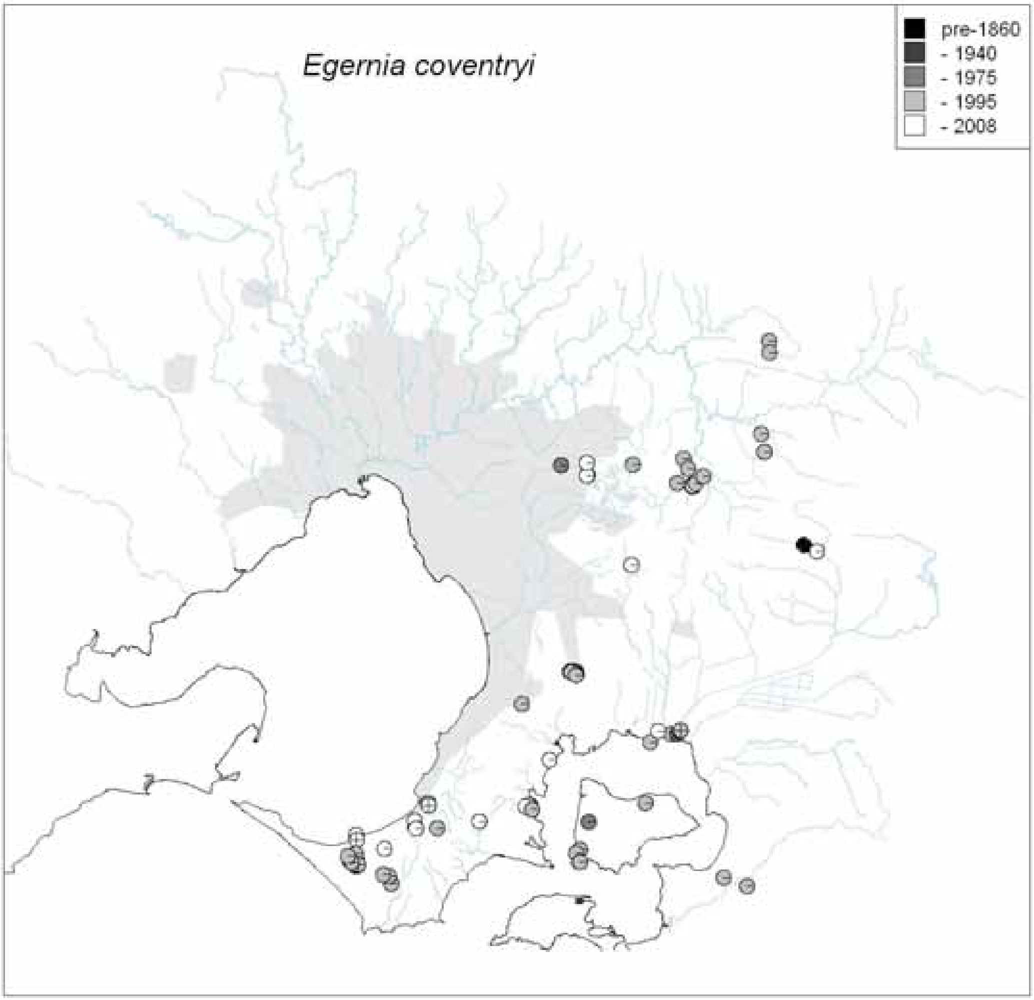


Figure A45. Records of *Egernia coventryi*: represented by a pie-chart for each location indicating period of record. *Egernia coventryi* are scattered across the eastern Melbourne and generally recorded more frequently outside the urban fringe, particularly along the Mornington peninsula (source: Atlas of Victorian Wildlife database).

Reproduction

Both males and females of *E. coventryi* mature at around 72mm. Skinks mate at the beginning of warmer weather (generally around October) and females give birth to between one and four live young (Chapple, 2003). Clemann *et al.* (2004) also found evidence to suggest that not all mature viable females reproduce annually in the wild.

Habitat

Egernia coventryi is an obligate inhabitant of densely vegetated freshwater wetlands, but has also been recorded in saltmarsh ecosystems (Clemann, 2006; Clemann *et al.*, 2004). As mentioned above it has been recorded in dense urban regions. They have a small home range ($10m^2$) that they will aggressively defend from other skinks wandering into their territory (Clemann *et al.*, 2004). *E. coventryi* have also been known to utilize crayfish burrows as shelter. Clemann (2006) has identified several areas within Melbourne where *E. coventryi* are suspected to contain suitable habitat but populations are not yet known (Montrose, Kilsyth and the western slopes of the Dandenong Ranges).

Threats

Clemann (2006) considered a wide range of threats to *E. coventryi*, primarily habitat loss, fragmentation, and degradation. All of these problems are most pronounced in the metropolitan area. A major urban degrader of habitat is the morphological, hydrological and chemical disturbances to water bodies associated with stormwater runoff and the infrastructure built to deal with it. It is unlikely that populations of *E. coventryi* could be re-established in the metropolitan area without reduction of DCI to near zero, as is required for many aquatic species. However, the return of habitat and connections between habitat patches in the metropolitan matrix is possibly even a greater challenge.

Management options

The most effective management for *E. coventryi* will be the protection of existing habitat, and creation and connection of new habitat in non-urban and urban-fringe areas, such as the Liverpool Road retarding basin. Management of human access and predators at Liverpool Road and establishment of vegetated corridors upstream are a priority for this remnant urban-fringe population.

Management actions intended to extend the range of this species into urban Melbourne are likely to be unsuccessful, particularly before DCI has been reduced to near-zero.

Birds

Anas superciliosa (Pacific Black Duck), *Anas gracilis* (Grey Teal)

Anas castanea (Chestnut Teal), *Chenonetta jubata* (Australian Wood Duck)

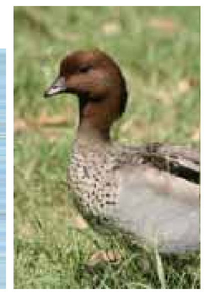
Urban category B_r: transient.
Abundant through the metropolitan area under current management regime

Recommended management:
1. Provision and protection of wetlands and their riparian margins
2. Exotic predator control.


Pacific Black Duck


Grey Teal


Chestnut Teal


Wood duck

Photos: http://photogallery.canberrabirds.org.au

General notes

Native ducks have been commonly targeted by hunters for many years and in the mid 1980s, *A. superciliosa*, *A. gracilis*, and *C. jubata* constituted ~80% of the total duck catch (Braithwaite *et al.*, 1986). All four species are listed as game birds; however, none are threatened species (DSE, 2007a, 2007b).

The reduction in rainfall over the past decade has lead to a large decline in native duck populations, resulting in the 2008 duck hunting season being closed (DSE, 2007b). The 2007 game bird index showed 68,500 birds against the 25 year average of 187,500 (Government of Victoria, 2007). The reduction in suitable habitat resulting from drought conditions has been the primary cause of the decline in duck abundance.

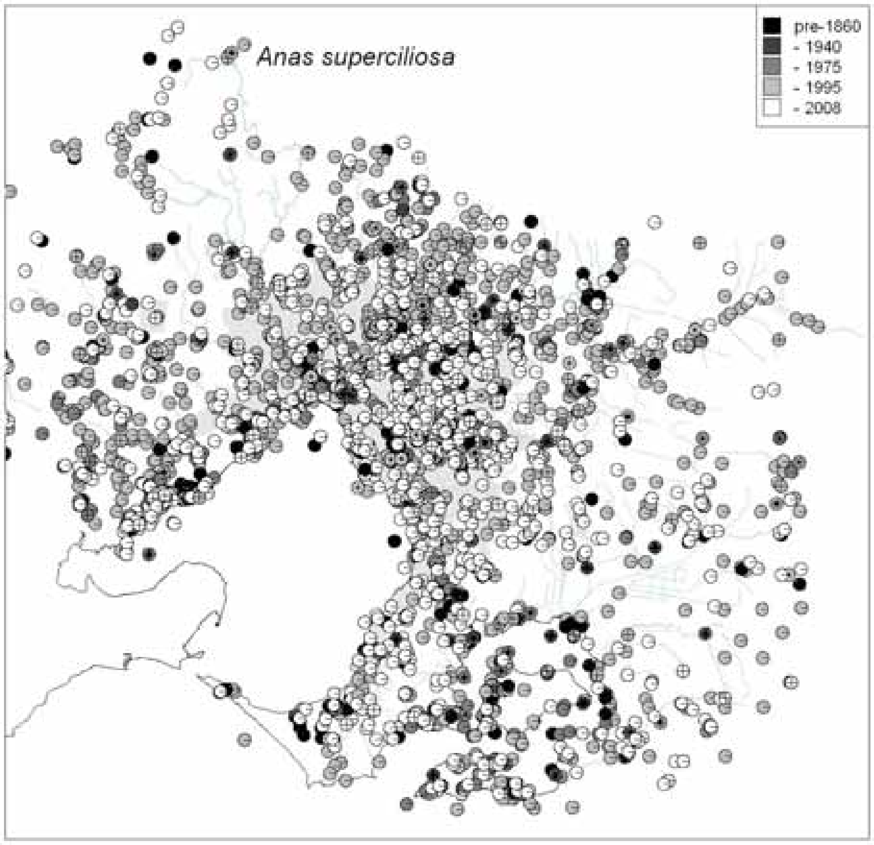


Figure A46. Records of *Anas superciliosa*: represented by a pie-chart for each location indicating period of record (source: Atlas of Victorian Wildlife database).

Distribution and abundance

These ducks are reliant on water and are generally found in all but the most arid parts of inland Australia (Flegg, 2002; Simpson & Day, 1993). *Anas superciliosa*, *A. gracilis*, and *C. jubata* are found over most of (non-arid) continental Australia and *A. castanea* has the most limited distribution and is restricted to S.E. Queensland, NSW, Victoria, Tasmania and coastal parts of South Australia and Western Australia (Flegg, 2002; Simpson & Day, 1993). All species can be locally common but only *A. gracilis* flocks in substantial numbers (Flegg, 2002; Simpson & Day, 1993).

The distribution and abundance of these ducks around Melbourne suggest that they are urban tolerant animals or at least are a transient species with high abundances throughout Melbourne (Figure A46 -49). This is helped by many ducks becoming tame and taking food from humans in places like botanical gardens.

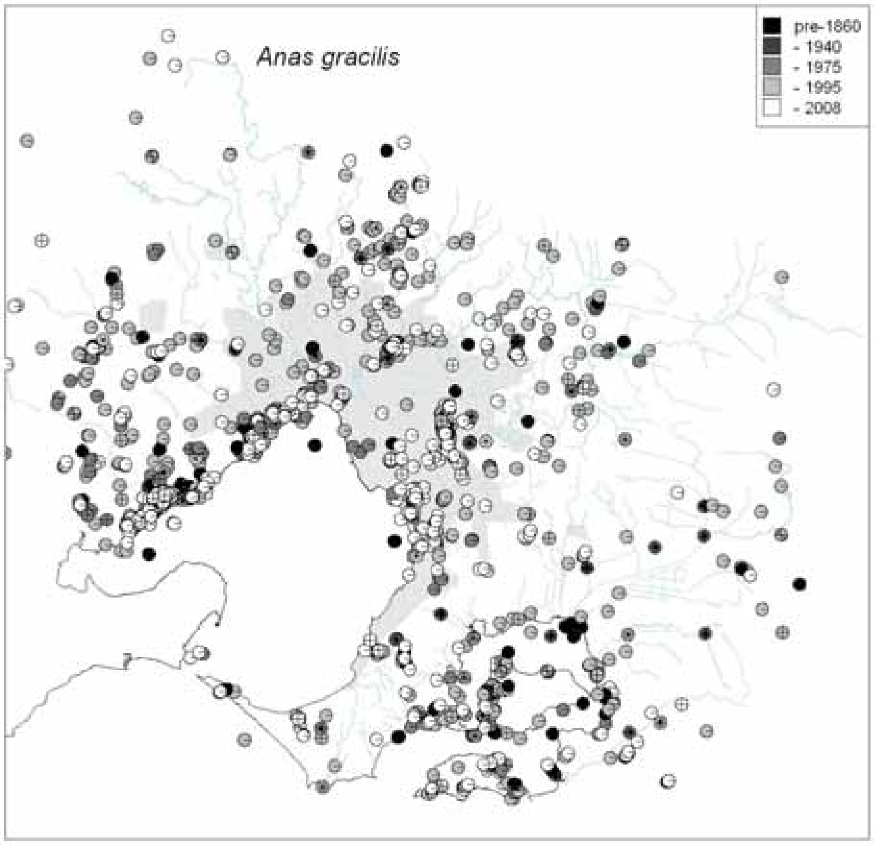


Figure A47. Records of *Anas gracilis*: represented by a pie-chart for each location indicating period of record. (source: Atlas of Victorian Wildlife database).

Ecology

Most ducks have highly erratic movement patterns and can quickly disperse from drying habitats to more suitable locations, often over vast distances (Chambers & Loyn, 2006; Roshier *et al.*, 2001).

Feeding strategy and diet

These ducks feed with several different methods in aquatic habitats. They can upend their bodies while floating in shallow water to feed on submerged vegetation; graze on surface foodstuffs; or employ a form of filter feeding called 'dabbling' when wading through shallow water and saturated grasslands, or when surface prey items are abundant (Hamilton *et al.*, 2005).

Anas superciliosa forages in aquatic and terrestrial habitats for seeds, leaves and invertebrates, but plants are by far the most preferred food item making up around 85% of the diet and invertebrates the remaining 15% (Goodrick, 1979).

The diet of *A. gracilis* has similar ratios of plant and animal consumption but their diet was almost fully comprised of aquatically derived food items (Goodrick, 1979).

Anas castaena has a similar dependency on aquatic foodstuffs as *A. gracilis*, but a higher proportion of vegetable matter was found in the guts of birds living on the Gippsland Lakes. 74% of their diet was plant matter with the other 26% comprised of aquatic insects, crustaceans and molluscs (Norman & Mumford, 1982).

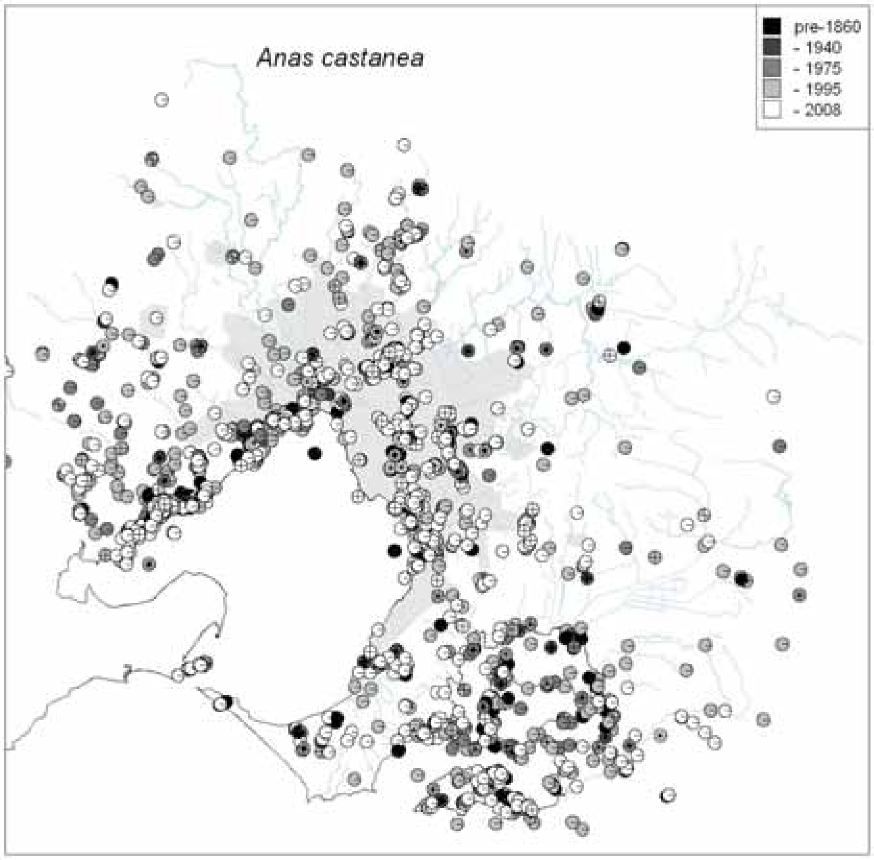


Figure A48. Records of *Anas castanea*: represented by a pie-chart for each location indicating period of record (source: Atlas of Victorian Wildlife database).

Reproduction

Reproduction in *Anas* spp. is generally, but not necessarily linked to rising water levels (Norman & Brown, 1988). *Anas superciliosa* and *A. gracilis* breed near permanent or semi-permanent freshwater bodies but *A. castanea* breeds in more saline waters (Norman & Brown, 1988).

All these ducks nest in hollows of tree branches and trunks that have fallen near water and they line the hollows with grass and feathers (Australian Museum, 2005c). Birds will also make nests from grass and feathers near the waterline and will defend the nest if a threat is perceived with the *A. castaena* feigning injury in order to distract predators (Australian Museum, 2005c).

Anas spp. generally lay one egg per day until around 10 eggs are being incubated. The main breeding season is between September and December and incubation takes an average of around 25 days and chicks fledge 25-30 days after hatching (Norman, 1982). Egg losses from the nest are high due to predation by other birds (coots and ravens) and foxes and breakages are also common (Norman, 1982).

Habitat

Anas spp. live in well vegetated running and standing waters including rivers, creeks, swamps, estuaries, mudflats and saltmarshes. *Anas superciliosa*, *A. gracilis* and *C. jubata* prefer freshwaters but *A. castanea* favour marine habitats (Simpson and Day, 1993; Flegg, 2002).

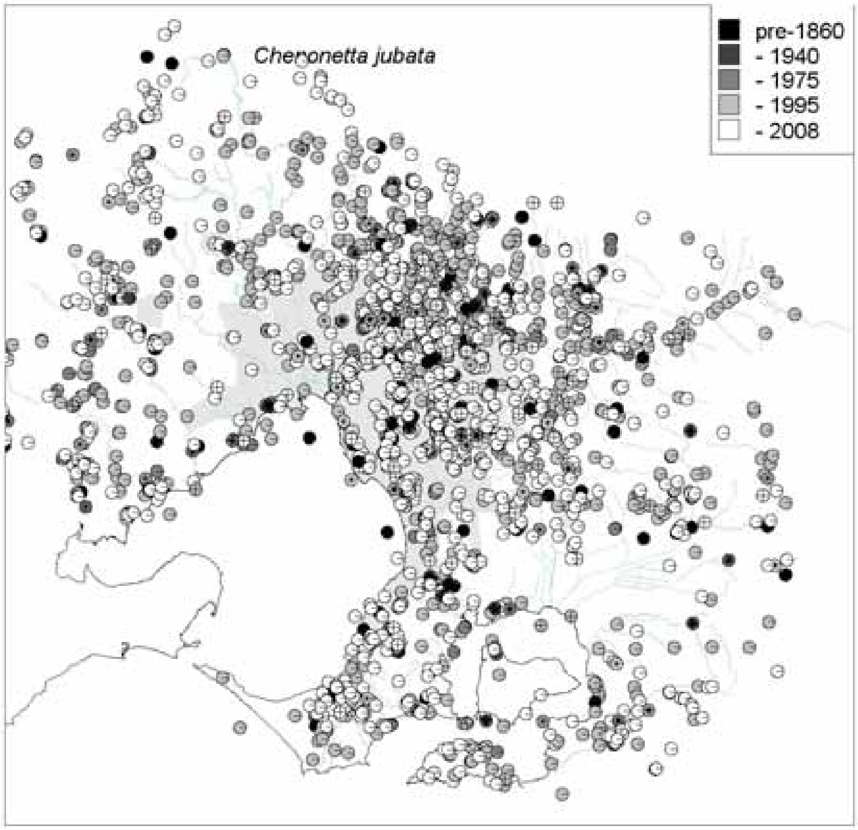


Figure A49. Records of *Chenonetta jubata*: represented by a pie-chart for each location indicating period of record. (source: Atlas of Victorian Wildlife database).

Threats

It is likely that the urban area of Melbourne acts more as a seasonal refuge (from drought or from hunting) than as a threat to these duck species. Once within the urban area, threats such as predation might have some influence on population numbers, but are unlikely to be a major threat to populations.

More broadly, outside the metropolitan area, predation of adults, juveniles and eggs by foxes and habitat loss through broad scale natural (climate change) and anthropogenic causes (river regulation and flood mitigation) are the major threats for *Anas* spp. (Crome, 1988).

Management options

Provision and protection of wetlands and their riparian vegetation, including control of exotic predators, is likely sufficient for the protection of populations of these duck species in the metropolitan area. It is however possible that large numbers of these and other bird species using urban streams could have negative impacts on the ecological health of streams (through nutrient inputs: see general discussion).

Tadorna tadornoides (Australian Shelduck)

Urban category C_r: Urban sensitive
Less frequently observed in urban areas

Recommended management:
1. Provision and protection of wetlands and their riparian margins
2. Exotic predator control.
3. Ecological/distributional research (incl. monitoring of health in treatment wetlands)

Photo: http://www.oiseaux.net

General notes

Tadorna tadornoides are not targeted as a hunting species as the flesh is not considered of edible quality. *T. tadornoides* are not a threatened species (DSE, 2007a).

Distribution and abundance

Tadorna tadornoides is widespread and common throughout southern Australia with separate populations in eastern and Western Australia (Flegg, 2002; Simpson & Day, 1993).

Records show that *T. tadornoides* occurs frequently across greater Melbourne but records in metropolitan areas are less frequent (Figure A50).

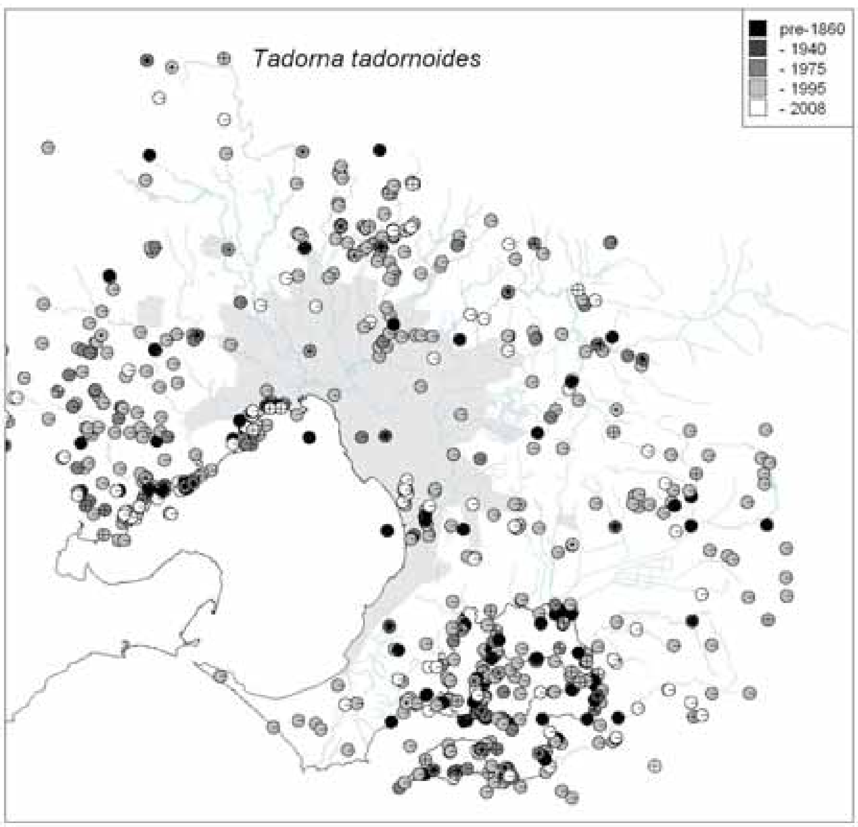


Figure A50. Records of *Tadorna tadornoides*: represented by a pie-chart for each location indicating period of record. All *Tadorna tadornoides* occurs frequently across outer regions of Melbourne but appears to avoid densely urbanized areas (source: Atlas of Victorian Wildlife database).

Ecology

Feeding strategy and diet

Tadorna tadornoides is omnivorous, eating small terrestrial invertebrates such as worms, gastropods and insects and also terrestrial vegetation. Aquatic invertebrates and algae are also components of their diet when foraging in shallow water.

Reproduction

Tadorna tadornoides usually breeds between July and December each year and lays clutches of 5-14 eggs. Chicks are self-sufficient at ~6 weeks old, and are mature after ≥2 years. Breeding pairs remain together for life. They nest in hollow trees, exposed undercut banks or other deep depressions such as unused rabbit burrows (http://www.oiseaux.net).

Habitat

Tadorna tadornoides inhabits open forests, pasture, farm dams, freshwater lakes and also brackish wetlands and can be found in considerably large congregations after the breeding season ends (Flegg, 2002; Simpson & Day, 1993).

Threats

Habitat loss, predation by domestic pets and foxes and loss of breeding and nesting sites are all threats to local populations of Australian Shelducks. *T. tadornoides* may also be susceptible to heavy metal build-up in some tissues (Bacher & Norman, 1984). There less frequent occurrence in urban areas suggests that they might be more sensitive to these threats than other duck species.

Management options

As for other duck species, *T. tadornoides* will likely benefit from the provision and protection of wetlands and their riparian vegetation, including control of exotic predators. Further research is warranted as to the causes of reduced occurrences in urban areas. The health of these species should be monitored if they are attracted to stormwater treatment wetlands, where toxicant accumulation might become a problem.

Ardea pacifica (White-necked heron or pacific heron)

Egretta novaehollandiae (White-faced heron)

Urban category A_r: urban tolerant
Widespread through the metropolitan area, not strongly dependent on streams

Recommended management:
1. No management identified in urban streams
2. Monitor for potential toxicant accumulation in stormwater treatment wetlands

White-necked Heron (*A. pacifica*)

White-faced Heron (*E. novaehollandiae*)

Photos: http://www.graemechapman.com.au; http://en.wikipedia.org

General notes

Neither *A. pacifica* nor *E. novaehollandiae* are listed as threatened.

Distribution and abundance

Both species are found Australia wide and are particularly abundant near and in shallow, permanent and temporary freshwater wetlands including those used for rice production (Richardson & Taylor, 2003).

Ardea pacifica and *E. novaehollandiae* are common throughout Melbourne (Figure A51). We were unable to find records of breeding in the metropolitan area, but their widespread occurrence throughout the metropolitan areas (Figure A51) suggests resident populations. We thus class these species as urban tolerant. While they can use urban streams for feeding, they are not likely to be solely dependent on them, being able to also use wetlands.

Ecology

Egrets and herons being high in the food chain are susceptible to bioaccumulation effects of pesticides (DDE and DDT) and also heavy metals (mercury, cadmium and selenium) (Henny, 2008).

Feeding strategy and diet

The feeding strategies and diets of *Ardea* and *Egretta* spp. are similar, feeding on fish, frogs and tadpoles and invertebrates in the shallow fringes of freshwater wetlands and mudflats and are occasionally found hunting in mangrove swamps and intertidal mudflats along the coastline (Simpson and Day, 1993).

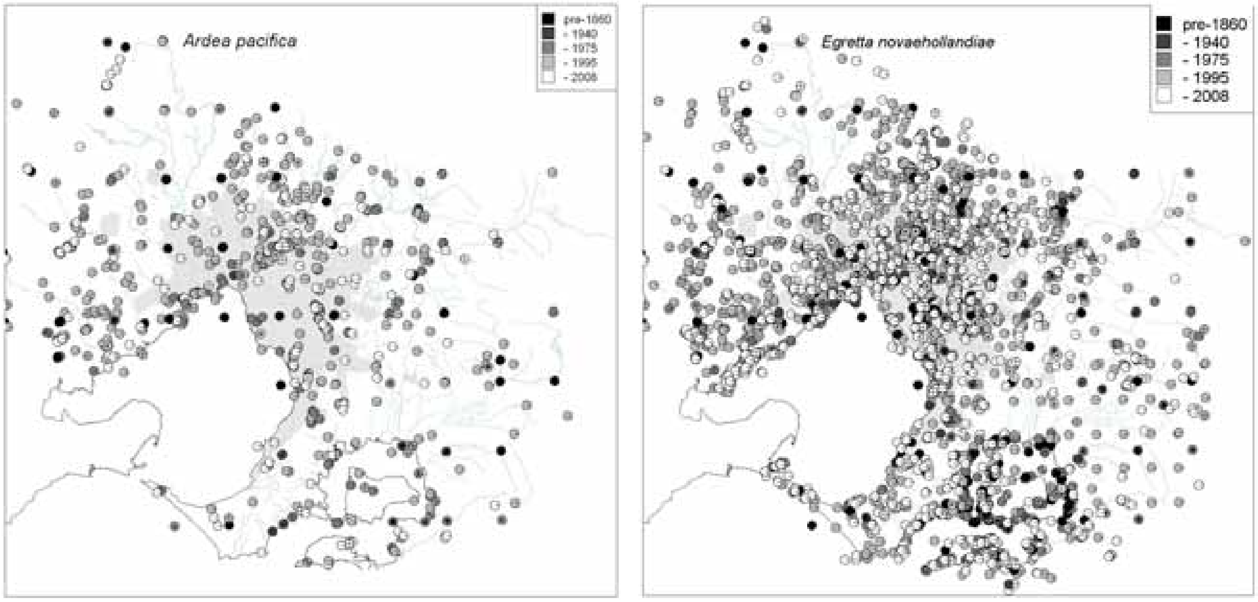


Figure A51. Records of *Ardea pacifica* and *Egretta novaehollandiae* represented by a pie-chart for each location indicating period of record. Both species are commonly observed through the Melbourne Water region, including the metropolitan area (source: Atlas of Victorian Wildlife database).

Reproduction

These two species can breed solitarily or in loose colonies. Breeding pairs make scrappy nests in trees that are either growing in or overhanging water. Two to seven eggs are laid, and males and females take turns to incubate the eggs in 42±2 days. They can breed year round but are highly dependent on the availability of shallow freshwater habitat.

Habitat

Ardea pacifica and *E. novaehollandiae* can be found in most areas that contain at least semi-permanent freshwater wetlands including farm dams, flooded pastures and roadside ditches (McKilligan, 2005; Richardson & Taylor, 2003). They prefer shallow water where they can hunt/stalk prey. They can also be occasionally observed hunting on mudflats or mangrove swamps (Simpson & Day, 1993).

Threats

Few threats to populations of these species are evident in the metropolitan area. Accumulation of pesticides and heavy metals in urban streams and wetlands are a potential threat (De Luca-Abbott *et al.*, 2001).

Cattle egrets, *A. ibis*, are an invasive species that can compete with other *Ardea* spp. by nesting in and defending suitable territory before other species are ready to nest (Richardson & Taylor, 2003). This might be a problem in parts of the Melbourne Water region.

Management options

Active management for these two species in the metropolitan area is not necessary. The health of these species should be monitored if they are attracted to stormwater treatment wetlands, where toxicant accumulation might become a problem.

Ardea intermedia (Intermediate egret, plumed egret, yellow-billed egret)

Ardea alba (Great egret)

Urban category B_r: transient

Recommended management:
1. No management identified in urban streams
2. Monitor for potential toxicant accumulation in stormwater treatment wetlands

Great Egret (*A. alba*) Intermediate Egret (*A. intermedia*)
Photos: http://www.naturalsciences.org; http://graemechapman.com.au

General notes

Ardea intermedia and *A. alba* are listed as threatened under the FFG act (DSE, 2007a).

Egrets typically live in mixed colonies along with similar birds such as *Phalacrocorax* (Cormorants) and *Anhinga* (Darters) (Baxter & Fairweather, 1989; Briggs *et al.*, 1998).

Distribution and abundance

Ardea spp. are found Australia-wide and are particularly abundant near and in shallow, permanent and temporary freshwater wetlands including those used for rice production (Richardson & Taylor, 2003).

Because members of *Ardea* are highly mobile they can tolerate urban conditions, but if conditions are sub-optimal, they can quickly disperse. *A. intermedia* is not commonly observed in the Melbourne Water region, and observations are equally spread between the metropolitan area and surrounding rural areas (Figure A51). There are no records of *A. alba* in Melbourne Water's faunal database.

Ecology

Egrets being high in the food chain are susceptible to bioaccumulation effects of pesticides (DDE and DDT) and also heavy metals (mercury, cadmium and selenium) (Henny, 2008). They can be either found solitary or in large flocks and can migrate large distances.

Feeding strategy and diet

Both species feed on fish, frogs and tadpoles, invertebrates and crustaceans in the shallow fringes of freshwater wetlands and mudflats and are occasionally found hunting in mangrove swamps and intertidal mudflats along the coastline (Simpson and Day, 1993).

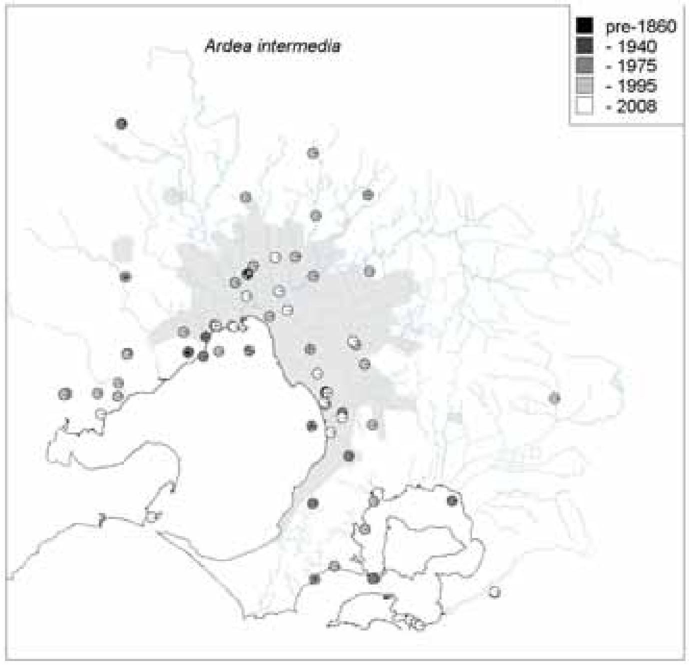


Figure A52. Records of *Ardea intermedia,* represented by a pie-chart for each location indicating period of record. *A. intermedia* are rarely recorded in the Melbourne Water region (source: Atlas of Victorian Wildlife database).

Reproduction

A. intermedia and *A. alba* breed in small or large colonies depending on available space and food resources (Baxter & Fairweather, 1989). There reproductive characteristics are similar to *A. pacifica.*

Habitat

Ardea spp. can be found in most areas that contain at least semi-permanent freshwater wetlands including farm dams, flooded pastures and roadside ditches (McKilligan, 2005; Richardson & Taylor, 2003). *A. intermedia*, in particular, is occasionally observed hunting on mudflats or mangrove swamps (Simpson & Day, 1993).

Threats

Few threats to populations of these species are evident in the metropolitan area. Accumulation of pesticides and heavy metals in urban streams and wetlands are a potential threat (De Luca-Abbott *et al.*, 2001).

Cattle egrets, *A. ibis*, are an invasive species that can compete with other *Ardea* spp. by nesting in and defending suitable territory before other species are ready to nest (Richardson & Taylor, 2003). This might be a problem in parts of the Melbourne Water region.

Management options

Active management for these two species in the metropolitan area is not necessary. The health of these species should be monitored if they are attracted to stormwater treatment wetlands, where toxicant accumulation might become a problem.

Egretta garzetta (Little egret, lesser egret)

Urban category B_r: transient

Recommended management:
1. No management identified in urban streams
2. Monitor for potential toxicant accumulation in stormwater treatment wetlands

Photo: www.birdsinbackyards.net

General notes

Distribution and Abundance

Egretta garzetta is found in all states of Australia but is limited mainly to the coastal fringe or places of permanent water. *E. garzetta* are much more common in the northern half of Australia but will migrate if a particular region is deficient of rainfall for an extended time.

In the Melbourne Water region, *E. garzetta* is most commonly recorded in the coastal area near the Western Treatment plant (Figure A53). It has also been recorded less commonly across the Melbourne Water region, and are as commonly observed in the metropolitan area as in rural areas (Figure A53).

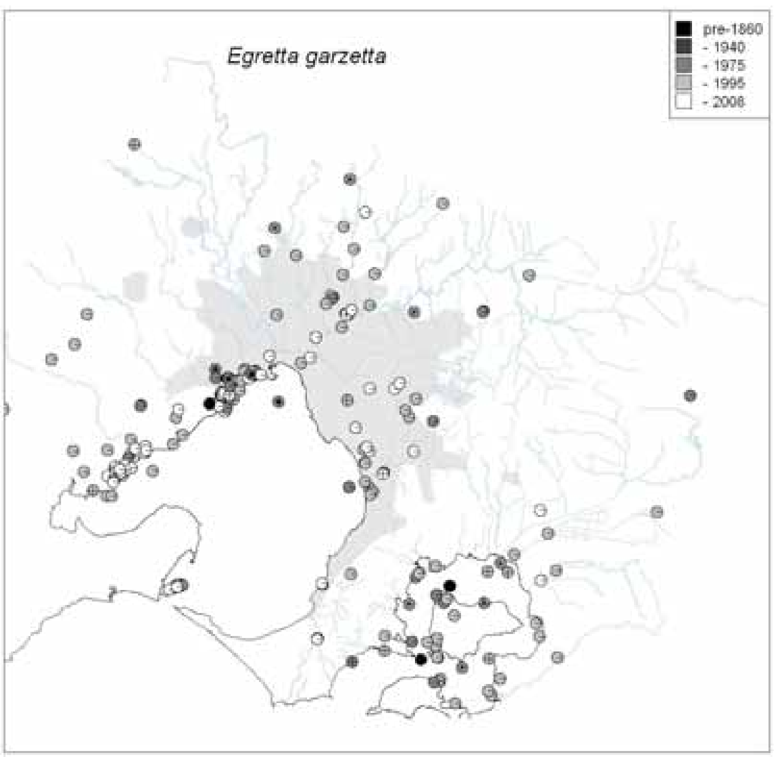


Figure A53. Records of *Egretta garzetta* in the Melbourne Water region: represented by a pie-chart for each location indicating period of record. (source: Atlas of Victorian Wildlife database).

Ecology

Feeding strategy and diet

Egretta garzetta preys on fish, tadpoles and small frogs, aquatic insects and crustaceans. *E. garzetta* is solely an aquatic feeder (Maddock & Baxter, 1991) employing a number of hunting methods: sit-and-wait; slowly movement thorough shallow water stirring the benthos with their feet to disturb prey items or; using a raised wing to ‘herd’ small fish into shallow water where they can pick off individual fish.

Reproduction

Egretta garzetta build large scrappy nests in shallow wetlands and swamps. The number of nests within a colony is unrelated to the size of the wetland and they occur in mixed colonies of Great, Intermediate and Cattle Egrets (Baxter & Fairweather, 1989). *E. garzetta* lay between 3 and 5 eggs with an incubation time of ~23 days with both parents guarding the eggs.

Habitat

Egretta garzetta colonize shallow fresh and brackish wetlands, lakes and mangrove swamps where they can use the littoral zone to forage for food (Simpson and Day, 1993; Flegg, 2002).

Threats

As most metropolitan records of *A. garzetta* are likely to be transient individuals, there are unlikely to be any threats specific to urban areas that are relevant to this species. More generally, habitat destruction (e.g. by land reclamation) is likely the major threat to the distribution and abundance of *E. garzetta*.

Management options

Active management for *A. garzetta* in metropolitan streams is not necessary. The health of swans should be monitored if they are attracted to stormwater treatment wetlands, where toxicant accumulation might become a problem.

Cygnus atratus (Black Swan)

Urban category A_r: urban tolerant

Recommended management:
1. No management identified in urban streams
2. Monitor for potential toxicant accumulation in stormwater treatment wetlands

Photo: www.australianfauna.com

General notes

A close relative of the white European Mute Swan (*Cygnus olor*).

Distribution and abundance

Cygnus atratus are common and widespread throughout the southern half of Australia including Tasmania (Flegg, 2002). *Cygnus atratus* abundances are positively correlated with higher rainfall and large wetlands (Chambers & Loyn, 2006; Kingsford *et al.*, 1999).

The abundance and distribution of *C. atratus* throughout Melbourne suggests that it is an urban tolerant species but nesting locations are probably restricted to shallow lakes and permanent wetlands (waste water treatment facilities) (Hamilton, 2002), and generally not streams or riparian wetlands (Figure A54).

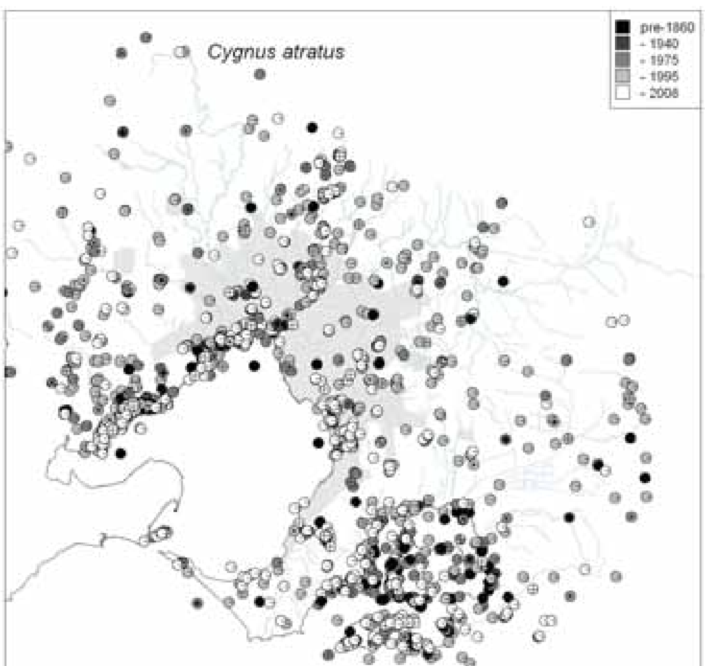


Figure A54. Records of *Cygnus atratus*: represented by a pie-chart for each location indicating period of record. In the metropolitan area *C. atratus* is most abundant in the main stem of the Yarra, permanent freshwater wetlands (wastewater treatment facilities) and the wetlands around Westernport Bay (source: Atlas of Victorian Wildlife database).

Ecology

Cygnus spp. are large, gregarious birds and often show complex social behaviours (Donaldson, Henein & Runtz, 2007; Rees, Bruce & White, 2005).

Feeding strategy and diet

Cygnus atratus are vegetarians and feed mainly on algae and aquatic macrophytes in water <1 m deep by plunging their heads underwater (Braithwaite, 1982; McKinnon & Mitchell, 1994; Mitchell & Wass, 1995). Swans contribute to wetland nutrient enrichment, but not as extensively as other waterbirds that forage on land and then retire to wetlands for shelter and nesting (Hahn *et al.*, 2008; Mitchell & Wass, 1995).

Reproduction

C. atratus are known to breed in flooded pasture, shallow wetland and sewage treatment sites around Melbourne and show a preference to breed during wetter months when there is more wetland habitat available (Chambers & Loyn, 2006; Hamilton, Taylor & Rogers, 2004). The nest is composed of reeds and grasses usually on small islands or floated in deeper water (Australian Museum, 2005d). Clutches can contain up to 10 chicks and there is a high incidence of broods having at least one chick from other parents (Braithwaite, 1977; Kraaijeveld *et al.*, 2004). Incubation time is ~40 days (Braithwaite, 1977).

Habitat

Cygnus atratus occupy shallow wetlands of varying salinities from purely fresh through to fully marine. Swans are found in larger wetlands with expanses of open water because they need at least 40 m of clear space to take off (Australian Museum, 2005d).

Swans do not readily disperse when suitable habitat is permanent but juveniles will move to other sites when local populations exceed sustainable numbers and both large groups and individuals can disperse large distances in search of suitable habitat if necessary (Chambers & Loyn, 2006).

Threats

The behaviour of some swan species is modified by interactions with humans (Donaldson *et al.*, 2007). Swans are aggressive toward predators and tend to nest on islands or floating nests so the usual predators in urban areas like cats, dogs and foxes should not significantly impact on swan numbers. Accumulation of pesticides and heavy metals in urban streams and wetlands are a potential threat (De Luca-Abbott *et al.*, 2001).

Management options

Active management for *C. atratus* in metropolitan streams is not necessary. The health of swans should be monitored if they are attracted to stormwater treatment wetlands, where toxicant accumulation might become a problem.

Ixobrychus minutus dubius (Kaoriki, minute bittern, leech bittern)

Urban category C_r: urban sensitive

Recommended management:
1. Ecological research
2. Provision and protection of wetlands and their riparian margins
3. Exotic predator control

www.okotura.gportal.hu/gindex.php

General notes

Ecological information is poor for bitterns in Australia (Kingsford & Norman, 2002). *I. minutus* is listed as threatened under the FFG act (DSE, 2007a).

Distribution and abundance

Ixobrychus minutus occurs worldwide, with subspecies in continental Europe (east to Siberia), northern India, Africa and Madagascar, but *Ixobrychus* are rare in southern Asia (McKilligan, 2005). They can be locally abundant, but Australian populations are patchy at best and limited to mainland eastern Australia (Cape York to Adelaide) and the south west corner of Western Australia (Flegg, 2002; Kingsford & Norman, 2002; Simpson & Day, 1993).

Only a small number of records from the more urban parts of the metropolitan area in the last 30 years suggest that this species is sensitive to urbanization (Figure A55).

Ecology

Feeding strategy and diet

Bitterns typically hunt at dawn and dusk. Prey items include fish, aquatic insect larvae, and smaller amphibians that they stalk at the waters edge (Flegg, 2002; Simpson & Day, 1993).

Reproduction

Dense wetland vegetation is essential for the breeding of *I. minutus*. They construct loose nests from available material such as reed stalks, bark and leaves. Both sexes help incubate between 4 –7 eggs for ~17 days and chicks are reliant on the parents for ~1 month after hatching (Flegg, 2002; Simpson & Day, 1993).

Habitat

Ixobrychus minutus are found mainly in densely vegetated freshwater wetland environments but sometimes occur in estuarine and littoral habitats providing they have sufficient vegetation cover (www.birdpedia.com).

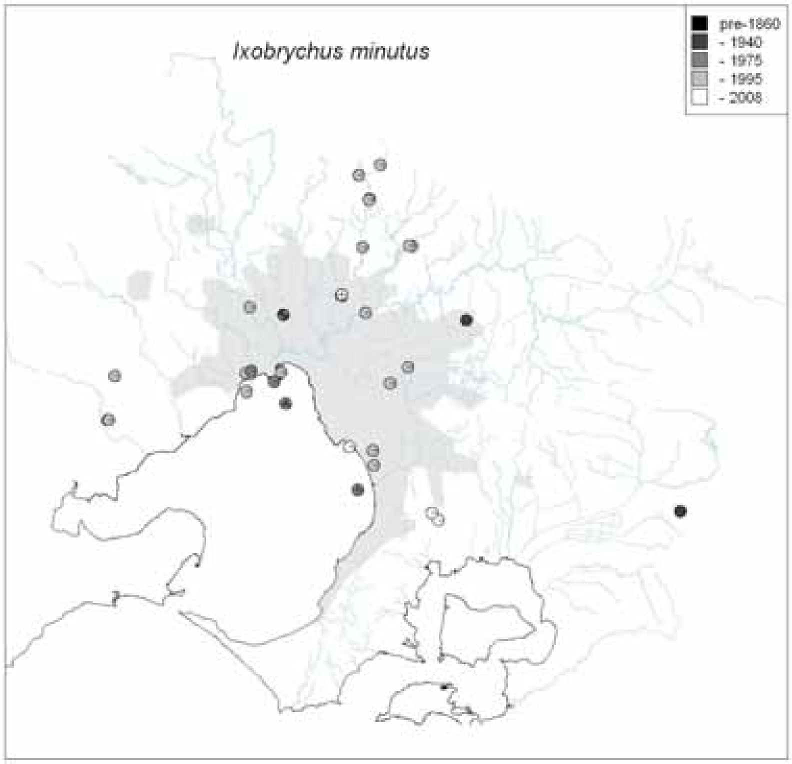


Figure A55. Records of *Ixobrychus minutus*: represented by a pie-chart for each location indicating period of record (source: Atlas of Victorian Wildlife database).

Threats

It has been suggested that bitterns in southern California are completely intolerant of even very slight human disturbances and do not occur near humans even if there is suitable habitat (Traut & Hostetler, 2004). The distribution of *I. minutus* in Melbourne suggests some tolerance of urban areas, but the rarity of records suggests that the metropolitan area provides sub-optimal habitat.

More generally, the loss of habitat through wetland draining and river regulation (flood prevention) is the biggest threat to the Little Bittern (Kingsford & Norman, 2002; Pearce, Green & Baldwin, 2007; Traut & Hostetler, 2004).

Management options

Primary research into the current distribution and abundance of *I. minutus* is a primary need to develop a management strategy for this species.

The primary conservation goal for *I. minutus* should be the protection of existing, densely vegetated, wetlands. As other bitterns have been shown to be highly sensitive to human disturbance, suitable wetlands (that are shown to support *I. minutus*), might need to incorporate total exclusion zones, and protection from exotic predators.

Botaurus poiciloptilus (Australasian bittern, brown bittern)

Urban category C_r: urban sensitive

Recommended management:
1. Ecological research
2. Provision and protection of wetlands and their riparian margins
3. Exotic predator control

General notes

Botaurus poiciloptilus is listed as threatened under the FFG Act 1988 (DSE, 2007a). As for the little bittern, there are very few Australian studies on *B. poiciloptilus*. However, the European species (*B. stellaris*) has been the subject of a considerable body of research (Gilbert *et al.*, 2007; Self, 2005; Tyler, Smith & Burges, 1998) and some basic biological traits of *B. poiciloptilus* have been extrapolated from these studies.

Distribution and abundance

Botaurus is found throughout Europe, Asia and America but *B. poiciloptilus* only lives in Australia, New Zealand and New Guinea (McKilligan, 2005).

Botaurus poiciloptilus can be locally abundant but Australian populations are patchy and limited to south-eastern Australia, Tasmania and south-western Western Australia (Flegg, 2002; Kingsford & Norman, 2002; Simpson & Day, 1993).

Botaurus poiciloptilus is moderately common around the Melbourne Water region, particularly near the wastewater treatment plants (Figure A56). It has been recorded much less frequently in the metropolitan area, suggesting it is sensitive to urbanization.

Ecology

Like the little bittern, *B. poiciloptilus* is generally a shy bird and rarely witnessed by humans in its natural habitat. They are substantially larger than the little bittern although similar colour patterns could make distinction difficult (Flegg, 2002).

Feeding strategy and diet

Botaurus spp. feed in shallow wetlands mainly on fish, but frogs, aquatic invertebrates, small mammals (and presumably reptiles) are also consumed (Self, 2005). They stalk prey along the edges of dense reed beds (Gilbert *et al.*, 2007; Tyler *et al.*, 1998).

Reproduction

Bitterns lay 3-5 eggs in a nest constructed mainly from the broken stalks of reeds (*Phragmites australis*) and other wetland grasses (Puglisi, Adamo & Baldaccini, 2005; Tyler *et al.*, 1998). Larger wetlands seem to be preferred breeding sites (Self, 2005). Chicks are fed by the female only and fledge <45days after hatching (Gilbert *et al.*, 2007). In Australia, *B. poiciloptilus* breeds during spring and early summer (Australian Museum, 2008a).

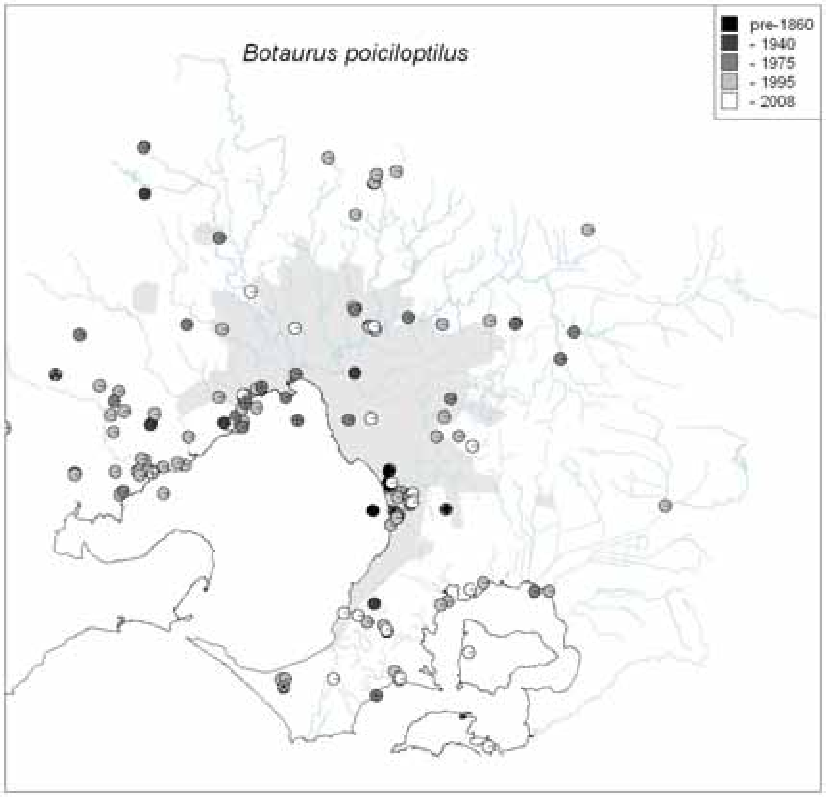


Figure A56. Records of *Botaurus poiciloptilus*: represented by a pie-chart for each location indicating period of record. (source: Atlas of Victorian Wildlife database).

Habitat

B. poiciloptilus lives and breeds in wetlands with established reed beds. Reeds are used for camouflage, nesting and as habitat to hunt prey (Gilbert *et al.*, 2007). They are usually non-migratory but can be abundant following floods when wetlands are plentiful (Australian Museum, 2008a).

Threats

Similar to the little bittern, the distribution of *B. poiciloptilus* in Melbourne suggests some tolerance of urban areas, but the rarity of records suggests that the metropolitan area provides sub-optimal habitat.

More generally, the loss of habitat through wetland draining and river regulation (flood prevention) is the biggest threat to the Little Bittern (Kingsford & Norman, 2002; Pearce *et al.*, 2007; Traut & Hostetler, 2004).

Management options

Primary research into the current distribution and abundance of *B. poiciloptilus* is a primary need to develop a management strategy for this species.

The primary conservation goal for *B. poiciloptilus* should be the protection of existing, densely vegetated, wetlands. As other bitterns have been shown to be highly sensitive to human disturbance, suitable wetlands (that are shown to support *B. poiciloptilus*), might need to incorporate total exclusion zones, and protection from exotic predators.

Nycticorax caledonicus (Nankeen Night Heron, Rufous Night Heron)

Urban category A_r: urban tolerant

Recommended management:
1. Riparian forest protection and restoration along urban streams
2. Exotic predator control

www.birdsinbackyards.net

General notes

There is little primary research literature on the *N. caledonicus*.

Distribution and abundance

N. caledonicus occurs in most parts of Australia that have permanent water bodies (rarely in Tasmania) (Flegg, 2002). Like many herons, *N. caledonicus* can be very abundant when and where prey is plentiful; which is usually in response to rainfall (Australian Museum, 2006b).

Nycticorax caledonicus is abundant throughout the Melbourne metropolitan area, particularly in the northern tributaries of the Yarra River (Figure A57).

Ecology

Feeding strategy and diet

Nycticorax caledonicus feeds at night on small fish, amphibians and aquatic invertebrates including crustaceans and larger insect larvae (Australian Museum, 2006b).

Reproduction

Like many herons, *N. caledonicus* nest in trees that overhang water bodies (Flegg, 2002). They can breed throughout the year depending on water (food) availability (Australian Museum, 2006b). They can form part of mixed-species waterbird colonies with similar predatory birds like cormorants and egrets. A loose nest of sticks is made above water where both parents tend to between 2-5 chicks (Australian Museum, 2006b).

Habitat

Nycticorax caledonicus occur in a variety of habitats including, muddy creeks and streams, wetlands, the margins of lowland rivers, lakes and farm dams, and estuaries and mangroves (Flegg, 2002).

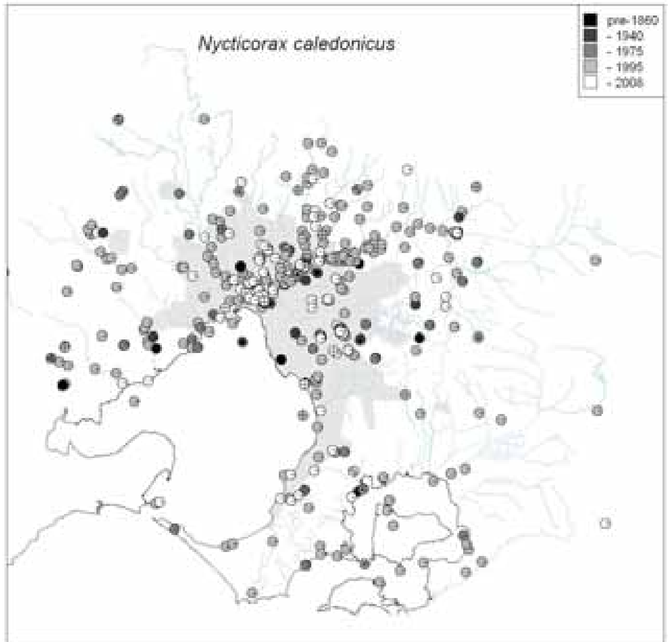


Figure A57. Records of *Nycticorax caledonicus*: represented by a pie-chart for each location indicating period of record. *Nycticorax caledonicus* occurs frequently in the Yarra River and its northern tributaries (source: Atlas of Victorian Wildlife database).

Threats

The draining of wetlands, the removal of riparian vegetation and the reduction in environmental flows to the Yarra River all reduce the available habitat of *N. caledonicus*. Further, predation by domestic pets and foxes could be significant considering that this species is most active at night.

Management options

Management of riparian, wetland and floodplain vegetation to provide adequate nesting sites, and the control of exotic predators will promote *N. caledonicus* populations in urban areas.

Porphyrio porphyrio (Purple swamphen; purple gallinule)

Urban category A_r: urban tolerant

Recommended management:
1. No action required in urban streams
2. Protection and provision of wetland habitat

www.austmus.gov.au

General notes

Bordering on extinction in parts of Europe in the mid 1900's, the purple swamphen has, with the aid of extensive protection and management actions, recently made a strong recovery in abundance and distribution, particularly in parts of Portugal and Spain (Sanchez-Lafuente *et al.*, 1992; Sanchez-Lafuente *et al.*, 2001). Their status is secure in Australia.

Distribution and abundance

Porphyrio porphyrio is found in the Mediterranean region of Europe, Africa, Asia, and the Australasian region. In Australia it is found in the eastern and northern regions of the continent, Tasmania and also far south-western Western Australia (Flegg, 2002; Pacheco & McGregor, 2004; Simpson & Day, 1993).

Porphyrio porphyrio is very common and abundant in all of Melbourne's permanent waterways and there appears to be no relationship with urbanization, nor has there been any obvious contraction of the species since the mid-1970s (Figure A58). We thus classify it as urban tolerant, and, because it is common in wetland habitats, not solely reliant on stream habitat.

Ecology

Porphyrio porphyrio superficially resemble *Fulica atra* but they are larger, have colourful plumage and a red frontal shield in contrast to white beak, frontal shield and darker plumage of *F. atra*.

Feeding strategy and diet

Porphyrio porphyrio is herbivorous and consumes a varied diet of shoots and seeds from an submerged and emergent aquatic vegetation (Moore, 1998; Norman & Mumford, 1985). Some animal species may be ingested (Norman & Mumford, 1985), but this may be incidental to normal feeding. *Porphyrio porphyrio* have also been observed attacking and consuming ducklings, and may also steal eggs (Australian Museum, 2007).

Reproduction

In Victoria, *P. porphyrio* breed from mid-August to December (Hamilton *et al.*, 2004). They form nests of trampled reeds in dense vegetation and incubation is communal with males and offspring from previous clutches sharing the incubation duties (Australian Museum, 2007).

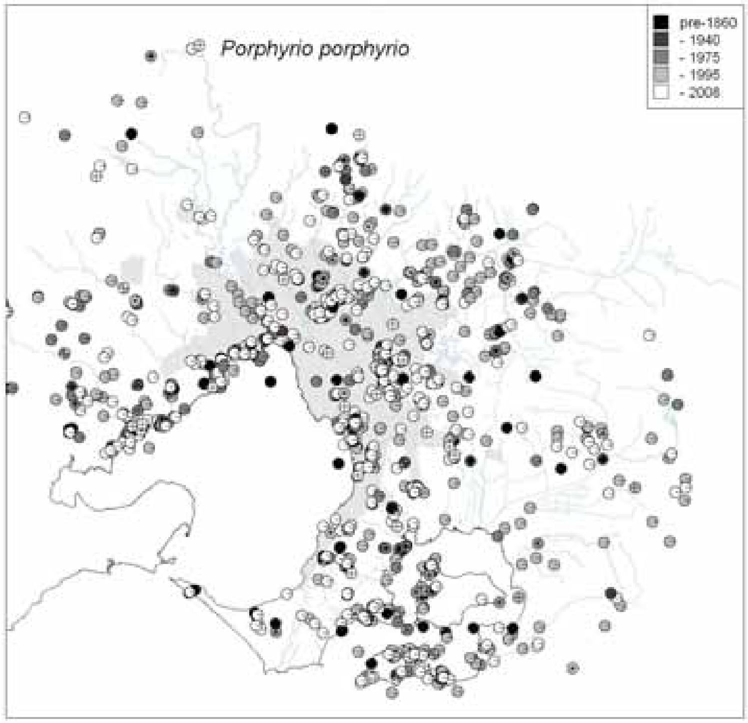


Figure A58. Records of *Porphyrio porphyrio*: represented by a pie-chart for each location indicating period of record. *Porphyrio porphyrio* are abundant and widespread throughout Melbourne. There appears to be no contraction in the distribution of swamphen since records began. (source: Atlas of Victorian Wildlife database).

Habitat

Porphyrio porphyrio occur almost exclusively in freshwater environments, inhabiting the edges of natural and artificial lakes, slow moving rivers as well as swamps, flooded paddocks, marshes and dry pasture (Norman & Mumford, 1985; Sanchez-Lafuente *et al.*, 1992).

Threats

In light of the European examples, habitat loss and habitat fragmentation are potential threats to *P. porphyrio* populations around Melbourne, particularly if drought conditions continue. Currently *P. porphyrio* populations around Melbourne do not appear to be affected by urbanization and thus, any further threats to the population are difficult to identify.

Management options

No management actions are required to protect existing *P. porphyrio* populations using urban streams of Melbourne. More generally, *P. porphyrio* populations will benefit from protection of wetland habitats.

Fulica atra (Eurasian coot, European coot, common coot)

Urban category A_r: urban tolerant

Recommended management:
1. No action required in urban streams
2. Protection and provision of wetland habitat

Photo: http://photos.rnr.id.au

General notes

Fulica atra is not listed as threatened under any fauna acts.

Distribution and abundance

Fulica atra is a cosmopolitan species, abundant across Eurasia, Africa and the Indo-Pacific regions and the similar *F. americana* occurs in North and South America. They are present across most of Australia where there is sufficient water to form suitable habitat (Flegg, 2002; Simpson & Day, 1993).

Fulica atra occurs commonly across the Melbourne Water region including the metropolitan area (Figure A59). We thus classify it as urban tolerant, and, because it is common in wetland habitats, not solely reliant on stream habitat.

Ecology

Fulica atra are superficially similar to *Porphyrio porphyrio* but they are smaller, have darker plumage and a white beak and frontal shield in contrast to the red beak, frontal shield and more colourful plumage of *P. porphyrio*.

Feeding strategy and diet

Fulica atra feed by a number of methods including surface pecking while floating, diving, tipping upside-down and foraging in terrestrial environments (McKnight & Hepp, 1998; Randler, 2006). *F. atra* are opportunistic but mainly graze the dominant macrophyte in the region. They will also ingest aquatic invertebrates and occasionally fish (McKnight & Hepp, 1998; Perrow *et al.*, 1997).

Reproduction

Fulica atra build nests in reed beds (typically *Phragmites australis*) or emergent vegetation (tree stumps) where they lay up to 16 eggs in one clutch (Brinkhof *et al.*, 2002) and will aggressively defend nests if a threat is perceived (Australian Museum, 2003a).

Fulica atra can have multiple clutches in a season but the success of the second clutch is higher the earlier the first clutch fledges (Brinkhof *et al.*, 2002).

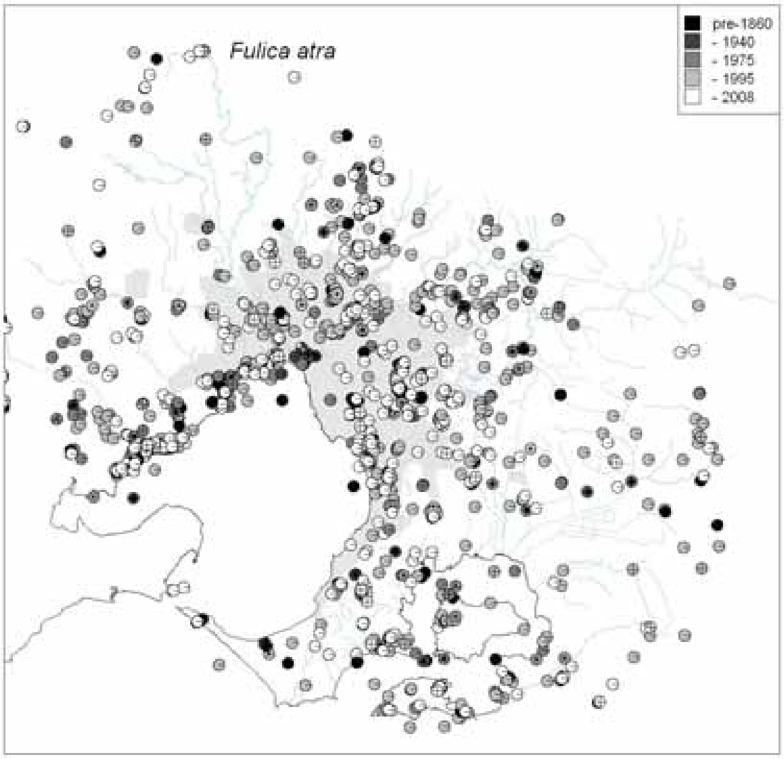


Figure A59. Records of *Fulica atra*: represented by a pie-chart for each location indicating period of record. *Fulica atra* are abundant and widespread throughout Melbourne. There appears to be no contraction in the distribution of coots since records began. (source: Atlas of Victorian Wildlife database).

Habitat

Fulica atra live in freshwater habitats such as slow moving rivers, swamps and lakes with abundant macrophytes for feeding, nesting and shelter (Australian Museum, 2003a).

Threats

As it shares many physical and behavioural traits with *Porphyrio porphyrio*, *F. atra* also share similar threats. Habitat loss and habitat fragmentation are potential threats to *F. atra* populations around Melbourne, particularly if drought conditions continue. Currently *F. atra* populations around Melbourne do not appear to be impacted by urbanization and thus, any further threats to the population are difficult to identify.

Management options

No management actions are required to protect existing *F. atra* populations using urban streams of Melbourne. More generally, *F. atra* populations will benefit from protection of wetland habitats.

Gallinula tenebrosa **(**Dusky Moorhen)

Urban category A_r: urban tolerant

Recommended management:
1. No action required in urban streams
2. Protection and provision of wetland habitat

www.birdsinbackyards.net

General notes

Dusky moorhens are similar to purple swamphens and Eurasian coots in appearance but are more varied in plumage colour and have red beaks with a yellow frontal shield (Flegg, 2002). They are not listed as threatened species.

Distribution and abundance

Gallinula tenebrosa is found throughout Australasia but is rare in Tasmania and absent from New Zealand (Australian Museum, 2008b; Flegg, 2002; Simpson & Day, 1993)

Gallinula tenebrosa occurs commonly across the Melbourne Water region including the metropolitan area (Figure A60). We thus classify it as urban tolerant, and, because it is common in wetland habitats, not solely reliant on stream habitat.

Ecology

Gallinula tenebrosa are communal birds forming loose flocks during the non-mating season and groups of up to seven birds comprising multiple males and females during the mating season (Garnett, 1978).

Feeding strategy and diet

Gallinula tenebrosa are generally herbivorous but also consume small amounts of aquatic invertebrates and sometimes carrion (Australian Museum, 2008b).

Reproduction

Multiple nests in reed beds are made by groups of birds that share feeding and protection responsibilities of new chicks, and groups often consist of juveniles from previous clutches who contribute as much as 33% of feed to chicks (Australian Museum, 2008b). *Gallinula tenebrosa* females mate with more than one male and can breed year round if conditions (warm winter temperatures and abundant food) are suitable (Shirley *et al.*, 2003). They lay up to 15 eggs in a nest and will aggressively defend eggs and chicks if threatened (Australian Museum, 2008b).

Habitat

Gallinula tenebrosa live in all freshwater waterways (wetlands, slow moving rivers, swamps, lake edges) that support dense stands of reeds (*Phragmites australis* or *Typha* sp.) (Garnett, 1978).

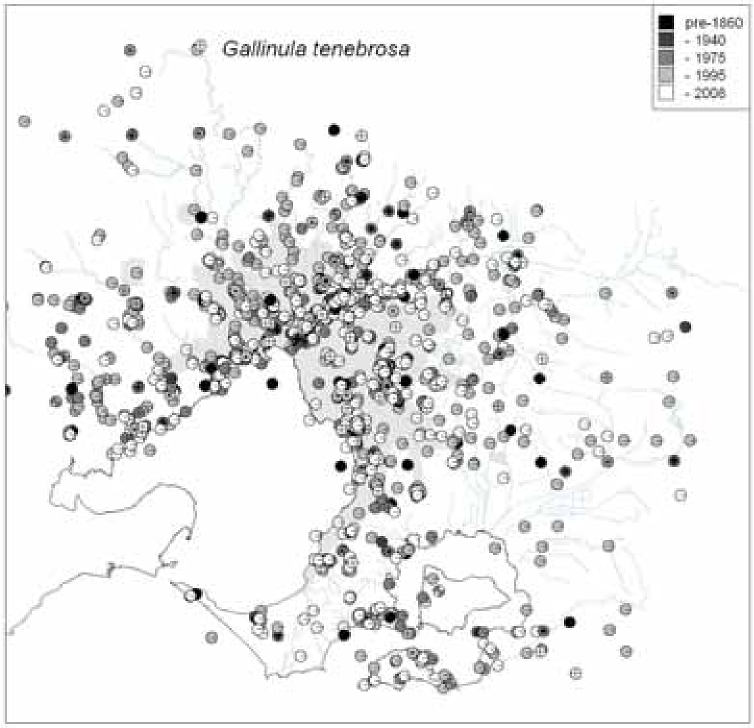


Figure A60. Records of *Gallinula tenebrosa*: represented by a pie-chart for each location indicating period of record. *Gallinula tenebrosa* are abundant and widespread throughout Melbourne. There appears to be no contraction in the distribution of moorhen since records began (source: Atlas of Victorian Wildlife database).

Threats

As it shares many physical and behavioural traits with *P. porphyrio* and *F. atra*, *G. tenebrosa* also share similar threats. Habitat loss and habitat fragmentation are potential threats to *G. tenebrosa* populations around Melbourne, particularly if drought conditions continue. Currently *G. tenebrosa* populations around Melbourne do not appear to be impacted by urbanization and thus, any further threats to the population are difficult to identify.

Management options

No management actions are required to protect existing *G. tenebrosa* populations using urban streams of Melbourne. More generally, *G. tenebrosa* populations will benefit from protection of wetland habitats.

Platalea flavipes (Yellow-billed spoonbill)

Urban category B_r: transient

Recommended management:
1. Ecological research
2. Provision and protection of wetlands and their riparian margins

www.birdsinbackyards.net

General notes

Platalea flavipes is similar to the royal spoonbill (*Platalea regia*). The yellow-billed spoonbill is shorter, and is more commonly associated with freshwater habitats.

Distribution and abundance

Nomadic throughout Australia but more common in northern regions, *P. flavipes* is abundant wherever there is suitable nesting and feeding habitat (Flegg, 2002; Simpson & Day, 1993).

It is common around the Melbourne Water region, particularly at the wastewater treatment plants (Figure A61). It appears to be less common in the metropolitan area than in surrounding areas, although without absence records, this is not possible to infer with confidence. Similarly the distributional record suggests that it has been recorded less frequently in the metropolitan area in the last 13 years than in earlier decades, but this might be an artifact of sampling that is impossible to discern without absence data (Figure A61). We have not been able to obtain breeding information, so cannot assess with confidence if this species breeds within the metropolitan area. We thus tentatively class this species as transient in the metropolitan area, and assume that most metropolitan records are non-breeding transients. Like other waterbirds, it is not solely reliant on stream habitats.

Ecology

The bill of *P. flavipes* has sensory organs that detect small vibrations caused by prey. Bills are also lined with papillae that act as teeth for holding and chewing larger prey items (Vestjens, 1975b).

Feeding strategy and diet

Because of its sensitive bill, *P. flavipes* can feed during both the daytime and at night and usually feed in water up to 400 mm deep (Vestjens, 1975b). They exploit smaller habitat patches than the Royal spoonbill and often favour small shallow pools and will also feed in flooded paddocks after heavy rains (Vestjens, 1975b).

Platalea flavipes feed mainly on aquatic crustaceans (*Cherax*), molluscs and insects (larvae and adults) as well as some smaller fish (*Gambusia*) and small amounts of vegetation (Vestjens, 1975b).

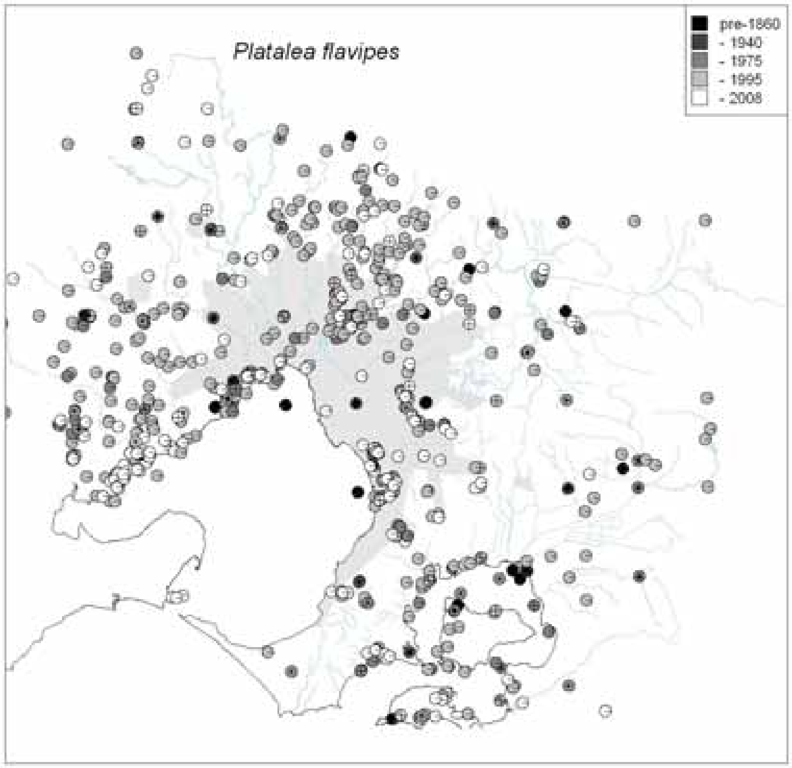


Figure A61. Records of *Platalea flavipes*: represented by a pie-chart for each location indicating period of record (source: Atlas of Victorian Wildlife database).

Reproduction

P. flavipes tends to breed in the wetter months (July to November in southern regions). They nest in the forks of tree branches or on the ground and lay 2-4 eggs (Australian Museum, 2005e). In the Murray-Darling, *P. flavipes* preferred to nest in live red gums (*Eucalyptus camaldulensis*) in large wetlands that had not dried for >4 months (Briggs *et al.*, 1998).

Habitat

P. flavipes live in freshwater wetlands, lakes, swamps and riverine habitat. Freshwater habitat is much preferred but they do occasionally use marine or estuarine environments (usually the domain of the royal spoonbill) (Flegg, 2002; Simpson & Day, 1993).

Threats

Habitat loss through urbanization may be a threat to *P. flavipes*, but further research is required to assess limiting factors for this species. Drought conditions might be partly responsible for the contraction in distribution around Melbourne.

Management options

Ecological research on the factors driving the distribution of this species in the Melbourne Water region is required for an informed management strategy. Like other waterbirds, *P. flavipes* populations will likely benefit from protection of wetland habitats.

Phalacrocorax (Microcarbo) melanoleucos (Little pied cormorant)

Phalacrocorax sulcirostris (Little black cormorant)

Phalacrocorax varius (Pied cormorant), *Phalacrocorax carbo* (Great cormorant)

Urban category A_r: urban tolerant
Recommended management: prevent habitat loss; wetland conservation

Little pied cormorant

Photo: http://home.vicnet.net.au

Little black cormorant

Photo: http://dl.id.au

Pied cormorant

Great cormorant

Photos: www.arthurgrosset.com; http//photogallery.canberrabirds.org.au

General notes

Phalacrocorax is a populous and widespread genus and no species in the genus is considered threatened (DSE, 2007a). During the late 1970s and early 1980s, cormorants were the subject of considerable study as pond aquaculture grew more popular, and they were considered a major threat to farmed fish stocks because of their vigorous fish predation (Barlow & Bock, 1984).

Distribution and abundance

Phalacrocorax are abundant in streams and lakes over much of inland and coastal Australia. They are generally not found in marine ecosystems, the domain of the black-faced cormorant *Leucocarbo fuscescens* (Llewellyn, 1983). *Phalacrocorax* spp. will, however, inhabit shallow bays and inlets, such as Westernport Bay, if prey is abundant (Dann *et al.*, 2003; Simpson & Day, 1993).

In Melbourne, most *Phalacrocorax* is very common and found in most freshwater habitats. The exception is *P. varius* which appears to strongly prefer coastal habitats (Figure A62). We class all of these species as urban tolerant, but note that they are not reliant solely on stream habitats.

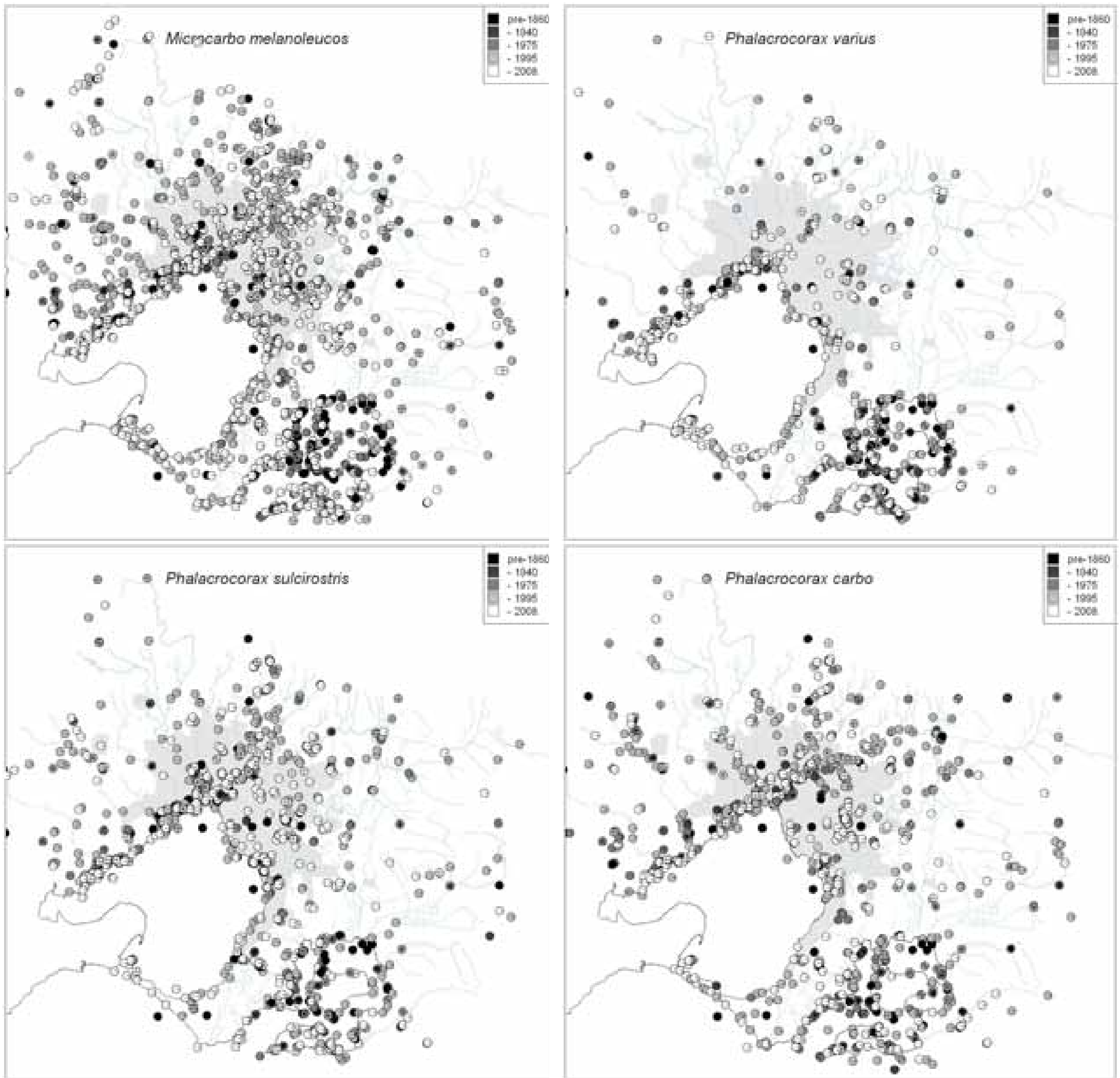


Figure A62. Records of *Phalacrocorax* sp.: represented by a pie-chart for each location indicating period of record. All *Phalacrocorax* species occur frequently across Melbourne's streams and wetlands, except *P. varius* which appears to favour coastal habitats (source: Atlas of Victorian Wildlife database).

Ecology

Cormorants are able to fly long distances and (with the exception of the little pied cormorant which flies separately) often form large flocks and fly in 'V' formation (Simpson and Day, 1993).

Feeding strategy and diet

All cormorants are visual predators and dive in shallow water to forage for food, but different species employ a number of hunting strategies. *P. melanoleucos* prefers to hunt individually and *P. sulcirostris* favours hunting in groups of various size (Miller, 1979).

Phalacrocorax spp. are highly nomadic and as such, congregate where and when there is an abundant food source (Dorfman & Kingsford, 2001). Because they readily disperse, even food sources that show high temporal variability are not safe from predation by cormorants.

Cormorants prey on many items depending on seasonal availability rather than preference. Their main diet consists of fish and crustaceans (Miller, 1979), but the overlap of prey items between species is restricted because different species target different prey items. For example, the little pied and black cormorants diets in a lake in NSW were almost identical in the range of species taken, but prey composition was very different (Miller, 1979).

Reproduction

Cormorants mostly nest in large colonies and show strong preference to breeding in trees above inundated floodplains (Llewellyn, 1974). The great cormorant prefers nesting in wetland areas where flood duration is >4 months (Briggs *et al.*, 1998), but other cormorant species are more likely to breed in areas that have more variable inundation lengths (Llewellyn, 1974).

Habitat

Cormorants are found near perennial or ephemeral aquatic systems that sustain enough prey items (Simpson and Day, 1993).

Threats

Due to the highly mobile nature of cormorants, there are few risks to the survival of the species either in urban or rural areas. As with many predatory birds however, there is always the risk of organochlorin (DDT, PCB's etc) and certain heavy metals (e.g. mercury) bioaccumulating to the stage where birds experience breeding failure (De Luca-Abbott *et al.*, 2001; Zimmermann *et al.*, 1997).

Cormorants may even be beneficial to urban water bodies as their diet (particularly *P. sulcirostris*) often consists of high amounts of introduced fish (Miller, 1979).

Management options

No management actions necessary to conserve urban stream populations. The health of cormorants should be monitored if they are attracted to stormwater treatment wetlands, where toxicant accumulation might become a problem.

Anhinga novaehollandiae (formally *A. melanogaster*)
(Darter; Australasian darter; snakebird)

Urban category A_r: urban tolerant

Recommended management: prevent habitat loss; wetland conservation

Photo: www.birdsinbackyards.net

General notes

There were formerly only two recognized species of Darter, *A. anhinga* (North America) and *A. melanogaster* (Africa, Asia and Australasia), but recently *A. melanogaster* has been split into several species including the Australasian species, *A. novaehollandiae* (Australian Museum, 2005b; Hone, 1978).

Distribution and abundance

Darters are widespread throughout Australasia but are not particularly common. They are reliant on freshwater but can sometimes be observed in marine environments (Flegg, 2002; Simpson & Day, 1993). Morton *et al.* (1993) showed that larger numbers of darter lived in a large wetland system in the Northern Territory during the dry season when the wetlands were most contracted.

Anhinga novaehollandiae are moderately common along rivers and in wetlands across the Melbourne Water region, including the metropolitan area. They have been observed particularly commonly along the Yarra River (Figure A63).

Ecology

Darters are closely related to cormorants but differ mainly in their long necks and in that their plumage becomes saturated after being immersed (Ryan, 2007).

Feeding strategy and diet

The diet of *A. novaehollandiae* mainly comprises fish but some aquatic insects and vegetation (probably ingested accidentally) are also consumed (Dostine & Morton, 1989). *Anhinga* spp. dive frequently during feeding bouts and the time spent underwater varies depending on water depth (Ryan, 2007). Reduced buoyancy, caused by the wettable plumage, helps *Anhinga* spp. dive in shallow water, where darter are thought to have a competitive advantage over cormorants because of their greater diving efficiency (Ryan, 2007). All fish caught during a dive a brought to the surface before being swallowed (Dostine & Morton, 1989; Vestjens, 1975a).

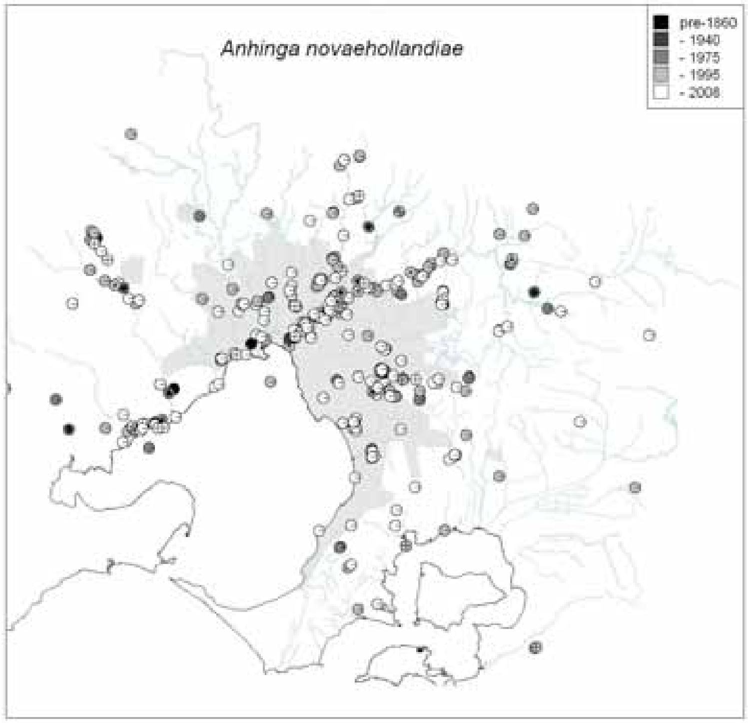


Figure A63. Records of *Anhinga novaehollandiae*: represented by a pie-chart for each location indicating period of record (source: Atlas of Victorian Wildlife database).

Reproduction

Similar to many herons and egrets, *Anhinga* spp. builds scrappy nests in trees that either stand in or overhang water. They often nest at the same time as herons and egrets and will even share trees with other species (Morton *et al.*, 1993; Vestjens, 1975a).

Both sexes incubate an average of four eggs and chicks usually take ~28 days to hatch. Most chicks are fledged before they are two months old (Vestjens, 1975a).

Habitat

Anhinga novaehollandiae prefer freshwater habitats but can sometimes be found in estuaries and marine environments (Flegg, 2002; Simpson & Day, 1993). They need vegetation that overhangs water for nesting and shallow water for foraging.

Threats

Due to their mobility, there are few risks to the survival of darter populations in urban or rural areas. As with many predatory birds however, there is a risk of toxicant accumulation (De Luca-Abbott *et al.*, 2001; Zimmermann *et al.*, 1997).

Management options

No management actions necessary to conserve urban stream populations. The health of darters should be monitored if they are attracted to stormwater treatment wetlands, where toxicant accumulation might become a problem.

Himantopus himantopus leucocephalus (Black-winged stilt, pied stilt)

Urban category B_r: transient

Recommended management:
1. Not a primary target for management in urban areas.
2. Protection of wetland habitats and exotic predator control in known breeding areas.

www.commons.wikimedia.org

General notes

A very unique species, *H. himantopus*, can wade for food in much deeper water than other wader species because of its very long legs (Flegg, 2002). It is not listed as threatened under the FFG Act (1988) (DSE, 2007a).

Distribution and abundance

Himantopus himantopus are found in Central and South America, across Eurasia, south-east Asia, Africa and Australia (Australian Museum, 2005a). They occur over much of mainland Australia (rarely Tasmania) where suitable habitat forms and can be locally abundant (Flegg, 2002; Simpson & Day, 1993).

In the Melbourne Water region, *H. himantopus* occurs most frequently on the mudflats of western Port Phillip Bay and the permanent wetlands associated with water treatment facilities (Figure A64). It has been recorded infrequently from the metropolitan area, which we consider to be transient records.

Ecology

Feeding strategy and diet

Black winged stilts feed in shallow water over mud- and sand-flats, predominantly in estuaries but also in freshwater wetlands (McConkey & Bell, 2005).

Himantopus himantopus use surface tension transport (STT) of water within their long narrow bills to draw small invertebrates up into their mouths (Estrella, Masero & Perez-Hurtado, 2007). Common prey items include Mollusca, Coleoptera, Trichoptera and Hemiptera with most prey being taken from emergent macrophytes. Plant material is ingested in very small quantities, probably accidently (Dostine & Morton, 1989b).

Reproduction

Himantopus himantopus build simple nests where they lay 3-4 eggs. Breeding season is not strongly defined but is more likely to occur August-December (Australian Museum, 2005a). They nest on the ground and are therefore susceptible to predation by mammals. Birds of prey are also known to attack stilt nests (Pierce, 1986). Kingsford *et al.* (1999) found a negative correlation between rainfall and *H. himantopus* numbers with a two year delay between large rain events and stilt numbers.

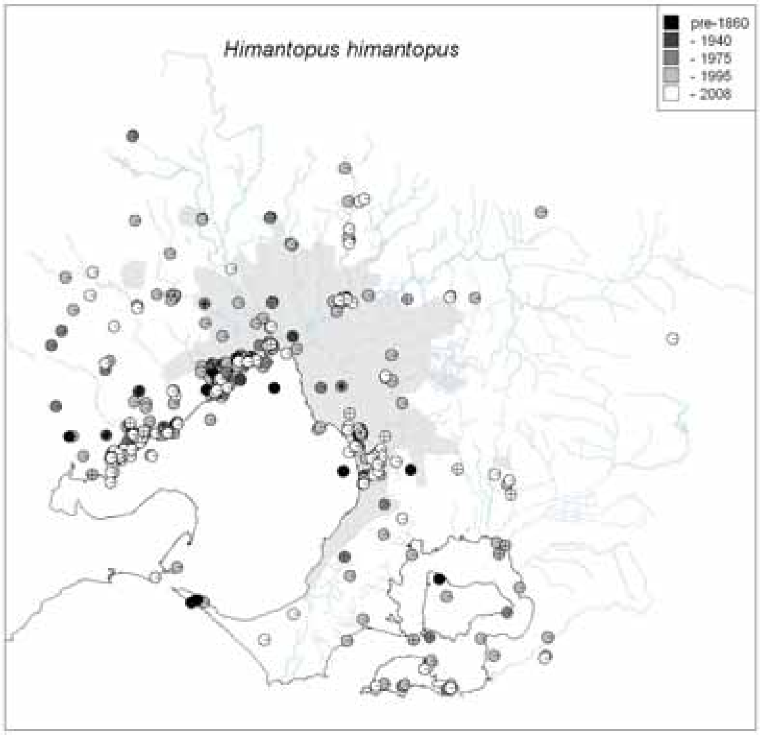


Figure A64. Records of *Himantopus himantopus*: represented by a pie-chart for each location indicating period of record. *Himantopus himantopus* occur infrequently away from the expansive mudflats on the western side of the bay (not influenced by urbanization) and the permanent wetlands associated with water treatment facilities (source: Atlas of Victorian Wildlife database).

Both sexes incubate the nests and chicks usually take ~25 days to hatch (Australian Museum, 2005a). The nest will often be aggressively defended from predators (Pierce, 1986).

Habitat

Usually found in estuarine environments, *H. himantopus* are equally adapted to freshwater environments such as wetlands and the littoral zone of lakes (Flegg, 2002; Simpson & Day, 1993). They can feed in much deeper water than many other wading birds due to their very long legs.

Threats

Feral cats and foxes could be major predators of stilt adults and eggs. The loss of shallow freshwater wetlands reduces habitat area and nesting sites in the area.

Management options

As infrequent transients, they are not a likely target for management actions in urban areas. They are more likely to be associated with wetlands than streams. If breeding was known in the metropolitan areas, the control of feral cats and foxes would reduce the predation pressure on stilt eggs and chicks. Preventing habitat loss of natural wetlands and active management of artificial wetlands such as those found at the two large treatment plants would secure valuable nesting and feeding habitat for *H. himantopus*.

Todiramphus sanctus (Sacred kingfisher)

Urban category A_r: Urban tolerant

Recommended management:
1. No action required in urban streams
2. Protection and provision of woodland (including riparian) habitat

Photo: www.austmus.gov.au

General notes

Todiramphus sanctus is part of a group of birds that include the iconic kookaburra. Unfortunately the sacred kingfisher does not share the research status of its close relative and few studies on the biology of *T. sanctus* could be found.

Distribution and abundance

Todiramphus sanctus is found throughout Australia and Tasmania except in the most arid regions of central Australia and also occurs in New Zealand, New Guinea, south-east Asia and the Pacific islands (Lindenmayer *et al*., 2001). In southern Australia they are considered migratory, flying to northern Queensland or New Guinea during winter and then returning to the south of the continent in spring to breed and raise young over the summer months (Lindenmayer *et al*., 2001).

In the Melbourne Water region it is commonly recorded in metropolitan areas and is particularly common throughout the Yarra catchment and the broader metropolitan area (Figure A65). *T. sanctus* is thus urban tolerant, and is not solely dependent on stream environments.

Ecology

Males and females show some sexual dimorphism with females generally having slightly duller plumage than males as mature birds. Juveniles are grey/brown until they mature and gain adult plumage (Flegg, 2002).

Feeding strategy and diet

Todiramphus sanctus perch on low branches and spot potential prey items from above. A surprise attack is launched and when the attack is successful it will return to the branch to feed. Perhaps surprisingly, *T. sanctus* is mainly a terrestrial feeder consuming adult and larval insects, crustaceans and small reptiles such as skinks. Hunting over water is rare but fish are occasionally taken (Australian Museum, 2003b).

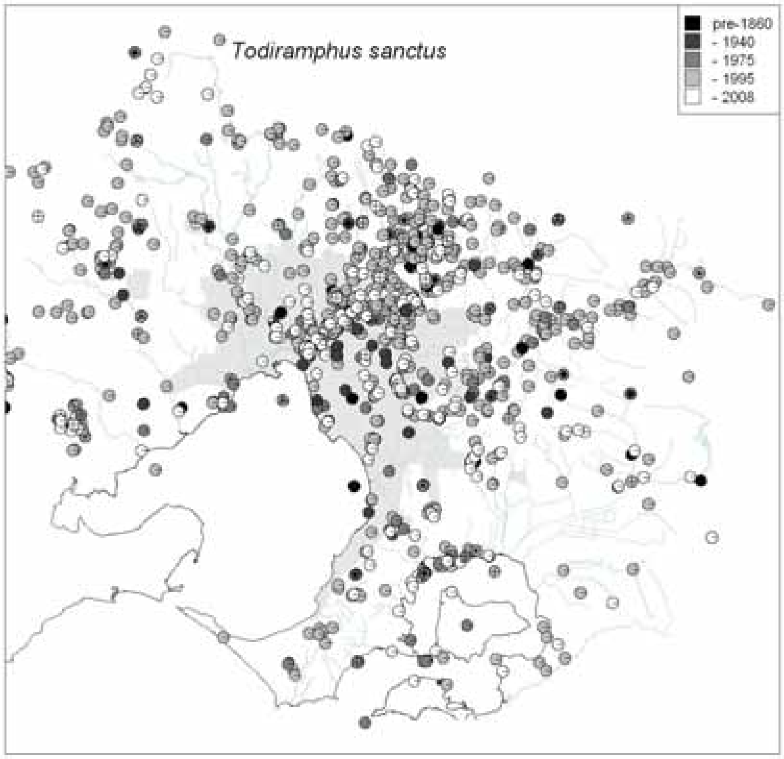


Figure A65. Records of *Todiramphus sanctus*: represented by a pie-chart for each location indicating period of record (source: Atlas of Victorian Wildlife database).

Reproduction

Todiramphus sanctus usually breeds between September and December but in favourable conditions the season can extend until March. They nest in hollow tree trunks, termite mounds or undercut river banks (Lindenmayer *et al.*, 2001). Females lay 4 eggs on average and both males and females will tend to the young. Couples can have 2 clutches in any one breeding season (Australian Museum, 2003b).

Habitat

Todiramphus sanctus lives in open native forest and woodlands, often near watercourses (Flegg, 2002).

Threats

Habitat destruction causing a lack of suitable nesting sites is the major threat to *T. sanctus* in the urban environment. Predation by domestic pets may also potentially constitute a threat to *T. sanctus* numbers.

Management options

Careful management of remnant vegetation patches and parkland areas combined with the appropriate replanting of streamside vegetation should secure the resident population in Melbourne. Expanding the extent of remnant vegetation patches may increase the abundance of *T. sanctus* in the local area, and riparian forests are undoubtedly an important element of *T. sanctus* habitat. However, urban stream management is unlikely to have a strong influence on *T. sanctus* populations.

Acrocephalus australis
(Australian reed-warbler, Australian great reed-warbler, long-billed reed-warbler)

Urban category A_r: urban tolerant

Management recommendations:
Protection of stream and wetland reed beds

www.birdforum.net

General notes

Acrocephalus australis was until recently considered the *australis* race of *A. stentoreus*. It is not listed as threatened under the FFG Act 1988 (DSE, 2007a).

Distribution and abundance

Acrocephalus australis is found throughout Australia and the Indo-Pacific Islands (Simpson & Day, 1993).

It is common along streams and permanent wetlands across the Melbourne Water region, including in the metropolitan area (Figure A66). It is thus urban tolerant, although not solely dependent on stream habitats.

Ecology

Acrocephalus australis often hop between reeds and usually fly in only in short bursts (Flegg, 2002) and are known for their singing ability (Berg *et al.*, 2005).

Feeding strategy and diet

Acrocephalus australis eats insects that it picks off reeds and stalks of reeds and tall grasses (Australian Museum, 2006a).

Reproduction

In southern Australia, male Australian Reed warblers begin building multiple 'deep cup' nests in home ranges amongst dense reeds in early September before females arrive and breeding occurs from September to February but only one nest is selected for laying by each mating pair (Australian Museum, 2006a; Berg *et al.*, 2005, , 2006). Three eggs are typically laid and the female incubates eggs for ~15 days with chicks fledging after a further 16 days. Males provides food for the chicks (Australian Museum, 2006a; Eikenaar, Berg & Komdeur, 2003).

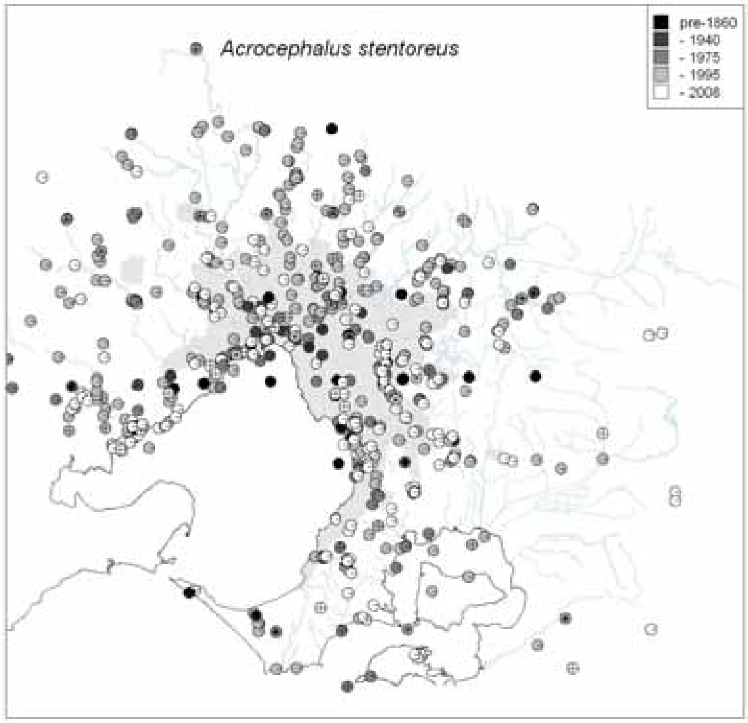


Figure A66. Records of *Acrocephalus australis* (listed as *A. stentoreus*): represented by a pie-chart for each location indicating period of record (source: Atlas of Victorian Wildlife database).

Habitat

As the common name suggests, *A. australis* lives in reed beds. Dense common reed (*Phragmites australis*) or Cumbungi (*Typha* spp.) stands are preferred for nesting and feeding (Berg *et al.*, 2005; Eikenaar *et al.*, 2003).

Threats

Habitat loss occurs through wetland draining and the removal or mowing of reed beds (as nuisance species) in some waterways. *Acrocephalus australis* appear quite resilient to the types of threats that ground nesting birds are subject to but are more restricted in range due to their specific habitat requirements.

Management options

Protection of reed beds along urban waterways and wetlands would benefit this species. Otherwise no additional management is required to secure populations along urban streams.

Cisticola exilis (Golden-headed cisticola; bright-headed cisticola, yellow-headed cisticola, tailor bird, corn bird)

Urban category A_r: urban tolerant

Recommended management:
Protection of stream and wetland reed beds

www.flickr.com

General notes

Cisticola exilis is underrepresented in primary research literature so few specifics of *C. exilis* are known. Studies from other *Cisticola* species were examined and extrapolation to *C. exilis* is made where feasible. *C. exilis* is not listed as a threatened species.

Distribution and abundance

Cisticola exilis is found along Australia's eastern seaboard, northern and north western coastlines but they are absent from Tasmania, the south west and southern central coasts (Flegg, 2002; Simpson & Day, 1993).

It is common along streams and permanent wetlands across the Melbourne Water region, including in the metropolitan area (Figure A67). It is thus urban tolerant, although not solely dependent on stream habitats.

Ecology

Cisticola exilis fly in short bursts and will often 'hop' along the ground and between reeds foraging for food. They are also known for their constant singing (Flegg, 2002).

Feeding strategy and diet

Cisticolas in Africa's grasslands eat mainly adult insects with a small amount of seeds and berries also consumed (Kopij, 2001). As *C. exilis* is strongly associated with aquatic vegetation, we assume that the composition of its diet would mainly be adult aquatic insects but also some plant seeds.

Reproduction

Nest is a small, rounded bag of grasses, plant down, and spider silk, attached to grasses or other vegetation. The female builds the nest, sometimes with help from the male, but incubates the 3-4 eggs herself (http://www.answers.com/topic/golden-headed-cisticola).

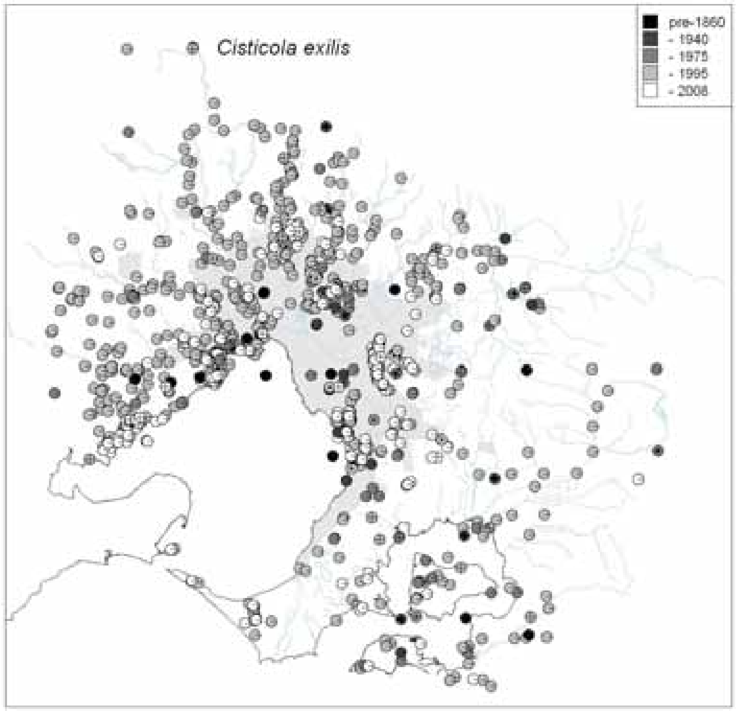


Figure A67. Records of *Cisticola exilis*: represented by a pie-chart for each location indicating period of record (source: Atlas of Victorian Wildlife database).

Habitat

Cisticola exilis appears to be dependent on reed beds in freshwater wetland environments for nesting and feeding, although other *Cisticola* species often use grasslands and wet pasture to forage but an African species preferred freshwater marsh habitat over open spaces (Owino & Ryan, 2006). Figure A56 suggests that *C. exilis* are dependent on freshwater reed-bed habitats to survive as the pattern of distribution closely matches that of other obligate reed bed dwellers such as Swamphens, Coots, Moorhens and Reed Warblers.

Threats

The loss of habitat through sustained drought conditions appears to have contracted *C. exilis* to areas that have reliable supplies of water to sustain habitat.

Management options

Securing in-stream flows as a method of retaining known habitat patches would benefit current *C. exilis* populations. The conservation of permanent wetlands, specifically areas of dense reed stands is also important.

Mammals

Antechinus minimus maritimus (Swamp Antechinus)

Urban category D_t: urban intolerant
(but not relevant to stream management)

Recommended management:
1. Reduce habitat loss and fragmentation
2. Review fire management practices

Photo: http://bird.net.au

Although the common name suggests it is found near swampy areas, *A. minimus maritimus* lives in isolated pockets of wet heath and tussock grasslands or sedgelands in the eastern parts of South Australia through to Corner Inlet in Victoria with the highest abundances in the western districts of Victoria. We therefore feel that it is not sufficiently water dependent to be included in this review, although it is undoubtedly urban intolerant Figure A68.

Basic management practices such as appropriate fire management, reducing habitat loss and habitat fragmentation due to agriculture and urbanization and feral animal control will all greatly benefit this species and arrest the decline of the population (Allison, Gibson & Aberton, 2006; Sale, Ward & Arnould, 2006).

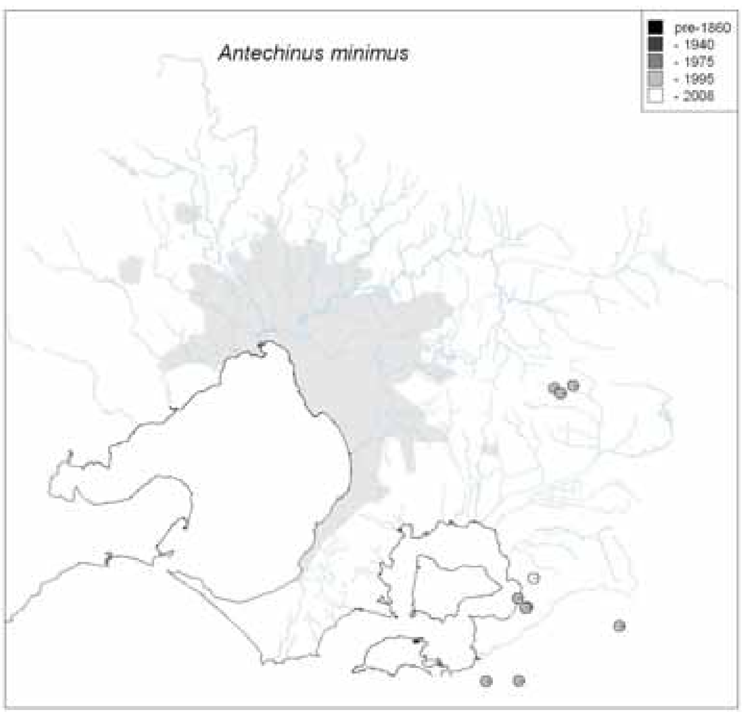


Figure A68. Records of *Antechinus minimus*: represented by a pie-chart for each location indicating period of record. *A. minimus* is not found near metropolitan Melbourne (source: Atlas of Victorian Wildlife database).

Hydromys chrysogaster (Water Rat, eastern water rat; rakali)

Urban category A_r: urban tolerant

Recommended management:
1. Distributional and ecological research
2. Riparian habitat protection
3. Exotic predator control
4. Community awareness programs

Photo: www.anbg.gov.au

General notes

Water rats are large, intelligent rodents. They have been known to teach hunting techniques to their offspring, and rats in the north of the country have evidently found ways to successfully consume cane toads (Sullivan, 2007).

Distribution and abundance

Hydromys chrysogaster is found abundantly over much of the eastern parts of Australia including south-eastern Queensland, NSW, Victoria, South Australia and Tasmania in regions where air temperature does not drop below ~15ºC (Fanning & Dawson, 1980). As the name suggests, it is always closely associated with water (Hampton *et al.*, 1982).

There are many records of *H. chrysogaster* in the Melbourne Water region, including the metropolitan area, but the lack of absence data makes formal statistical analysis of its distribution against DCI impossible. *Hydromys chrysogaster* are patchy in urban streams (Figure A69), but the paucity of surveys specifically targeting *H. chrysogaster* means that they may be more abundant in urban streams than the current data shows. Williams and Serena (2004) collected water rats more commonly in urban streams than in rural streams.

Because it is likely that *H. chrysogaster* in urban streams is more dependent on terrestrial food sources than their rural counterparts, we have classed this species as not solely dependent on stream habitats.

Ecology

Hydromys chrysogaster modifies its behaviour and feeding during winter months to counter its relatively poor thermoregulatory ability (Fanning & Dawson, 1980; Woollard, Vestjens & Maclean, 1978).

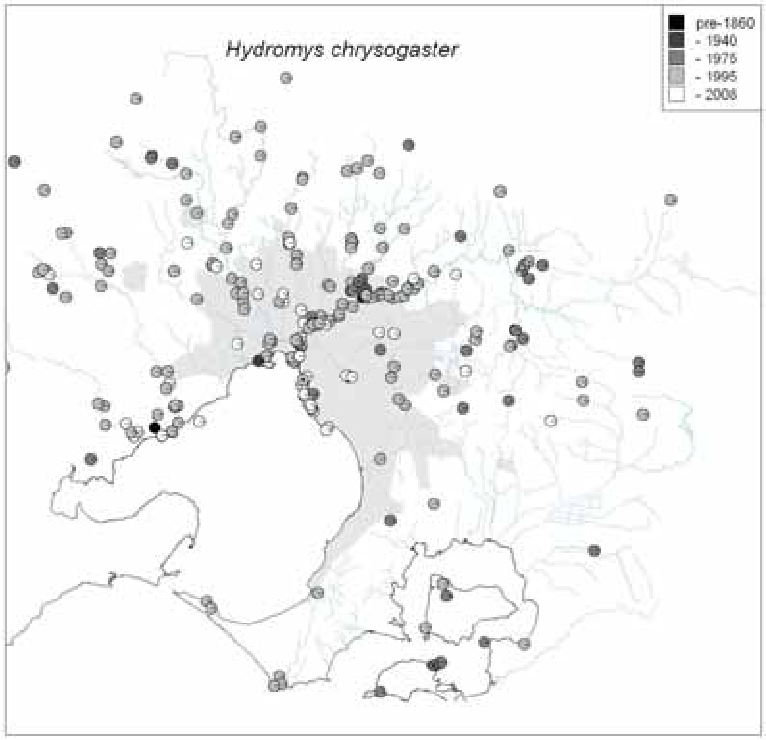


Figure A69. Records of *Hydromys chrysogaster*: represented by a pie-chart for each location indicating period of record (source: Atlas of Victorian Wildlife database).

Feeding strategy and diet

Hydromys chrysogaster is an opportunistic feeder. It has been known to scavenge carrion, actively hunt, cannibalize and also graze on aquatic and terrestrial plant matter (Woollard *et al.*, 1978). It is a frequent diver and uses its rear legs and partially webbed hind feet for propulsion and the front legs for steering, anchoring, digging and prey manipulation, but prey are captured by mouth (Woollard *et al.*, 1978). The main prey item in healthy streams is large or late instar aquatic invertebrates such as odonates, hemiptera, yabbies and mussels. Their diet also regularly includes native and introduced fish, other small mammals, reptiles, frogs and even birds (Woollard *et al.*, 1978).

Reproduction

In suitable conditions (warm weather and abundant food), *H. chrysogaster* can reproduce year-round but are more typically reproductively active during warmer months. They can produce up to 7 young (mean = 3) an average of 3 times per year. Young are generally weaned after one month and most females are mature after 8 months (Olsen, 1982).

Habitat

Hydromys chrysogaster are found near any suitable aquatic habitat. It can live near rivers, lakes, swamps, estuaries and also fully marine systems but requires dense vegetation along these habitats for protection and nesting sites (Hocking & Driessen, 2000; Seebeck & Menkhorst, 2000).

Threats

Rather than being a threat to the water rat, urbanization seems to have a net benefit to some local populations (Williams & Serena, 2004). Their common occurrence in urban streams and their feeding plasticity suggests that urban populations are secure. Domestic pets however, may prey on *H. chrysogaster* (Williams & Serena, 2004). Extended periods of drought may also be a major threat to *H. chrysogaster* (Sullivan, 2007).

Management options

The common observation of water rat middens on large boulders placed on urban streams for channel stabilization suggests that these features can provide useful habitat for the species. However, these sorts of structures are not a recommended management action as they are likely to cause subsequent geomorphic and ecological problems in the future if in-catchment stormwater management successfully returns a more natural hydrologic regime.

With the possible exception of yabbies, the large aquatic invertebrate prey species that dominate diet of *H. chrysogaster* are not abundant in degraded urban streams. It is therefore likely that water rats inhabiting urban streams are more reliant on terrestrial food sources than their rural counterparts. Research into variations in diet and more targeted surveys of *H. chrysogaster* populations in urban and peri-urban streams are warranted.

The conservation of existing urban water rat populations could be helped by: the planting and maintenance of riparian vegetation (including understorey), including control of weed species such as spiny rush (*Juncus acutus*) (Way & Conole, 2002); control of exotic predator species, including domestic dogs and cats; and a range of community awareness programs as suggested by Williams and Serena (2004).

Myotis macropus (Large-footed myotis, southern myotis, river myotis)

Urban category D_r: urban intolerant

Recommended management:
1. For potential expansion into urban area, in-catchment stormwater retention
2. Promotion of old-growth floodplain trees
3. Riparian forest connectivity
4. Distributional research

www.threatenedspecies.environment.nsw.gov.au

General notes

Myotis macropus is part of a diverse bat genus comprising over 90 species in four subgenera (Bickham *et al.*, 2004; Fenton & Bogdanowicz, 2002).

Distribution and abundance

Myotis spp. is very widespread, occurring on every inhabited continent (Bickham *et al.*, 2004). Locally they are restricted to the southeast corner of Australia from south-eastern Queensland to South Australia including the Murray-Darling basin (Law & Anderson, 1999).

In the Melbourne Water region, it is common along rural rivers with the largest known colony in Victoria located 40 km north-east of the city at Yan Yean (six individual bats) (Campbell, 2008), but it has been recorded from only one site with DCI > 0%: the lower Yarra (~3% DCI). *M. macropus* have the ability to travel over 40 km to foraging grounds (Campbell, 2008), so the low occurrence in urban Melbourne waterways suggests they are intolerant of catchment urban impacts (Figure A70). Because of its use of wetlands and lakes as well as rivers, we have classed this species as not solely dependent on stream habitats.

Ecology

Population dynamics of *Myotis* spp. in warm temperate climates are linked to the number of aquatic insects, which are in turn related to seasonal patterns of rainfall (Lloyd, Hall & Bradley, 1999).

Feeding strategy and diet

Myotis macropus has been observed to capture prey by 'trawling' for food by trailing their long feet over the water surface, or aerial feeding just above the water surface. Bats use echolocation to detect, track, and assess prey targets for both these methods (Fenton & Bogdanowicz, 2002). Small fish are taken by the trawling method whereas aerial hunting techniques mainly take the flying stage of aquatic insects (Fenton & Bogdanowicz, 2002). Water surfaces that are chocked with weeds, or are particularly turbulent are not optimal for foraging due to echolocation interference so *M. macropus* is usually confined to large expanses of water such as lowland rivers, estuaries, lakes and wetlands (Campbell, 2008; Law & Anderson, 1999). The diet of bat colonies near Melbourne consists mainly of mosquitoes but also a small portion of fish (Campbell, 2008).

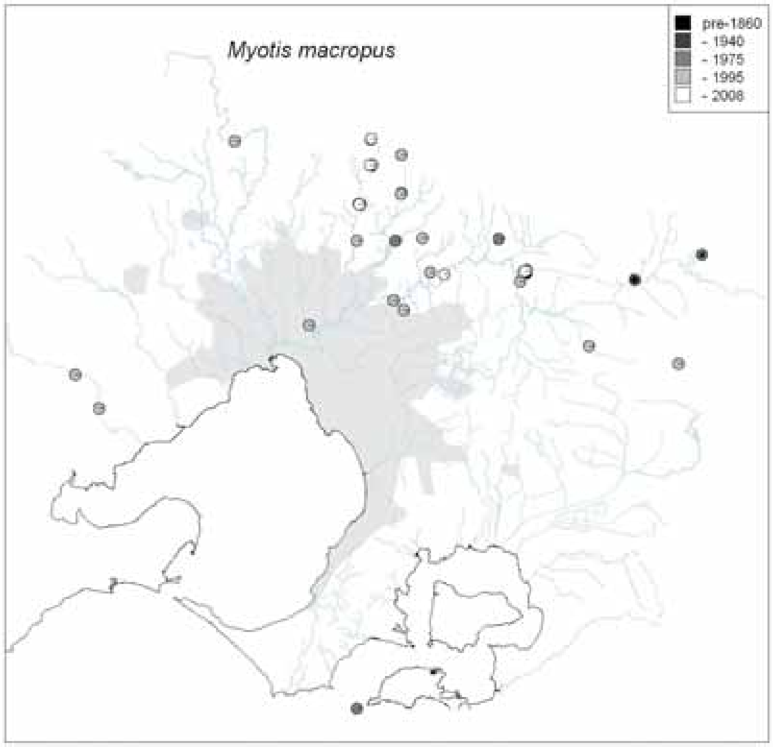


Figure A70. Records of *Myotis macropus*: represented by a pie-chart for each location indicating period of record. *Myotis macropus* are rare in urban Melbourne but do occur in the rural outer north of the city. (source: Atlas of Victorian Wildlife database).

Reproduction

Campbell (2008) detected two maternity roosts at Yan Yean, one inside an aqueduct tunnel just outside the reserve and another in a hollow formed by the loss of a large river redgum branch located within a large block of native woodland. Colonies at both these roosts succeeded in raising young.

Habitat

Myotis macropus generally live near water and roost in a variety of places including hollowed trees, caves, unused mineshafts and tunnels, aqueducts, beneath bridges and even stormwater drains/culverts in some instances (Barclay, Chruszcz & Rhodes, 2000; Campbell, 2008; Law & Anderson, 1999). Similar species have also been known to roost some distance from suitable foraging sites and 'commute' from the roost site multiple times per night (Barclay *et al.*, 2000).

Threats

Although *M. macropus* seem to be reasonably plastic in their selection of roost site, the lack of suitable roosting sites through habitat loss is a major threat to urban *Myotis* populations. *Myotis* need hollow tree branches and trunks typically found in late-succession forests, preferably within 200 m of water (Campbell, 2008). Much of the urban riparian and remnant vegetation in Melbourne is not old enough to provide suitable hollow trunk/branch habitat.

Myotis macropus may be sensitive to the availability, accessibility and quality of permanent water for foraging (Campbell, 2008).

Management options

The absence of *M. macropus* from streams affected by catchment urbanization suggests that expansion of its distribution into metropolitan streams will require catchment-wide reduction of DCI. The health of lowland reaches of river (important for foraging) is imperative for bats employing 'trawling' hunting techniques, so catchment scale impacts must ultimately be managed to sustain populations of *Myotis* in the long-term. Management to improve fish stocks will also benefit *M. macropus* (Campbell, 2008).

Reach scale management of riparian vegetation is important to *M. macropus*, particularly the protection of old-growth riparian vegetation (Campbell, 2008). Therefore, immediate management options for *M. macropus* generally include protecting mature eucalypt patches (possibly with fencing); improving the quantity and quality of existing riparian habitats (habitat for bats and prey items); encouraging greater community awareness of *M. macropus* populations and consulting with bat experts on the timing of high flows through the aqueduct at Yan Yean to avoid inundation of the maternity colony.

Longer term management should focus on enhancing connectivity between patches of riparian vegetation known to support *M. macropus* populations as this may catalyze gene flow among the small populations (Campbell, 2008).

For the colony at Yan Yean, the implementation of gates on the aqueduct is not encouraged at this stage as gates can dissuade a bat colony from using a roost site. The water level flowing through the aqueduct is usually low, but highly variable. Melbourne Water is urged to consult with bat experts on the dates and timing of the breeding season so that flooding and inundation of the maternity colony can be minimized or avoided during critical breeding times (Campbell, 2008).

Campbell (2008) further suggests that the Yarra River should provide suitable foraging and roosting habitat for *M. macropus* but notes that it is not known if populations exist along the Yarra. Further study is needed to identify if colonies exist in the Yarra and why they cannot recruit to this system if no bats are located.

Ornithorhynchus anatinus (Platypus, duck-billed platypus)

Urban category C: Urban sensitive

Recommended management:
1. In-catchment stormwater management, beginning with isolated populations 2. Selected reach-scale recommendations of Williams and Serena for rural populations, urban populations within 4km of rural river, urban catchments receiving catchment management

Photo: www.australianfauna.com

General notes

Platypus are not listed as threatened under the FFG (DSE, 2007a), but are generally considered vulnerable as they are sensitive to human impacts both rural and urban. There is only one recognized species of platypus, however individuals grow much larger in cooler climates in southern parts of Australia than their northern counterparts. They are fully protected Australia-wide.

Distribution and abundance

Ornithorhynchus anatinus are widely distributed over eastern Australia east of the Great Dividing Range from central Queensland to Victoria and also throughout Tasmania. Because platypuses are cryptic there is a perception of low abundance but this is not the case and platypus numbers are generally secure over their range. While they are abundant in rural streams of the Melbourne Water region, there is strong evidence for a contraction of their range as a result of urbanization in the metropolitan area.

There are historical records of platypus from all medium to large streams of the metropolitan area, from which they are now largely absent. Once abundant populations in Merri and Darebin creeks, and likely similar populations in Gardiners and lower Dandenong creeks, were extirpated during the 20th century (Serena & Williams, 2008). Most recently, there is evidence that urban consolidation from Knoxfield to Ferntree Gully has reduced the population of platypus in lower Monbulk Creek. An overall 45% reduction in catch per unit effort in the decade since 1996 along Monbulk Creek, that could be partly explained by drought conditions, was most pronounced in the lower section, which has been developed substantially in that time (72% decline downstream of Lysterfield Rd, compared to a 39% decline upstream of Mount Morton Rd) (Serena & Williams, 2008). Thus there is substantial temporal evidence that platypus are sensitive to catchment urban impacts (Figure A71).

Platypuses are highly mobile: male home ranges are typically 1-4 km, and as far as 7 km in the lower Yarra, while female home ranges are typically 1-4 km (Serena & Williams, 2008). Therefore an analysis of spatial distribution can be misleading unless records are restricted to likely residents. Serena and Pettigrove (2005) used capture rate as a measure of platypus abundance and found that platypus were not found in sites with >11% total imperviousness (excluding reaches of urbanized streams close to the Yarra River). Here, we use the inferences of Serena and Williams (2008) to classify platypus records into three categories of residential status: resident population, transient or seasonal use, or no records in the last decade. Resident populations of platypus are absent from all sites with > 2.2% DCI, with the exception of reaches at the bottoms of Ruffey and Mullum Mullum creeks, within 2 km of the Yarra River (Figure A71and Figure A72). Otherwise, the only sites with DCI > 1.5% and with resident platypus populations are in Jacksons Creek downstream of Sunbury, for which DCI estimates are likely to be overestimates.

Therefore it must be concluded that platypus are highly sensitive to catchment urbanization, and are only able to reside in reaches of urban streams if they are within 2-4 km of healthy reaches of river unimpacted by urban land use (i.e. within their home range). The distribution of platypus in the metropolitan area has contracted over the last century, and there is a high risk of this trend continuing. Serena and Williams (2008) noted that populations in four streams isolated, at least in part by catchment urbanization, are in danger of extinction: the upper reaches of Olinda, Dandenong, Monbulk and Stringybark creeks.

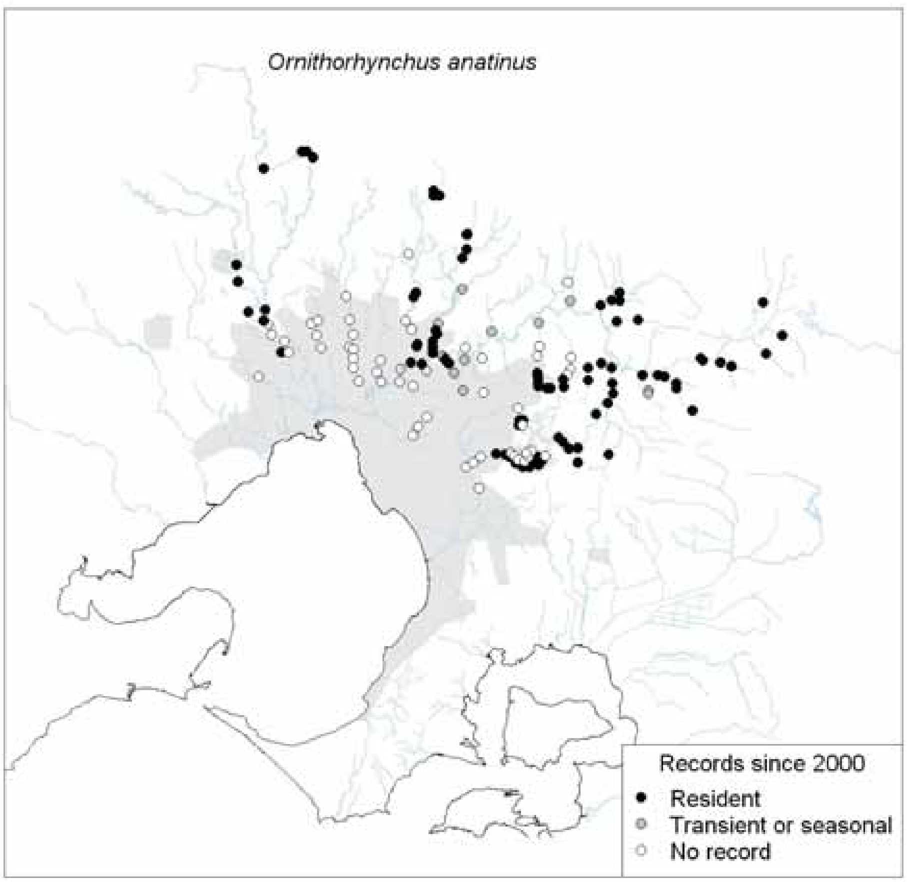


Figure A71. Records of *Ornithorhynchus anatinus* derived from the inferences of Serena and Williams (2008). Resident = reaches where resident populations were inferred in the last decade. Transient or seasonal = reaches where platypus have been captured in the last decade, but Serena and Williams inferred that the use of the reach was either transient or seasonal. Open circles indicate reaches that Serena and Williams inferred were not being used by platypus at all. This map does not include records from the Werribee and Bunyip catchments.

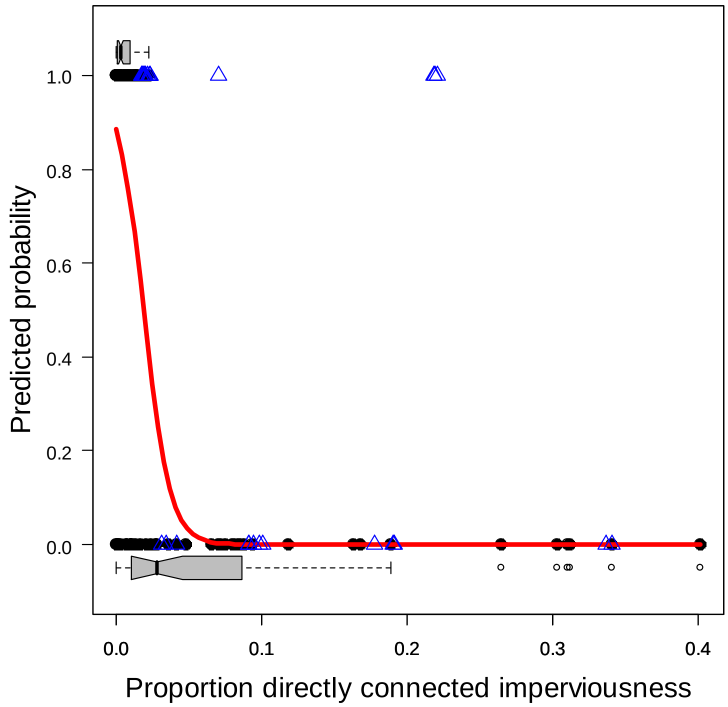


Figure A72. Presence and absence of resident *Ornithorhynchus anatinus* (points and box plots at predicted probability of one and zero respectively) in relation to directly connected imperviousness (DCI) for locations illustrated in Figure A71. The predicted probability curve (red solid line) was calculated using sites indicated by black circles, and excluding sites indicated by blue triangles which have >1,5% DCI and are within 4 stream km of a large non-urban river (the Yarra or Deep Creek in the Maribyrnong catchment). Platypus are likely to reside in streams with no catchment urbanization and were not found in any stream with > 2.2%DCI, with the exception of the lower reaches of Ruffey and Mullum Mullum Creeks, within 2 km of the Yarra River. (Data from Serena and Williams, 2008).

Ecology

Ornithorhynchus anatinus make frequent short dives to the bottom of streams and lakes in order to hunt for food. Typically a single dive lasts for < 1 minute (Kruuk, 1993; Serena & Pettigrove, 2005) largely because they are positively buoyant and have to actively swim to stay submerged.

They have few natural predators but large birds of prey can take adults and goannas, snakes and water rats can prey on eggs and juvenile platypus.

Ornithorhynchus anatinus have home ranges that vary in size according to season (Gust & Handasyde, 1995) and possibly food availability (Serena *et al*., 2001), and both sexes wander extensively throughout their range when not foraging or nesting.

Feeding strategy and diet

Platypus spend up to 14 hours per day foraging and during this time can consume up to 30% of their body weight in food (Serena *et al*., 2001). They forage on the stream bed using sensitive electroreceptors in their bill to detect minute electrical impulses of prey items (Proske *et al*., 1998).

Faragher *et al* (1979) found that the diet of *O. anatinus* consists mainly of benthic invertebrates such as Trichoptera, Ephemeroptera, Odonata, Diptera and Decapoda. Worms, molluscs and ostracods are also occasionally consumed along with small fish and frogs but their stomach contents were strongly linked to densities of prey items sampled from the benthos (Faragher *et al.*, 1979).

After locating and catching prey, *O. anatinus* stores items in cheek pouches on either side of the mouth when underwater and needs to surface in order to chew and swallow (http://www.dpiw.tas.gov.au).

Serena and Williams (2008) posited that *O. anatinus* are most likely to be limited by food availability, and suggest that factors which encourage productive communities of aquatic macro-invertebrates are also known to favour platypus populations. It should, however be noted that the nutrient enrichment associated with urban stormwater runoff produces highly productive macroinvertebrate assemblages of limited diversity, which do not favour platypus (i.e. sites with substantial DCI but no platypus in Figure A72). Thus, the composition of macroinvertebrate assemblages is likely to be as important as their productivity.

Reproduction

Platypuses are one of only two mammals to lay eggs (monotremes). As such, there has been much interest in fully sequencing Platypus DNA in order to assess odd evolutionary traits (Brown, 2008; Warren *et al.*, 2008). Platypus and Echidnas are the only two animals on earth that lay eggs but also produce milk for their young.

Mating occurs in spring and a female will tend to her young, in the nest, for several months (Serena & Williams, 2008).

Habitat

Because they use bankside burrows for shelter during the day and to brood young, platypus need relatively steep, earthen, slightly undercut and densely vegetated banks. These factors have several advantages such as tunnel flood prevention, bank stabilization and entrance discretion (Fox & Monamy, 2007; Serena *et al.*, 1998; Serena & Williams, 2008).

Ornithorhynchus anatinus forage in substrates with slow water flowing over large boulders and tend to avoid soft mud and silt dominated substrates (Serena *et al.*, 2001), however, the broad range of this species, including urban regions, suggests that they can adapt well to altered physical habitat and are quite tolerant of low water quality if sufficient food is available (Serena & Pettigrove, 2005).

Threats

In light of the size and apparent robustness of platypus populations in the rural reaches of the Yarra, Maribyrnong, Werribee, and Bunyip catchments (Serena & Williams, 2008), the priority focus for management effort for the conservation of this species should be the threat of extinction of four isolated platypus populations. For the Olinda, upper Dandenong and upper Monbulk catchments, the primary threat is a) increased urban stormwater impacts from new development in the catchments in which the populations persist, b) isolation of the population by barriers to stream migration formed by severely degraded urban reaches downstream and associated physical barriers such as Lilydale Lake and the piped section of Dandenong Creek below Liverpool Rd and possibly c) lack of overland corridors to permit inter-catchment dispersal and recruitment. For the Stringybark Creek catchment, urban degradation of the creek below Little Stringybark Creek might contribute to the isolation, but the primary problem is channel diversion and degradation in the agricultural land at the bottom of the catchment (Serena and Williams, 2008).

Serena and Pettigrove (2005) demonstrated the importance of sediment and water quality in explaining the loss of platypus populations from urban streams, but as for other animals and stream processes, the combined and compounding effects of complex chemical, physical and flow stressors associated with urban runoff, that degrade in-stream habitat, are inseparable elements of catchment urban impacts. In addition urban stormwater runoff is the primary source of litter that has been identified as a proximate cause of death in many platypuses (Serena & Williams, 2008). Furthermore, other threats such as predation by dogs and foxes, and accidental kills through recreational fishing (and illegal net fishing) are heightened by increased human interaction with streams that is associated with urbanization.

Management options

Serena and Williams (2008) identified twelve reach-scale management actions for the conservation of platypus populations: willow removal, removal of other woody weeds, design and management of walking tracks to separate humans from platypus habitat, reduction of artificial lighting over water, reduction of predation by dogs and foxes, litter reduction, fisher education and regulation, provision of large woody debris and other habitat features, several actions to minimize the impacts of heavy machinery used in channel works, provision of 'platypus friendly' lakes and wetlands, creation of drought refuges along streams, and appropriate provision of environmental flows.

They suggested that recent observations of platypus at Brimbank Park on the Maribyrnong River could have been the result of works to improve habitat along that river. This is possible, as the Maribyrnong remains relatively uninfluenced by urbanization to that point (< 2% DCI). However, their suggestion that the range of resident platypus could be extended up Mullum Mullum Creek through habitat improvement is not supported by the evidence that no resident population has been observed in a stream with > 2.2% DCI more than 2-4 km from a healthy metapopulation in a large, unurbanized stream. It is very unlikely that any habitat improvement works in streams with > 2.2% DCI could result in the re-establishment of resident platypus populations.

Therefore the management actions for improvement of habitat listed by Serena and Williams for the conservation of platypus are likely to be only applicable in a) rural streams unaffected by catchment urbanization; b) reaches of urban streams within 4 km of a stretch of unurbanized river (e.g. the Yarra and its tributaries 4 km downstream of Mullum Mullum Creek, which is about the current extent of resident platypus populations); or possibly c) reaches of urban streams that are slated for catchment-scale works to reduce catchment urban impacts.

Their suggestions for the reduction of incidental impacts of urbanization such as walking track design, fisher regulation and dog and fox management are more widely applicable in reaches of urban streams that are used seasonally or by transient platypus. Such reaches include the Yarra mainstem to the estuary, Mullum Mullum Creek upstream to the Deep Creek Reserve and the lower Plenty River. In addition the management of physical barriers to migration to allow platypus passage is likely to be an important management action for such reaches.

Opportunities to build 'platypus friendly' lakes and wetlands are likely to be limited in urban environments, and each of the examples that they listed present new problems for stream ecosystems that are likely to outweigh any perceived benefit to platypus populations. Toorourrong Reservoir in the upper Plenty River catchment presents a significant barrier to migration of many aquatic fauna and the Liverpool Road retarding basin presents a major barrier that contributes to the isolation of the upper Dandenong Creek population; the Hull Road wetlands along Olinda Creek divert baseflows from the creek, and alter thermal and chemical state of the creek downstream (Walsh *et al.*, 2004a).

But the primary management action for the conservation of platypus should be the protection of the isolated populations in danger of extinction. This will require targeted actions to retrofit stormwater infrastructure in each of the catchments, and careful regulation of new development. As all of the isolated urban populations rise in the Dandenong Ranges, the ongoing road upgrade program of the Shire of Yarra Ranges is a particular threat that requires regulation for the protection of platypus.

Rattus lutreolus (Swamp rat, eastern swamp rat, tawny rat, tawny long-haired rat, velvet furred rat, dusky-footed rat)

Urban category D_t: urban intolerant

Recommended management:
1. For potential expansion into urban area, in-catchment stormwater retention
2. Riparian vegetation and bank restoration and protection
3. Exotic predator control

Photo: www.parks.tas.gov.au

General notes

Rattus lutreolus are not listed as threatened on the FFG Act (1988) (DSE, 2007a).

Distribution and abundance

Rattus lutreolus is found throughout south-eastern Australia and Tasmania. It is a reasonably common species and have the reproductive capacity to quickly build numbers. *R. lutreolus* is not abundant in metropolitan Melbourne and are therefore considered urban intolerant (Figure A73).

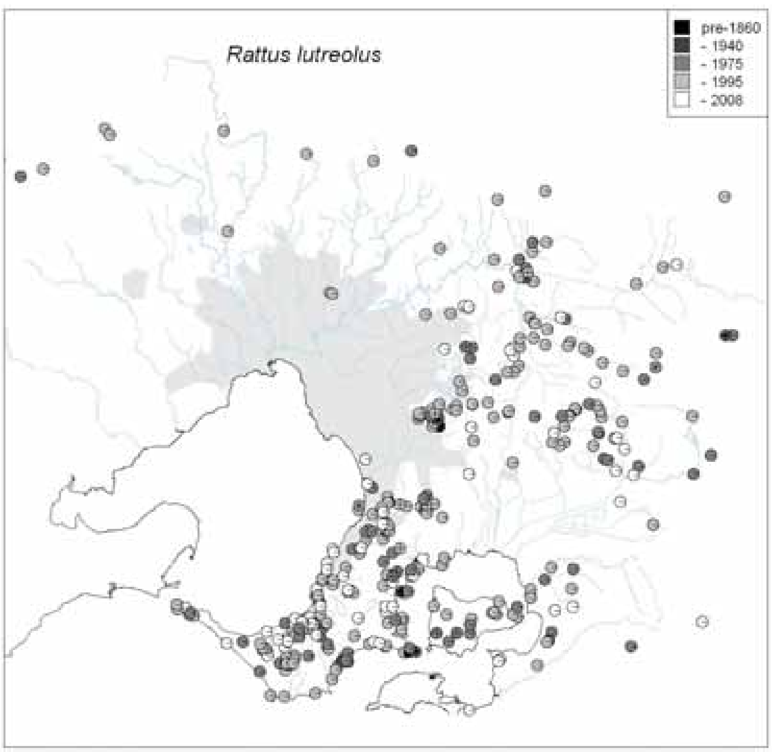


Figure A73. Records of *Rattus lutreolus*: represented by a pie-chart for each location indicating period of record. *Rattus lutreolus* are absent in urban Melbourne but occur frequently in the outer east and are very abundant along the Mornington peninsula and Westernport Bay (source: Atlas of Victorian Wildlife database).

Ecology

The main predators of *R. lutreolus* are birds of prey, feral cats and foxes in the wild and domestic pets closer to urban centres. They are most active during twilight hours but if conditions are favourable then *R. lutreolus* are active day or night (Fox & Monamy, 2007).

Feeding strategy and diet

Swamp rats are primarily herbivores eating the stems and seeds of native vegetation but also consuming fungi and occasionally insects (Luo & Fox, 1996).

Reproduction

Like all rodents, *R. lutreolus* are prolific breeders and have the ability to breed throughout the year, although they may not always exercise this ability (Fox & Monamy, 2007). They usually breed over warmer months and give birth to between 3-5 young. Sexual maturation is rapid with some females three months old able to reproduce (http://www.parks.tas.gov.au).

Habitat

Rattus lutreolus mainly inhabit the margins of creeks, wetlands, swamps and rivers where it can form burrows above high water lines. *R. lutreolus* needs dense vegetation for a combination of feeding and also shelter from birds of prey. Although they live near water, *R. lutreolus* rarely swim and generally avoid doing so (Fox & Monamy, 2007).

Threats

Typical threats to *R. lutreolus* include foxes, domestic and feral cats. Banks (1999) however proposes that foxes only have the ability to control ‘surplus’ numbers of rats and did not constitute a direct threat to a similar species (*Rattus fuscipes*).

The deep incision of streams and rivers in urban areas combined with the removal of dense vegetation (fire risk control) could greatly reduce the available nesting and foraging habitat of *R. lutreolus*.

Management options

Catchment scale stormwater retention is important to reduce the fundamental cause of bank incision and general stream degradation.

Similar to the water rat, the control of domestic and introduced predators will benefit *R. lutreolus* numbers. The restoration of natural habitat by selecting appropriate vegetation type and limiting habitat fragmentation will also improve *R. lutreolus* populations.

Appendix 3 – Managing for in-stream functions

Urban streams function very differently to streams that are unaltered by humans (Groffman, Dorsey & Mayer, 2005; Meyer, Paul & Taulbee, 2005), however our knowledge of how they are different remains poor (Paul, Meyer & Couch, 2006). There are many important functions (sometimes referred to as processes) that constantly occur within a healthy stream system. DCI can alter stream functions in urban streams to the extent that stream health is severely compromised. The creation of an environment that is not suitable for many stream-dwelling animals results and the biological assemblage suffers as a consequence (Walsh, 2004).

Effective management of stream functions potentially benefits many animals in a stream reach. This approach should be preferred over managing for individual species as it can simultaneously target many species rather than a single species.

One important process is organic matter (OM) processing. OM processing (and closely related processes) was identified as vital to the long term sustainability of many of the water dependent animals in Appendix 2.

Organic matter processing

Background

Currently, there are few local or even international studies of the mechanisms that a) deliver organic matter to the stream and b) the processes that transform coarse and fine particulate organic matter fractions into dissolved constituents for urban streams. Pathways for OM delivery and processing are well documented in healthy streams and there are even several local studies on the subject in rural streams near Melbourne (Boulton, 1991; Campbell *et al.*, 1992). In urbanized streams, however, much less is known about either OM delivery or subsequent OM processing dynamics (Imberger *et al.*, 2008).

Organic matter is typically classified into one of three major fractions. The largest and most voluminous fraction is coarse particulate OM (CPOM). This is primarily composed of leaves but also small woody debris (SWD) such as sticks and plant reproductive material and large woody debris (LWD) such as branches and trunks of trees that are > 1mm. The size fraction of OM between ~1 mm and 0.5 µm is referred to as the fine particulate OM (FPOM) and the fraction <0.5µm is dissolved OM (DOM).

The ultimate end point of OM processing is the removal of OM from a reach of stream or river via downstream transport of DOM into receiving waters, or the export of larger material in flood events (typically as FPOM). FPOM is primarily exported in large quantities when stream power is sufficient to suspend this larger OM fraction in the water column (Wallace *et al.*, 1991).

The natural model

In temperate Australia, the timing of OM entry into small streams plays an important role in the healthy functioning of an ecosystem. The majority of OM enters a stream during the summer months when eucalypt leaf abscission is highest (Bunn, 1988a; Campbell *et al.*, 1992), flow is relatively low and stream temperatures are elevated (Boulton, 1991). Leaves are then subject to complex processing pathways conceptualized in Figure A74.

The crux of the natural model (Figure A74) is the ability of the stream to retain a bulk of the CPOM that enters the stream and also to retain the FPOM that is subsequently generated. Once

CPOM is retained in the system, there is a high chance that it will remain in the system while conditions are favourable for the material to be fully processed. Leaves are primarily retained against immovable objects such as small cobbles and LWD snags in fast flowing regions and on the bottom of deep pools in slow flowing regions when the stream velocity cannot keep transported leaves in suspension. Additionally, stream margins also contribute to OM retention and in particular, OM processing will begin in stream margins that are constantly moist.

Once retained, OM processing proceeds via several well understood pathways: chemical leaching, biological consumption and physical breakdown (Figure A74) (Cummins *et al.*, 1989).

Immediately upon being wetted, soluble chemical constituents begin to leach from the leaves. Chemical leaching is sometimes important for further biological processing by microbes and macroinvertebrates (Bunn, 1988b). Danger (unpublished data) showed that ~5-10% of total eucalypt leaf mass can be lost via chemical leaching primarily as DOM.

Biological consumption follows two distinct pathways. Firstly, bacteria and fungi colonize leaves. This is referred to as microbial colonization and highest microbe densities typically occur after several weeks of immersion and after this time leaves are considered microbially 'conditioned' (Boulton & Boon, 1991). The second pathway involves macroinvertebrates that directly consume leaf material for nutrition (Cummins *et al.*, 1989). In undisturbed native systems, obligate shredding invertebrates assist in the rapid transformation of CPOM to FPOM (for a review see Boulton & Boon 1991).

Physical breakdown, or mechanical abrasion, is largely restricted to material retrained in riffles. Less attention has been paid to this processing pathway in undisturbed Australian streams but physical breakdown can also act in two main ways to reduce CPOM to FPOM. Firstly the suspended sediment load and sediment entrained within clusters or 'packs' of leaves acts as an abrasive on the leaf surface, and secondly the turbulent nature of small streams constantly bends leaves causing microscopic fractures on the leaf surface. The consequence of either process is analogous and complementary to microbial conditioning and in some situations has been known to contribute significant portions of total OM processing (Ferreira *et al.*, 2006; Heard *et al.*, 1999).

The urban model

Under the influence of urban stormwater runoff, the primary mode of CPOM delivery to streams changes from direct litter-fall from riparian vegetation, to supply from the greater catchment (Figure A75). This is because stormwater pipes directly connect the catchment to the stream, effectively by-passing the riparian zone (Walsh *et al.*, 2007). A much greater volume of readily labile material is thus piped directly to streams with inherently diminished processing capacity (Danger & Walsh, unpublished data).

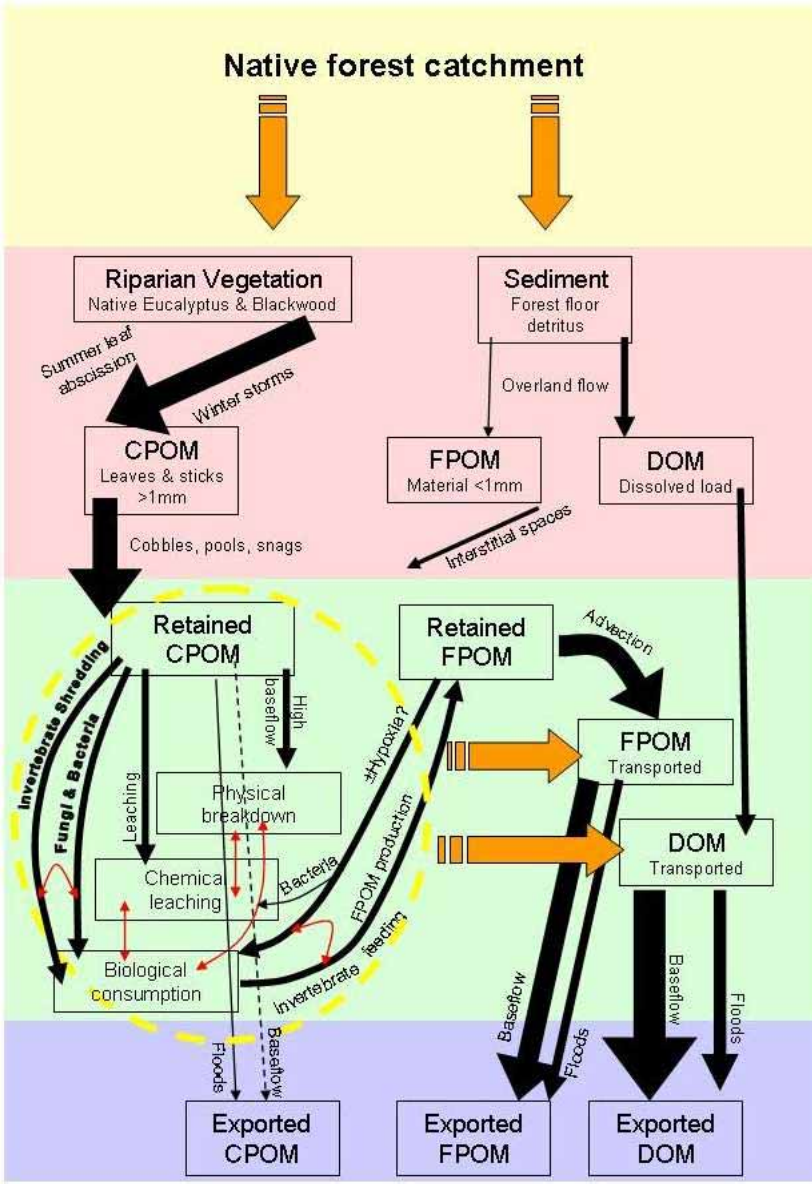


Figure A74 OM processing model for small unmodified streams. Yellow = catchment; Red = riparian zone; Green = in-stream and Blue = receiving waters. The thickness of arrows joining boxes indicates the strength of associated links between boxes and red arrows between links indicate known interactions between factors. The main focus of this model is the complex nature of natural processing pathways highlighted by the yellow circle. Summer leaf falls and sediment washed in from overland flows delivers OM to the stream where it is effectively retained by complex benthic structure. Immediately on wetting, CPOM begins to rapidly leach readily soluble chemicals and much DOM is removed in this process. Fungi and bacteria then colonize CPOM and begin to consume bioavailable OM constituents. As a direct result of microbial colonization, leaves are conditioned to the extent that they become palatable for obligate shredding invertebrates which then feed directly upon the CPOM. Any CPOM exposed to turbulent water will further be subject to abrasion and physical forces that act to break or fracture CPOM which catalyze other processing pathways. DOM is produced by chemical leaching and the by-product of microbial feeding and is the processing endpoint for a substantial proportion of retained OM. FPOM is produced by invertebrate feeding and physical abrasion and can either be exported during floods or utilized by microbes and other insect detritivores. Practically all OM exits the stream as either DOM or FPOM except during major floods where CPOM may be transported out of the stream system.

OM is generally greatly reduced in moderate to severely urbanized streams. Channelization, removal of LWD snags, loss of benthic heterogeneity through siltation and reduced wetted perimeter through lowered base-flows all contribute to loss of bed complexity and a reduction in CPOM retention (Paul, 1999). CPOM retention is particularly vital in an urban context as some major pathways and interactions are lost, thus lowering a stream's gross capacity to process OM along normal pathways: i.e. more immersed time is needed for OM to be fully processed *in situ* (Figure A75).

Shredding invertebrates are particularly sensitive to urban disturbance and are lost with very low amounts of DCI (Imberger *et al.*, 2008). Hydrology, water quality and siltation are all major factors contributing to the loss of sensitive taxa from the invertebrate assemblage but further, the decrease in habitat for shredders due to a reduction in CPOM retention will greatly contribute to the loss of invertebrate processing pathways in urban streams. It also remains to be tested whether exotic OM material is palatable to invertebrates but *Salix* spp has been shown to reduce invertebrate diversity and biomass in a Tasmanian study (Read & Barmuta, 1999), and if similar trends are found in Melbourne streams then it could be reasonably expected that the occurrence of exotic species (particularly willows) could reduce OM processing by invertebrates.

Paul *et al.* (2006) postulated that increased physical abrasion could cause increased OM processing in urban streams, but did not directly measure abrasion. A recent study in the Melbourne region demonstrated that physical abrasion can in fact be reduced in urban streams that still show increased OM processing rates (Imberger *et al.*, 2008). Modified hydrology likely lowers physical breakdown through the lowering of base-flow and thus the reduction in constant suspended sediment load (Imberger *et al.*, 2008).

The replacement of native vegetation with exotic species is of particular note because of the timing of leaf fall. Autumn leaf losses preceding the winter dormant stage in exotics (such as willows, *Salix* spp.), is much different to the predominantly summer fall of *Eucalyptus* species. This adds complexity to the urban model (Figure A75) because exotic vegetation processing drastically changes all established pathways in the undisturbed native model (Figure A74). Imberger *et al* (2008) also demonstrated the potential of exotic leaf material to break down much faster in an urban environment compared with an undisturbed system but that the trend is not necessarily similar for native leaf material.

Eutrophication is a major stressor to urbanized stream environments (Paul & Meyer, 2001; Taylor *et al.*, 2004) and elevated nutrients have been shown to accelerate leaf processing (Paul *et al.*, 2006). This effect is exacerbated by pulsed nutrient release by the rapid breakdown of exotic leaf material (Maloney & Lamberti, 1995) and further, wet OM material that remains in the drainage system immediately after a runoff event will continue to leach nutrients and DOM and these components will be rapidly flushed during subsequent rainfall events.

Processing in lowland rivers

The ability of large lowland rivers to process quantities of CPOM is lower than smaller streams. The number of retention features declines as a result of a change in channel profile, so formation of small leaf packs that are colonized by invertebrates is limited, thus reducing invertebrate processing. Water velocities also drop and this greatly reduces any physical breakdown processing.

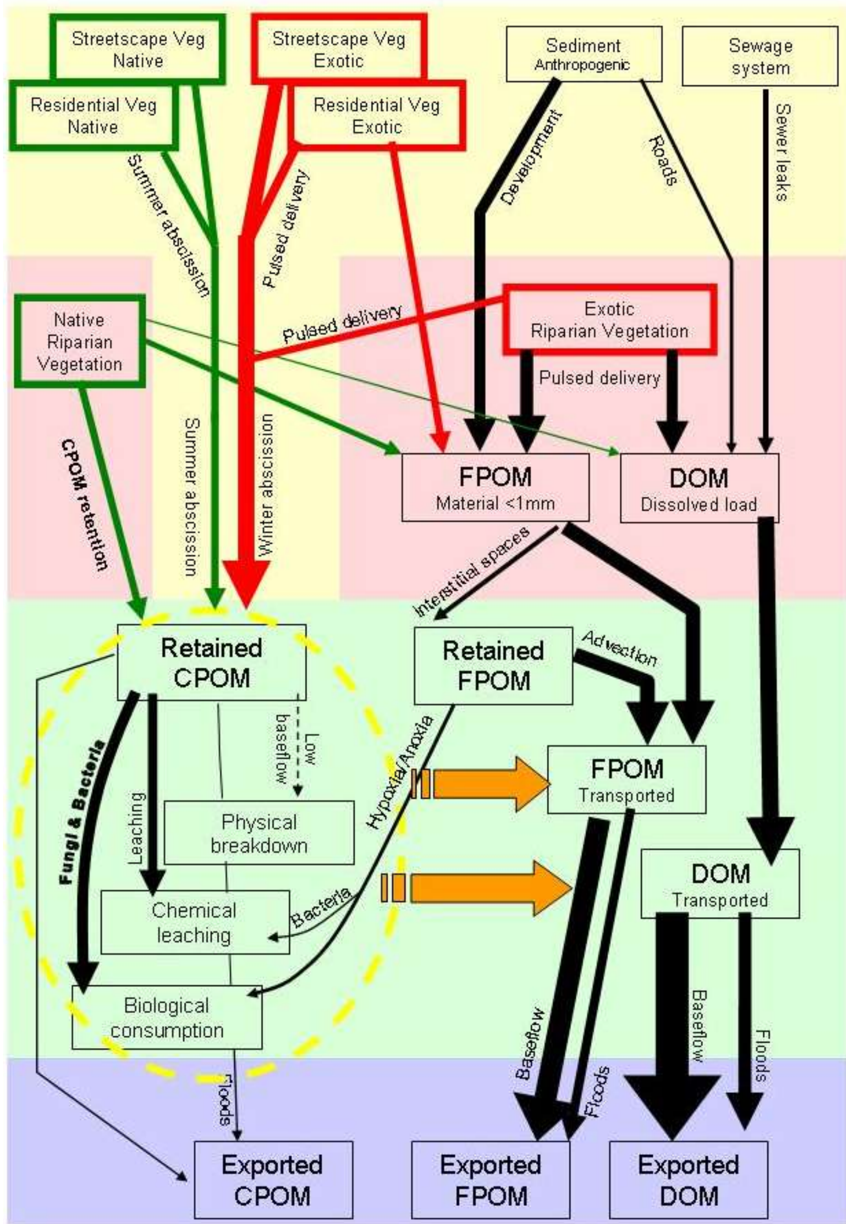


Figure A75: OM processing model for small streams flowing through urbanized catchments. Yellow = catchment; red = riparian zone; green = in-stream and blue = receiving waters. The thickness of arrows joining boxes indicates the strength of associated links between boxes and red arrows highlight exotic vegetation introduced anthropogenically. Much complexity is introduced to the top (catchment) of the model at the expense of in-stream complexity highlighted by the yellow circle. The timing of OM delivery changes from predominantly warmer months to autumn/winter and delivery of sediment is associated with small rainfall events >2mm (enough to cause runoff). Leaking sewer systems also delivers DOM, nutrients and *E. coli* to the stream. A bulk of the delivered OM bypasses the riparian zone thus reducing the chance for interception and subsequent terrestrial processing. Exotic vegetation rapidly releases DOM and nutrients and is also subject to increased microbial but decreased invertebrate consumption. Rapid DOM release can cause localized respiration rates to elevate and potentially cause anoxic conditions in slow flow areas of the stream such as pools. Physical breakdown is reduced as baseflow decreases. As a result, exported OM may be higher because of the increase in catchment OM delivered to the stream, but in-stream processing is lower because natural processing pathways are lost or heavily reduced. OM exits the stream as DOM or FPOM except in flood events where CPOM is also exported.

The consumption of DOM in lowland rivers however, is far greater than in smaller headwater streams. Densities of phytoplankton and zooplankton are much higher in the lower reaches of a river and these fauna have the potential to consume much DOM before it is exported from the system (Allan, 1995).

Management practices

In urban streams, there are several reach-scale actions that could in part help to restore rates of OM import, processing and export, and mitigate the effects of the stormwater drainage system. Gross pollutant traps (GPTs) on drains are, if maintained and designed well, can effectively reduce the import of leaf litter from urban catchments. GPTs have been installed on many large drains around Melbourne, and are an appropriate short-term solution to litter management in the absence of in-catchment stormwater treatment. However, GPTs have almost no other mitigating effect on stormwater impacts to streams, and in-catchment stormwater retention using rain-gardens are a much more effective means of keeping litter in the catchment.

The removal of willows (*Salix* spp.) and other woody riparian weeds, and revegetation with native flora helps to maintain lower OM processing rates in urban streams, because breakdown of the more refractory leaves of native Eucalypts is less strongly affected by stormwater-induced enrichment than the leaves of at least one introduced tree (Imberger *et al*., 2008). The seasonal loss of willow leaves is another potentially damaging aspect of willow trees. Their possible negative impact on macroinvertebrate assemblages is less relevant in urban streams, as macroinvertebrates are more likely to be limited by catchment stormwater impacts.

Artificial riffle construction can be used to increase bed complexity and provide OM retention sites. Such retention structures have been shown to be hotspots for nutrient cycling in degraded urban streams (Groffman *et al.*, 2005). However, the effectiveness and sustainability in urban streams will be much reduced if the stream continues to suffer from catchment stormwater impacts. Actions to increase habitat complexity in streams are generally not recommended until stormwater runoff has been adequately controlled by in-catchment retention measures.

Appendix 4 – Review of knowledge of selected Melbourne estuaries

Arundel and Barton (2007) conducted a review of knowledge of selected estuaries of Port Phillip and Westernport bays, identifying a) knowledge gaps relevant to integrated estuary management and b) potential threats to the estuaries. Like streams in urban Melbourne, many of the estuaries of the region are highly modified by urbanization. Here we outline the findings of the estuaries review that are also relevant to the terms of this review.

Physical disturbance

The installation of levee banks and lined channels prevents inundation and allows safe navigation, but has restricted the lateral extent of many estuaries (e.g. Yarra River; Maribyrnong River; Mordialloc Creek; Patterson River; Kananook Creek; Tooradin Creek; Cherry Creek; Stoney Creek; Brokil Creek; Sheepwash Creek; Dunns Creek; Chinamans Creek; Lower Bunyip Creek; Yallock Creek; Lang Lang Creek). This restricts the lateral connectivity of the estuary, a process that is vital to the biological health and water quality condition of the water body. Many species included in this review such as migratory fish (e.g. galaxiids, grayling, eels and lampreys), transient birds (e.g. herons, egrets, cormorants and kingfishers) and some resident mammals (water rats) are likely to be sensitive to reduced habitat size and heterogeneity, and reduced water quality, as a direct result of lost lateral connectivity.

Accurate physical descriptions, including bathymetric profiles of estuaries, are particularly necessary in estuaries to assess hydrological characteristics. The upper extent of saltwater intrusion and the extent of sandbar build-up at the mouth are two variables that have potential implications for estuary management when considering urban animals. The extent of an estuary partly determines the assemblage of animals that are found within a particular portion of the river. This guides management practices best suited for any given estuary. Estuaries in Melbourne that have barriers to their freshwater rivers include the Yarra (Dights falls), Werribee, Patterson, Maribyrnong and Lower Bunyip rivers and Skeleton, Kananook, Balcombe and Brokil creeks. The extent of sandbar build-up at estuary mouths influences the open or closed status of the estuary (e.g. intermittently closed estuaries such as Skeleton, Balcombe, Sheepwash, Main, Stony, East and Merricks creeks). The status of the mouth has potential to influence the movement patterns of migratory fish that have a marine life stage (e.g. galaxiids, grayling, eels and lampreys).

Further benefits to estuary management may be made with better description of catchments. Arundel and Barton (2007) suggest that accurately defining the size and land use of estuary catchments is difficult, primarily because of the complex nature of the urban drainage system. Better knowledge of catchment size and land use may help explain hydrological patterns within a particular estuary and this information should be used to further develop estuarine management framework, and strategic management plans for individual estuaries. We now have an excellent catchment use and drainage data for the Yarra River and this should be a) built upon with mapping of other catchments and b) used to identify how to best ameliorate catchment scale stressors.

Biological assemblages

Similar problems with biological databases were identified for estuaries that have been identified in this review for rivers. Problems limiting the ability to analyze biological data (including the distribution of animals) included: estuarine association strength (analogous to our transient species category); the timing and method of biological data collection; the age of some biological records and the extent of estuarine riparian area. Comprehensive surveys of flora and fauna have been done for very few estuaries in the Melbourne region, so there is broad scope for increasing knowledge of biota (including many urban sensitive animals) with more intensive biological surveys. Particular attention should be paid to Ecological vegetation class (EVC) and the association of EVCs with rare and threatened plants.

Habitat protection was suggested as the most effective way to maintain populations of birds associated with estuarine habitats. Particular attention should be placed on those birds that feed, roost and breed in estuaries. Birds commonly associated with estuaries and streams in the Melbourne regions include herons, egrets, kingfishers, bitterns and cormorants.

Estuary mouth-opening cycles, water depth, salinity and season are all important factors that can influence the occurrence of particular fish species in estuaries such as those of Skeleton, Balcombe, Sheepwash, Main, Stony, East and Merricks creeks. Mouth status is particularly important when considering the management of migratory fish species such as grayling, eel and galaxiids because, with the exception of grayling, they are common in urban streams and estuaries. Further, galaxiids can spawn in the estuary so management decisions involving mouth opening could potentially consider the loss of eggs and larvae as well as the reduction in foraging habitat for fish and birds.

Threatening processes

Stormwater was identified as a major threat to estuarine waterways. Stormwater degrades estuaries in similar ways to streams; however, sediment and nutrient loads and anthropogenically derived litter are of greater concern as they are retained in estuaries more effectively than in streams. The flashiness of urban stormwater delivery also reduces stream bank stability.

Entrance modification alters hydrological regimes which are potentially threatening to many processes occurring within estuaries and has many different consequences to biological assemblages (outlined above).

Barriers to upstream extent and fish migration are present on many estuaries (see above). The removal of barriers limiting upstream extent may be difficult, but Melbourne Water currently has projects to remove or circumvent fish barriers (Coleman, 2008).

Sediment and water quality are other important factors that may be involved in limiting the distribution of urban sensitive animals. The processes degrading sediment and water quality generally come from the greater catchment, so addressing stream health will also address estuarine sediment and water quality condition. Kororoit and Mordialloc creeks have been shown to have sediment concentrations exceeding interim guideline values established by the Australian and New Zealand Environment Conservation Council (mercury, nickel and zinc in Kororoit, and lead and zinc in Mordialloc).

Reach scale management options

The removal of barriers may be a reach scale management option with significant chance of improving the health of urban estuaries. The removal of levee banks would likely restore some lateral connectivity to estuaries and their riparian zones however this seems an unlikely option considering threats to inundation that would likely result from levee bank removal. A thorough investigation of levee banks that could potentially be removed would benefit research into removal viability.

The artificial opening of some estuaries (e.g. Skeleton, Balcombe, Sheepwash, Main, Stony, East and Merricks creeks) is known to occur (legally or illegally) without full understanding of the physical, chemical and ecological implications. Data collection and examination is necessary to predict the response of the estuary after mouth opening.

Catchment scale management options

Reducing DCI along entire stream (and subsequently estuary) catchments will reduce the impact of stormwater derived disturbance to the natural hydrological regime, but as the catchments of estuaries are generally large, such a management action, must be part of a long-term strategy.

Summary

There are many gaps regarding the knowledge of estuaries in urban environments and much overlap between threats that act upon both estuaries and streams.

Estuaries are subject to similar reach and catchment scale threats as streams. Reach scale management may have benefits to the condition and extent of estuaries but the distribution of all but a handful of animals found in the urban environment are unlikely to be greatly enhanced by reach scale management of estuaries. Catchment scale reductions in DCI will restore a more natural hydrological cycle to estuaries, improve water quality, reduce nutrient and sediment toxicant loads, and restore baseflow to estuaries and thus benefit broad range of animals found in urban areas.

Appendix 5 - Glossary of terms

Abscised	fallen leaf material
Aestivation	a state of dormancy, usually when aquatic habitats dry
Ammocoetes	juvenile lamprey
Anadromous	live in the ocean but move into freshwater to breed
Berried	female decapods carrying eggs under the tail
Dabbing	a form of feeding in ducks
DCI	directly connected imperviousness
Detritus	dead or decaying organic material
Detritivore	animals living off detritus
Diadromous	move between fresh and saltwater
Filter feeder	animals that filter water for suspended OM particles to gain nutrition
Grazer	a functional feeding group of animals that graze on plants or algae
Hydroperiod	the period of time that habitat is inundated with water
Instar	an insect larvae goes through a series of molts called 'instars'
Macrophytes	flowering aquatic plants (generally not algae)
Metamorphosis	the change from juvenile to adult in frogs and fish
NS	not significant
OM	organic matter
Pelagic	mid-water
Perennial	permanent
Predator	an organism that hunts an organism lower in the food chain
Pugging	cattle damage to the water-land interface caused by hooves sinking into mud
Sedimentation	the process which deposits fine organic or in-organic particles on the bottom of streams and wetlands
Sexual dimorphism	physical differences between males and females of the same species
Shredders	a functional feeding group of invertebrates that 'shred' particles of OM.
Urban stream	streams with > 1% DCI

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