Australian Rivers Institute

Mini-review of major threatening processes and mechanisms of impact on freshwater biodiversity in northern Australia

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For summary of mechanisms of impact of different threats to freshwater biodiversity in northern Australia, see Table 1 (below).

Swamp buffalo

Swamp buffalo (*Bubalus bubalis*) and feral pigs (*Sus scrofa*) are the most conspicuous alien vertebrate pests that degrade aquatic ecosystems of northern Australia. Buffalo have caused severe damage to wetland environments in the Northern Territory, including accelerated soil erosion and sedimentation, channelling of floodwaters, saltwater intrusion into freshwater habitats, loss of wetland vegetation, and reductions in the diversity of wetland plants and animals (Petty et al 2007).

Feral pigs

Feral pigs represent another significant threat to waterways throughout the wet–dry tropics, particularly as their distribution is largely limited by access to water, as they are easily heat stressed. Like buffalo, pigs increase riverbank erosion and the spread of weeds through trampling and rooting. Pigs are omnivorous, consuming a variety of wetland and riparian seedlings, freshwater invertebrates and amphibians, and eggs of ground-nesting turtles, crocodiles and birds (Bayliss et al 2006, Pusey and Kennard 2009, Mitchell 2010). Pigs have relatively small home ranges (Caley 1997), which results in herds congregating around permanent waterholes and wetlands during the dry season (Cowled et al 2009), thus concentrating their activity and increasing their local impact. They uproot and eat riparian seedlings as they root along riverbanks in search of food. During the hottest months, pigs wallow in the wet margins of waterholes, dramatically increasing the amount of suspended sediment in the water column and reducing water clarity. The physical disturbance associated with wallowing may reduce the capacity of wetlands to rejuvenate with the onset of summer rains.

Cane toads

The impacts of the cane toad (*Bufo marinus*) may be greater on terrestrial organisms than on aquatic organisms. However, reports of declines in abundance of freshwater crocodiles (*Crocodylus johnstoni*) (Letnic et al 2008) and two species of water monitor (*Varanus mertensi* and *V. panoptes*) are known, and the latter were listed as threatened in the Northern Territory in 2006 (Fox 2008). Cane toads have been shown to rapidly reduce local populations of water monitors and alter their occupancy of suitable sites (Griffiths and McKay 2007). Interestingly, there is recent evidence that the omnivorous fish *Hephaestus fuliginosus* (black bream, or sooty grunter) can consume cane toads with no ill effects (Davis and Perna 2009). Recent research has indicated that the impact of toads may not be as great as previously thought.

Toads were originally introduced into Queensland in the early 1930s to control insect pests in cane fields—which seemed like a good idea at the time. While we still do not know whether they fulfilled this role of cane beetle consumers, we do know that they have spread widely from the point of introduction, and continue to do so. Moreover, they are now spreading at a faster rate, due to both rapid physical and behavioural change. Toads on the invasion front now have longer legs, move in a straighter line, stay in one place for less time, use existing road networks, and are not averse to hitching a ride in vehicles (Brown et al 2006, Phillips et al 2006, Alford et al 2009, White and Shine 2009) The invasion front now moves at about 55 km each year, compared with 10 km each year when toads were restricted to Queensland. Urban et al (2007) predicted that toads will eventually colonise every mainland state.

Toads are highly toxic at all life stages. The toxins—a variety of bufogenins or bufodienolides—are rapidly acting and frequently cause death upon ingestion. Declines in native wildlife associated with toads have occurred, although no species has been driven to extinction. Mass mortality in native anuran tadpoles has been reported, because tadpoles eat the highly toxic eggs (Crossland et al 2008). Presumably, the many anecdotal accounts of fish kills associated with high toad densities may also be associated with egg predation.

Declines in the abundance of monitor lizards have coincided with the appearance of toads (Ujvari and Madsen 2009). Doody et al (2009) found that, within a year of the cane toad colonising the Daly River catchment, some species of monitor lizards (*Varanus panoptes, V. mitchelli and V. mertensi*) all greatly decreased in abundance. Notably, they also found that the freshwater crocodile, *Crocodylus johnstoni*, did not also decline at this time, despite the fact that seven dead specimens had eaten toads shortly before they died. Other studies reported declines in *C. johnstoni* due to toads in the Daly River (Letnic et al 2008), and that this species is highly susceptible to toad toxins (Smith and Phillips 2006). Interesting indirect effects of the reduction in *V. panoptes* abundance include increased survivorship of pig nosed turtle nests (Doody et al 2006) and an increase in abundance of the dragon lizard, *Lophognathus gilberti* (Doody et al 2009). Both turtle eggs and dragons are a major food source of *V. panoptes*. Such indirect effects are likely to be common and perhaps very important in changing patterns of biodiversity in toad infested areas. Greenlees et al (2006) reported that toads reduce the abundance of grounddwelling invertebrates, but only to the same extent as the equivalent biomass of native frogs. However, toads may attain extraordinary densities on floodplains (more than 2000 per hectare; Phillips et al 2003), and may become a major sink for carbon (in the form of insects) that becomes unavailable to other higher-order consumers until the toads die and re-enter the food web via decomposer organisms. Given their mobility, toads may also export energy from the ecosystem.

***Grazing* (and other Agricultural land use)**

Agriculture can affect aquatic ecosystems in many ways, including increased sedimentation, nutrient enrichment, contamination with biocides and other chemicals, changes in run-off rates and increased likelihood of alien weed invasions. Importantly, the effects of agriculture on aquatic systems may be persistent and difficult to correct; thus agriculture may have significant negative legacy effects (Allan 2004).

Sediment mobilised by agricultural and pastoral activity is delivered to aquatic environments via run-off, causing a variety of deleterious physical and ecological effects. Suspended sediments reduce water clarity and hence the availability of light needed for photosynthesis. Thus, increased sediment loads can depress primary production and hence impair ecosystem function. Sedimentation can reduce habitat quality for bottom-dwelling animals (e.g. by infilling the interstitial spaces of sand and gravel streambeds), and suspended sediments may also clog the gills and respiratory surfaces of invertebrates and fishes. Prolonged increases in sediment loads can ultimately result in changes in river channel form, loss of pools through infilling and overall reduction in habitat diversity.

Nutrients applied to crops often find their way into aquatic environments, sometimes in large and damaging quantities. Nutrient enrichment can massively increase rates of primary production (the process of eutrophication), potentially causing proliferation of filamentous algae and blooms of toxic blue-green algae. Ganf and Rea (2007) assessed the potential for blooms to occur in rivers of northern Australia. They found that nutrients were limiting—that is, in short supply—in natural circumstances, and were consumed by plants and algae before large algal blooms could occur. More importantly, they found that the necessary inoccula for algal blooms, including species of toxic cyanobacteria (blue-green algae), were present in northern Australian rivers, but were kept at very low biomass because of nutrient limitation. These findings indicate that algal blooms could occur if nutrient levels increased as a result of human activities so that they were no longer limiting. This is of particular concern in the generally nutrient-poor systems of northern Australia (Douglas et al 2005).

Contaminants arising from agricultural practices include pesticides, herbicides and heavy metals. Biological impacts on aquatic organisms (e.g. invertebrates and fish) from these chemicals include increased rates of physical deformities, impacts on behaviour (such as the propensity for larval invertebrates to disperse, or drift, in the water current), reduced growth rates, reductions in reproductive capacity and a host of other effects. In tropical Australia, the rate of delivery of contaminants from agricultural lands to aquatic ecosystems may be significant.

Many of the impacts described above are particularly associated with broadacre agriculture, although they are not limited to this type of agriculture. Despite the patchy nature of mosaic-style agriculture, it may still have widespread impacts across river–floodplain ecosystems. Although best practice irrigation should see no water exiting from cropped areas during the dry season, high-intensity rainfall events during the wet season will still result in the mobilisation of sediments and residual fertiliser and toxicants. In addition, the development of road infrastructure to service widespread and patchy mosaic-style development is likely to have its own suite of impacts (e.g. barriers to movement, increased rates of erosion). Widespread extraction of groundwater to irrigate mosaic-style agriculture is likely to reduce groundwater inputs to river systems and cause drawdown of groundwater in subterranean systems. Careful monitoring of aquifers may regulate the extent of this impact, but this may be difficult in areas with diffuse, poorly recognised aquifers; where the links between aquifer recharge and subsequent discharge to river systems are poorly understood; where the distribution and needs of groundwater-dependent ecosystems are unknown; and where there may be significant time lags in groundwater recharge and hence responses to extraction.

***Altered flow regimes* (particularly dry season water extraction)**

Maintenance of the natural flow regime is critical to the integrity of aquatic ecosystems and biodiversity. Changes in natural patterns of river flow due to changing land use, water resource development and projected global climate change are at the forefront of the many processes that threaten aquatic habitats and biota regionally, nationally and globally. The distinctive flow regimes of northern Australia thus remain largely unaffected by human activities; however, impoundments, riparian extraction (i.e. direct pumping from the river) and groundwater extraction have the potential to affect the natural run-off and recharge rates in particular areas.

Dry season water extraction reduces baseflow, dewatering important flow-sensitive habitats that are critical for many fish species, and for aquatic algae and invertebrates, which provide food for larger species such as freshwater crocodiles, barramundi and black bream (Douglas et al 2005, Webster et al 2005, Townsend and Padovan 2009, Chan et al 2010). Extreme reductions in flow can disconnect river reaches, preventing the movement and migration of numerous species of crustaceans, fish and turtles, and resulting in isolated populations that are more at risk from localised disturbances.

Water extraction can affect groundwater recharge rates and riparian vegetation communities that rely on groundwater (O'Grady et al 2006, Tien 2006). Groundwater extraction may disturb subterranean and groundwater ecosystems, which are thought to play important roles in filtering and water purification (Humphreys 2008, Pusey and Kennard 2009). Naturally isolated waterholes are a common feature of many intermittent rivers in northern Australia. They are critical refuges for water-dependent biota and are key watering points for many terrestrial animals during the dry season. Waterholes are often sustained by connection to groundwater once surface flow has ceased. When this connection is prevented by lowered groundwater levels, the waterholes dry out more quickly and their value as a refuge can be compromised by an unnaturally rapid deterioration in water quality (e.g. low dissolved oxygen and increased concentration of salts). Dry-season waterholes may be the only source of aquatic refuge over many hundreds of kilometres of otherwise dry streambed. The refuge provided by isolated waterholes is very important as they are the point from which recolonisation and dispersal along the river occurs once connectivity is restored by wet season flows. Human impacts on the spatial distribution and persistence of dry-season waterholes can therefore have widespread and prolonged ecological consequences.

Barriers to movement caused by physical infrastructure **(weirs and road crossings)**

Many northern Australian species of fish, crustaceans and other biota move extensively throughout river networks, on and off seasonally inundated floodplains, and between freshwater and marine ecosystems. Such movements are necessary to complete life cycles and are vital for maintaining viable population sizes and genetic integrity. Water infrastructure developments such as dams, weirs and tidal barrages can be significant barriers to such movement. These barriers can prevent access to upstream riverine habitats, which are vital for development of fish that spawn in estuaries (barramundi, sawfish, bullsharks and a host of other species) but can also spend much of their early lives in fresh water, often far upstream. Barriers may therefore affect commercial fishery values.

Cascading impacts throughout the riverine ecosystem can occur because many such species are top predators and play an important role in the structure of natural communities and the movement of carbon and energy through aquatic food webs (Douglas et al 2005, Pusey and Kennard 2009). Freshwater prawns also migrate upstream after they have developed from larvae into juveniles in estuarine or downstream river habitats. Freshwater fish such as black bream (*Hephaestus fuliginosus*) and eel-tailed catfishes (*Neosilurus* spp.) can be prevented from accessing tributary streams required for spawning. Without such movement, local populations diminished by seasonal drought or flooding cannot be replenished.

Although there are relatively few large dams in northern Australia, there are numerous smaller dams and weirs that can pose a barrier to the movement of aquatic organisms. Road crossings can also form artificial barriers to movement, particularly during low-flow periods when many species of fish disperse throughout river networks (Lamche 2006, van Dam et al 2008a, Pusey and Kennard 2009). Any development of northern Australia is likely to involve expansion of the existing road network, which may place further pressure on these migratory species.

Reservoirs, weirs and barrages may also act as barriers to the movement of materials other than biota. For example, reservoirs act as sinks or storage sites for suspended sediment and the nutrients attached to them, and also trap sand being transported along the riverbed. When fine sediment becomes trapped and is no longer available for downstream and lateral transport in floodwaters, the annual replenishment of floodplain habitats, which is vital for natural communities and agricultural production, is reduced. Transmission of sediment is also important for the maintenance of natural geomorphological processes and downstream habitat. Without continual replenishment, features such as sandbars gradually become smaller and less abundant. These habitats are crucial for reproductive success of freshwater crocodiles and turtles in northern Australia.

Aquatic weeds

Many plant species now recognised as invasive weeds were deliberately introduced into the environment to support pastoralism (Cook and Dias 2006). Invasive plants pose a serious threat to the waterways and floodplains of northern Australia. The release of aquarium plants by the public and their dispersal from fish ponds to waterways during the wet season also poses a major risk to the aquatic environment. Fishing equipment and boats are a common means of spread of invasive weeds. Five such weed species in northern Australia— *Mimosa pigra, Hymenachne amplexicaulis, Cabomba caroliniana, Salvinia molesta* and *Cryptostegia grandiflora*—are listed as weeds of national significance because their impacts on natural and agricultural systems are so severe. These five species illustrate the spectrum of the impact of weeds on aquatic systems.

Salvinia molesta is a surface-dwelling plant that also grows and reproduces extraordinarily rapidly. It may completely blanket the surface of waterbodies in a very short time, doubling its dry weight every 2.5 days under optimal conditions (Room et al 1981). Prolific stands may prevent the transmission of sunlight into the water column and effectively curtail photosynthesis and primary production. *Mimosa pigra* (prickly mimosa) forms dense thickets on floodplains and on the margins of waterholes, monopolising space and nutrients and preventing access to permanent water by species such as waterbirds and wallabies. It is estimated that mimosa now infests about 800 square kilometres of coastal floodplains across the Northern Territory. The combined pressures of climate change, land use and feral animals may facilitate the growth and spread of this weed (van Dam et al 2008a).

Hymenachne amplexicaulis is an introduced pasture grass that invades permanent waterbodies and seasonally inundated wetlands. Because it is capable of growing in several metres of water, hymenachne can choke waterways sufficiently to prevent water movement and intensify flooding. It forms dense stands that reduce native plant diversity and available habitat for native animals, particularly fish (Ferdinands et al 2005). It can also out-compete important native grasses. *Cabomba caroliniana* is a fully aquatic plant that grows prolifically and is highly invasive. It is present in Darwin River. Its profuse growth ensures that it is able to quickly dominate waterways, and it is a serious problem in irrigation canals and impoundments as well as natural waterways. The plant secretes a sticky mucus around its leaves, which inhibits consumption by herbivorous animals and reduces its value as fish habitat. In dense stands in still waters, it may cause dissolved oxygen levels to fall so low through nocturnal respiration that fish kills occur (due to asphyxiation), although this feature is not restricted to alien aquatic plants. Its potential to disrupt aquatic food webs is extremely high. *Cryptostegia grandiflora* (rubber vine) is a serious pest species that occurs as isolated outbreaks in the Kimberley region and the eastern edge of the Northern Territory but is especially widespread in the Gulf region of Queensland. In Queensland, the Queensland Land Protection (Pest and Stock Route Management) Act 2002 requires landholders to control its spread and abundance. Rubber vine is a vigorous growing shrub whose seeds are spread in waterways. It forms dense, impenetrable thickets along streambanks, preventing stock access to water and reducing riparian biodiversity. From streambanks, it may spread to the surrounding savanna (Doak et al 2004).

Many other weeds have serious impacts on northern Australia's aquatic ecosystems, even though they are not listed as weeds of national significance. These alien plants include water lettuce (*Pistia stratiotes*), para grass (*Urochloa mutica*) and water hyacinth (*Eichorna crassipes*). Water hyacinth is of considerable concern as it may quickly establish surface mats that then become the substrate for other weeds, such as para grass. This alien vegetation complex then becomes an impenetrable, stable cover on the water's surface, which can only be dislodged by the very largest of floods. Such mats have been a persistent problem in irrigation areas such as the Burdekin delta and have been shown to depress water quality (Perna and Burrows 2005) and eliminate native fish communities (Perna 2003).

In 2009, five tropical invasive pasture grasses were listed as a key threatening process under the Environment Protection and Biodiversity Conservation Act 1999. Four of these species pose serious threats to inland waters in the region, including para grass and olive hymenachne (*Hymenachne amplexicaulis*), which threaten wetland and floodplain habitats, decreasing native biodiversity. Other weeds have also become a concern in recent years, including the introduced pasture grass gamba grass (*Andropogon gayanus*), Noogoora burr (*Xanthium occidentale*) and the perennial and annual mission grasses (*Pennisetum polystchoin* and *P. pedicellatum*, respectively) (van Dam et al 2008a). Gamba grass and mission grass threaten riparian habitats, monopolising space and increasing fire intensity and risk (Rossiter et al 2003, van Dam et al 2008a).

In contrast to feral animals, which are mostly very widespread across the region, most of the weeds that have serious impacts are not yet so widely distributed. Some are currently quite restricted in distribution. Riparian areas provide an ideal habitat for such species to establish, since they are relatively cool and moist. The spread of weeds from riparian areas is greatly facilitated by the annual dispersal of propagules in floodwaters. Thus riparian areas may act as a staging point for further spread.

Table 1. Summary of mechanisms of impact of different threats to freshwater biodiversity in northern Australia.

Primary threats	Mechanisms of impact on freshwater biodiversity		Implications for ecological resources and processes
	Direct	Indirect	
Swamp Buffalo	Trampling	suspension of sediments leading to elevated turbidity and reduced primary production	Water quality, Food availability (plants & animals)
		direct damage to nests/eggs (all taxa) and juveniles (birds, turtles)	Habitat availability (refuge, reproduction)
		accelerated soil erosion on land and in Riparian zone leading to increased sedimentation of aquatic habitats	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
		channelling of runoff on floodplains and loss of local floodplain inundation	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals), Connectivity
		saltwater intrusion into freshwater habitats,	Water quality, Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals), Connectivity
		loss of aquatic and riparian vegetation	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
	Competition for food	grazing of aquatic and riparian vegetation	Food availability (plants)
	Defecating & Urinating	nutrient enrichment and increased algal growth	Water quality, Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
	Defecating	addition of fine particulate organic matter leading to smothering of benthic aquatic habitat	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
Feral pigs	Predation	direct predation on waterbirds and turtles (adults, juveniles, eggs)	direct decline in abundance
	Competition for food	grazing of aquatic and riparian vegetation	Food availability (plants)
		consumption of aquatic and riparian animals (e.g. molluscs, crustaceans, insects, vertebrates)	Food availability (animals)
	Trampling and rooting	suspension of sediments = elevated turbidity	Water quality, Food availability (plants & animals)
		accelerated soil erosion on land and in Riparian zone leading to increased sedimentation of aquatic habitats	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
		channelling of runoff and loss of local floodplain inundation	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals), Connectivity
		saltwater intrusion into freshwater habitats,	Water quality, Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals), Connectivity

Primary threats	Mechanisms of impact on freshwater biodiversity		Implications for ecological resources and processes
	Direct	**Indirect**	
		loss of aquatic and riparian vegetation	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
	Defecating & Urinating	addition of nutrient rich organic matter leading to elevated nutrients, smothering of benthic aquatic habitat	Water quality, Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
Cane toads	Predation	direct predation on fish eggs (& juveniles & adults?)	Direct decline in abundance
	Poisoning	predation by fish (& turtles?) on toad eggs & tadpoles (& adults?)	Direct decline in abundance
	Competition for food	tadpole grazing of aquatic detritus and algae	Food availability (algae & detritus)
		adult consumption of aquatic and riparian animals (e.g. crustaceans, insects, vertebrates)	Food availability (animals)
Grazing (and other agricultural land use)	Trampling	suspension of sediments leading to elevated turbidity	Water quality, Food availability (plants & animals)
		direct damage to nests/eggs (all taxa) and juveniles (birds, turtles)	Habitat availability (refuge, reproduction)
		accelerated soil erosion on land and in Riparian zone leading to increased sedimentation of aquatic habitats	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
		loss of aquatic and riparian vegetation	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
	Competition for food	grazing of aquatic and riparian vegetation	Food availability (plants)
	Defecating & Urinating	nutrient enrichment and increased algal growth	Water quality, Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
	Defecating	addition of fine particulate organic matter leading to smothering of benthic aquatic habitat	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
Altered flow regimes (dry season water extraction)	Reduced river baseflow	Reduction in habitat volume	Habitat availability (refuge, feeding, reproduction)
		Reduced extent of shallow fast-flowing habitats	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
		Reduced depth of deep slow-flowing habitats	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
		Exposure of submerged bankside structures (e.g. wood, root masses undercut banks)	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
		Reduced longitudinal connectivity over shallow riffle areas	Movement

Primary threats	Mechanisms of impact on freshwater biodiversity		Implications for ecological resources and processes
	Direct	Indirect	
		Increased risk of exposure to predation, competition for resources, transmission of diseases	direct decline in abundance
		Risk of exposure eggs and nests if rapid reduction in water levels	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
	Reduced groundwater-surfacewater connectivity	Reduced persistence of waterholes as aquatic refugia	Habitat availability (refuge)
		Reduced integrity of riparian vegetation	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
Barriers to longitudinal connectivity (weirs and road crossings)	Reduced ability to move within river networks	restricted access to habitats for spawning, rearing or growth for diadromous species (large scale)	Habitat availability (feeding, reproduction), Food availability (plants & animals)
		restricted access to habitats for spawning, rearing or growth for non-diadromous species (local scale)	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
Aquatic weeds	Proliferation and blanketing of water surface (e.g. *Salvinia*)	reduced light transmission into water column, curtailing photosynthesis and primary production (algae and native macrophytes)	Water quality, Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)
	Proliferation on floodplains and waterhole margins (e.g. *Mimosa*)	dense thickets monopolise space and nutrients and prevent access to permanent water by species such as waterbirds	Habitat availability (refuge, feeding, reproduction), Food availability (plants & animals)