Australian Government

MURRAY–DARLING BASIN AUTHORITY

Mozambique tilapia

The potential for Mozambique tilapia *Oreochromis mossambicus* to invade the Murray–Darling Basin and the likely impacts: a review of existing information


Illustration: Marjorie Crosby-Fairall

Michael Hutchison, Zafer Sarac and Andrew Norris
Department of Employment, Economic Development and Innovation

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> *Authors: Michael Hutchison, Zafer Sarac and Andrew Norris – Department of Employment, Economic Development and Innovation*
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Recommendations

From an ecological perspective, it is recommended that programs that promote early detection of tilapia and prevention of infestation in the Murray–Darling Basin be made a high priority. The best way of protecting aquatic ecosystems and native fish populations from the possible impacts is to make sure tilapia do not enter the Murray–Darling Basin system. A key facet of any prevention program for tilapia must be education and awareness, as people are a primary factor in the spread of this species in Australia.

Executive summary

Mozambique tilapia (*Oreochromis mossambicus*) is a major pest fish species in Australia. A successful invader, it has managed to dominate natural waterways into which it has been introduced. It is not currently found in the Murray–Darling Basin; however, it has established thriving populations in catchments neighbouring the Basin. In some places, it is only a short distance from the northern headwaters. There is a high risk that this species will be introduced to the Basin.

Despite the high risk of introduction, little work has been done to estimate the potential range tilapia might occupy in the Basin, or to predict its possible impacts on natural, economic or social assets. This report provides a literature review and impact assessment in an attempt to provide some information about these potential threats.

ESTIMATING THE POTENTIAL RANGE OF MOZAMBIQUE TILAPIA IN THE MURRAY–DARLING BASIN

An important factor in determining the extent of impacts of Mozambique tilapia is to estimate the potential range it could occupy in the Murray–Darling Basin. Tilapia has a wide and varied diet and can occupy a diverse range of habitats, from freshwater to hypersaline conditions; therefore, its distribution is unlikely to be limited by many environmental, physical or chemical conditions. However, the one factor that appears to affect tilapia is its vulnerability to cold temperatures. Tilapia is traditionally viewed as a tropical to warm-temperate species; therefore, its survival and potential distribution in the Basin is likely to be governed by its ability to survive lower water temperatures and to live through winter periods (overwinter). Similarly, the likelihood of tilapia populations reaching numbers significant enough to cause impacts in waterways also relates to temperature suitability. In essence, water temperatures in the Basin must remain warm enough to permit feeding and to allow sufficient time for breeding.

In order to estimate the potential range of tilapia in the Murray–Darling Basin, this report attempts to:

- predict the range in the Basin where tilapia may survive through colder winter temperatures
- determine the length of the feasible breeding season (including the number of broods possible in that time) in different ranges
- determine the portion of the year in which tilapia may feed and is therefore likely to have impacts on ecological processes through the food web.

This includes:

- estimating the lower temperature tolerance for tilapia based on literature and survival rates of populations already infesting locations in Queensland
- identifying the minimum winter temperatures recorded at different locations throughout the Basin
- using the distribution of native fish with similar temperature tolerances to tilapia as a surrogate.

The literature shows varying lower temperature tolerances of tilapia, including evidence that saline waters can enhance this species's cold tolerance. After investigating lower thermal tolerances, this report took the view that:

- conservatively, a location with a water temperature minimum of 10°C can be viewed as a place where tilapia is highly likely to survive the winter
- between 8.0 and 9.9°C, there is still a reasonable probability that tilapia would survive the winter
- below 7.9°C, the survival of tilapia in the Basin would be compromised.

Based upon these suppositions and the minimum water temperature data available, Mozambique tilapia have the potential to infest the northern Basin in Queensland and parts of New South Wales, through the western inland catchments of NSW and down to the Lower Lakes and lower Murray in South Australia. This equates to a core distribution occupying approximately 50% of the Basin.

Most of the Darling River is therefore capable of supporting overwintering populations of tilapia. Water temperatures of rivers flowing from Victoria into the River Murray and most of the rivers in southern New South Wales are likely to be too cold to support overwintering tilapia. However, it is possible that there will be some pockets of warmer water, or some years in which sites may permit overwintering of tilapia in parts of southern and central New South Wales. These warm water refuges may also allow tilapia to have temporary expansions and extend the range in which impacts are felt from invasion of this species in the Basin. However, it is important to note that an increase in winter minima of only around 2°C could enable tilapia to overwinter in most of the lowland areas of the Basin. This would be entirely feasible under moderate climate change scenarios. In addition, this report used the best estimates of water temperature it could find. Therefore, it would be possible to extend or contract these distribution range estimates with more comprehensive temperature records.

Tilapia is capable of sustaining viable populations under the conditions found in much of the Murray–Darling Basin, as breeding and feeding can occur for significant portions of the year. In the northern parts of the Basin, and many southern parts, median water temperatures could see a breeding season of at least 3–6 months in duration with around 4–6 broods for each female in each breeding season. Tilapia would remain prolific breeders under such conditions. It could be expected that tilapia may feed (and grow) for at least 9–10 months of the year, and at some sites they could feed almost year round. In areas that could potentially be occupied by tilapia in the Basin, native fish species could only be expected to be free from competition for food resources with tilapia over a 2–3 month period at best.

THE CAPACITY FOR TILAPIA TO COLONISE AND DOMINATE WATERWAYS

Rapid spread of Mozambique tilapia through the Murray–Darling Basin is plausible if it were to be introduced. Experiences in both north Queensland and Western Australia have demonstrated rapid dispersal of tilapia. The rate of spread has been exacerbated where human-assisted dispersal is combined with the natural abilities of tilapia to move up and downstream of an introduction site. Dispersal rates of up to 250 km per year have been recorded in such cases.

Tilapia are highly adaptable and have been reported to aestivate (maintain a prolonged state of inactivity) in wet river sands in their native African habitat. This enables them to survive as river pools dry. This would enable tilapia to rapidly recolonise areas when dry periods end. Under adverse conditions such as drought, tilapia can switch from a normal growth and maturation rate (where fish first breed at two or three years old and at a size of 25–35 cm), to stunted populations where fish mature at very small sizes (9–10 cm) and breed at only a few months old. As noted above, tilapia can produce 4–6 broods over a summer season. Tilapia also provide parental care, where the female broods eggs and young in her mouth to protect them from predation. These traits and behaviours mean tilapia have the capacity to rapidly increase their numbers and dominate waterways.

THE POTENTIAL IMPACTS OF TILAPIA IN THE MURRAY–DARLING BASIN

Tilapia impacts have been recorded in a number of locations both in Australia and overseas. The key impacts recorded include major declines in commercial and traditional fisheries, fish extinctions, destruction of beds of macrophytes (large aquatic plants) and declines in water quality.

Tilapia tolerate a broad range of habitat types, from full freshwater to hypersaline conditions. In Australia they have been recorded in diverse habitats including waterholes in ephemeral rivers, reservoirs, lakes, ponds, farm dams, rivers, creeks, drains, swamps, salt lakes and tidal areas. There are few habitats that they will not inhabit.

Tilapia also have broad dietary tolerances and are extremely adaptable; thus there is potential for them to compete with native species where their diets overlap. Although primarily feeding on detritus, algae, macrophytes and other organic matter, tilapia have been known to shift their diet according to food availability. They can range from complete herbivory, to omnivory and total carnivory, even reverting to cannibalism. Contrary to previous perceptions, tilapia have been known to prey directly on native fish. Recent experiments showed that tilapia consume juvenile native fish, including members of genera that occur in the Murray–Darling Basin, such as *Melanotaenia*, *Hypseleotris*, *Craterocephalus*, *Nematalosa* and *Ambassis*. It is possible that the potential piscivory of tilapia has been underestimated.

Some of the predicted direct impacts of tilapia on the Murray–Darling Basin include:

- impacts on native fish and other biota by:
  - direct predation by tilapia
  - competition for resources (food, habitat)
  - destruction of macrophytes and other aquatic plants used as breeding or nursery habitat by native species
  - habitat disturbance
  - transmission of diseases and parasites
  - competitive exclusion of native fish from favourable habitat by tilapia's aggressive behaviour
- reduction in water quality, including potable water supplies, through:
  - increase of blue-green algal blooms (through resuspension of nutrients)
  - winter die-offs of tilapia (polluting waterways)
  - undermining river banks due to destruction of river plants and nesting behaviour.

It is likely that introduction of tilapia would lead to reduced abundance of at least two recreational fish species – silver perch and eel-tailed catfish. In situations where tilapia stunt and attain high densities, indirect food chain effects could also lead to either reduced abundance or condition of other recreational species such as Murray cod and Golden perch. The stunted tilapia would not provide an alternative recreational species. Fisheries in other parts of the world have declined by between 67–80% following tilapia invasion and impacts on fishing activities are likely to be felt in the Basin.

Native fish of the Murray–Darling Basin most at risk from tilapia

Olive perchlet *(Ambassis agassizii)*

Murray–Darling rainbowfish *(Melanotaenia fluviatilis)*

Bony bream *(Nematolosa erebi)*

Hyrtl's tandan *(Neosilurus hyrtilii)*

Flathead gudgeon *(Philypnodon grandiceps)*

Dwarf flathead gudgeon *(Philypnodon macrostomus)*

Desert rainbow fish *(Melanotaenia splendida taetei)*

Silver perch *(Bidyanus bidyanus)*

Freshwater catfish *(Tandanus tandanus)*

Rendahl's tandan *(Porochilus rendahli)*

South Australian populations considered vulnerable to tilapia

Murray River hardyhead *(Craterocephalus fluviatilis)*

Southern purple spotted gudgeon *(Mogurnda adspersa)*

Western blue spot goby *(Pseudogobius olorum)*

Lagoon goby *(Tasmanogobius lasti)*

Common galaxias *(Galaxias maculatus)*

Flat-headed galaxias *(Galaxias rostratus)*

Southern pygmy perch *(Nannoperca australis)*

Yarra pygmy perch *(Nannoperca obscura)*

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Introduction

Tilapias of the genus *Oreochromis* are a popular species for aquaculture in several regions of the world. However, many of the characteristics of tilapias that make them most suitable for farming — general hardiness, ease of breeding, rapid growth rate and the ability to efficiently utilise organic wastes (Stickney et al. 1979; Pullin and Lowe-McConnell, 1980; Balarin and Haller, 1982) — have also made them a successful invader and help them to survive well and dominate natural waterways. As a consequence, Mozambique tilapia *Oreochromis mossambicus* is rated as one of the 100 most invasive species in the world (Global Invasive Species Database, 2006). Regions invaded by Mozambique tilapia include Japan, India, Indonesia, Sri Lanka, the Philippines, Guam, Papua New Guinea, Fiji, California, Mexico, Nicaragua, Venezuela, Madagascar, temperate parts of Africa (outside of its natural range) and Australia (De Silva, 1985; Bhagat and Dwivedi, 1988; Kawanabe and Mizuno, 1989; Allen, 1991; James and Bruton, 1992; Concepcion and Nelson, 1999; Perez et al. 2003; Costa-Pierce, 2003; Canonico et al. 2005; Jenkins et al., 2010). Mozambique tilapia have successfully colonised freshwater lakes, rivers, swamps, estuaries, brackish coastal lagoons, coral atolls, hypersaline desert pools and thermal springs (Trewavas, 1983).

Within Australia, Mozambique tilapia have invaded parts of south-east Queensland adjacent to the northern region of the Murray–Darling Basin. There is concern that this species could be translocated into the Basin and establish feral populations. This document reviews available information on the current distribution of Mozambique tilapia and aspects of its physiology and ecology to determine its potential to invade the Murray–Darling Basin. This includes examining areas of potential spread, likely rates of spread and probable impacts. A review of the biology, distribution and control of Mozambique tilapia was recently completed by Russell et al. (2010) and although our paper refers to some of the same literature as this review, we examine the information in the context of impacts and likely spread within the Basin. Russell et al. provide further information on Mozambique tilapia beyond the scope of this paper and we recommend their review should more information be required.

MOZAMBIQUE TILAPIA DISTRIBUTION IN AUSTRALIA

Wild populations of Mozambique tilapia have been established in Australia since at least the 1970s (Russell et al. 2010). Populations currently exist in a number of locations in tropical and sub-tropical Australia (Figure 1). In Western Australia the species occurs in ephemeral rivers of the arid and semi-arid Pilbara region, including the Chapman, Gascoyne, Minilya and Lyndon rivers (Morgan et al. 2004). These rivers resemble some of the systems in the semi-arid northwest of the Murray–Darling Basin.

> Unless otherwise specified, 'tilapia' in this paper refers to *Oreochromis mossambicus*, the Mozambique tilapia. 'Tilapia' is used where possible for the sake of brevity.

In Queensland, tilapia populations occur in both northern and southern areas of the state. Around the Cairns region they are found in Delaney Creek, the Barron River catchment (including Tinaroo Falls Dam), the upper Herbert River, the Endeavour River (near Cooktown) and some creeks to the north of Cairns (Blühdorn and Arthington, 1989; Russell et al. 2010). There was also an incursion into the upper Mitchell system in the Gulf of Carpentaria drainage, but this is believed to have been successfully eradicated using rotenone (a poisonous chemical used to kill fish) (Russell et al. 2010). In 2004, $1.4 million was expended by Sunwater to screen irrigation channels in order to prevent transfer of tilapia eggs and larvae from the east coast to Gulf drainages. A further $100,000 was spent in 2005 on screen cleaning equipment (Greiner and Gregg, 2008).

Tilapia have also established populations in the Townsville area including the Ross, Alice and Black Rivers and various creeks to the north and south of Townsville (Russell et al. 2010). Tilapia have also invaded the Burdekin River system (Veitch et al. 2006) and now occupy almost the entire catchment from the mouth to the headwaters (Malcolm Pearce, pers. comm.).

Further south, tilapia have established in the upper Burnett River system in Boondooma Dam, only a short distance from the Basin. Recently tilapia have also been recorded in waterways near Bundaberg and Gin Gin (Fisheries Queensland, unpublished data). Tilapia are common in the greater Brisbane area, occurring in the Pine Rivers catchment (including North Pine Dam and Lake Kurwongbah), the Caboolture River, drains near Deception Bay, the Brisbane River (including Lakes Wivenhoe and Somerset), the Bremer River near Ipswich, Tingalpa Reservoir, parts of the Lockyer Valley, the lower Albert and Logan Rivers and some drainages near the Gold Coast (McNee, 1990; Arthington and Blühdorn, 1994; Fisheries Queensland unpublished data; DEEDI Agri-Science unpublished data). There have also been recent (2010) unconfirmed reports of tilapia from Moogerah Dam in the Reynolds Creek catchment (an upper tributary of the Bremer River), very close to the northern headwaters of the Murray–Darling Basin.

Tilapia strains appear to differ within their distribution in Queensland. Those from south-east Queensland are a pure strain of *O. mossambicus*, whereas those from the Cairns region may have hybrid introgression from one or more of *O. niloticus*, *O. honorum* and *O. aureus* species (Arthington and Blühdorn, 1994). It is fortunate that this hybrid strain (referred to as the Cairns strain) is currently distantly

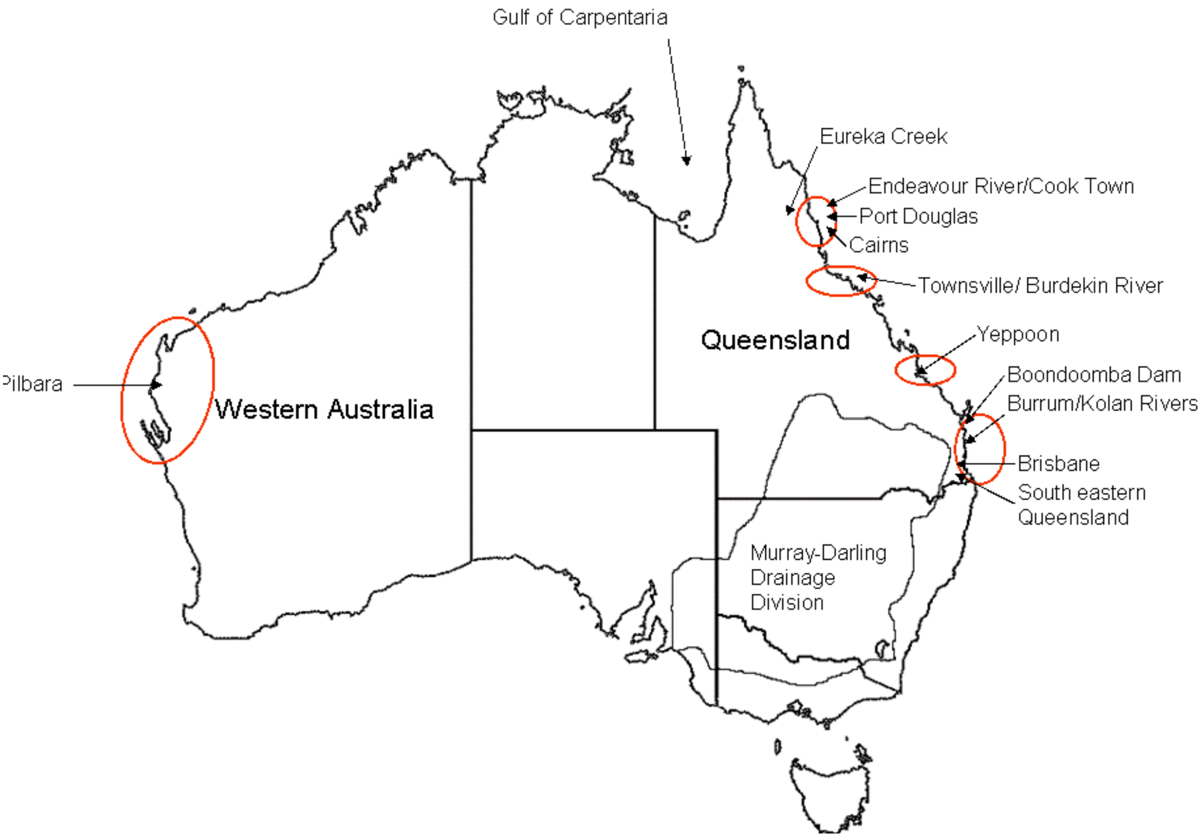


Figure 1: Map of Mozambique tilapia *(Oreochromis mossambicus)* distribution in Australia (adapted from Russell et al. 2010)

located from the Basin, as there is evidence that these hybrids are more cold tolerant than the pure strain (Wohlfarth and Hulata, 1983; Wohlfarth et al. 1983; Behrends et al. 1990; Cnaani et al. 2000). Preventing translocation of the Cairns strain southwards is therefore of high importance. This Cairns strain already occurs in comparatively cool waters in upland areas in the upper Barron River catchment on the Atherton Tablelands and in the upper Herbert River. However, the most imminent risk to the Murray–Darling Basin is invasion by pure strain *O. mossambicus*, which currently occurs in catchments immediately adjacent to its northern boundaries.

Tolerance of Mozambique tilapia to high and low temperatures and other physico-chemical parameters

Mozambique tilapia has very broad environmental tolerances and its distribution within the Murray–Darling Basin is unlikely to be limited by most of these factors. Tilapia is a tropical to warm temperate species native to Africa (Pullin and Lowe-McConnell, 1980); therefore, the primary limiting factor to its potential distribution in inland and more temperate regions of Australia is likely to be its cold water temperature intolerance. Water temperatures also have a strong influence on length of breeding season and feeding activity. Through an understanding of the thermal tolerances of tilapia (including water temperatures within their current distribution), their preferred breeding and feeding temperatures and a knowledge of water temperatures in different parts of the Basin, it should be possible to predict:

- areas where tilapia could survive winter
- the length of their breeding season
- the proportion of the year during which tilapia could impact on ecological processes through the food web.

LOWER THERMAL TOLERANCES AND MINIMUM RECORDED TEMPERATURES OF WATER BODIES WITH SELF-SUSTAINING TILAPIA POPULATIONS

There is substantial variability in the literature reporting on the lower thermal tolerances of tilapia. Due to the popularity of this species for aquaculture, some reported studies contain data for this purpose and may need to be extrapolated or re-interpreted for field conditions. Therefore minimum recorded temperatures of water bodies with self-sustaining tilapia populations are also important for predicting potential range in the context of this report. Experiments on the cold tolerance of tilapia may produce variable results due to factors such as different acclimation temperatures, different genetic strains and variations in the type of temperature challenge (for example cold shock versus gradual temperature reduction).

A table in Wohlfarth and Hulata (1983) shows reported minimum temperature tolerances ranging from 9ºC to below 6ºC. Cnaani et al. (2000) found considerable variation in the cold tolerance of *O. mossambicus* and concluded that the variation in cold tolerance could be improved through genetics. However, heritability of cold tolerance in the related Nile tilapia *O. niloticus* has been estimated to be 0.09 (Charo-Karisa et al. 2005) i.e. only 9% of the phenotypic variation in cold tolerance can be accounted for by genetics.

Allanson et al. (1971) reported disturbed orientation (i.e. ability to remain upright in the water column) in tilapia at 11ºC. Tilapia that were transferred abruptly from 25ºC to 15ºC experienced chill coma and developed fungal infections (Al Amoudi et al. 1996). Although abrupt temperature changes may be relevant to handling and transport in the aquaculture industry, such abrupt temperature changes would be less likely under wild conditions. Smit et al. (1981) reported that tilapia experience osmoregulatory collapse (an inability to maintain body salts) if kept at 15ºC for more than a few days, yet Schnell and Seebacher (2008) successfully acclimated tilapia from south-east Queensland to 14ºC for 28 days. Schnell and Seebacher concluded the capacity for phenotypic plasticity (an ability to adapt that is not necessarily genetically linked) in Mozambique tilapia means that the fish would not be limited by its swimming ability or metabolic physiology to expand its range into cooler thermal environments. Behrends et al. (1990) determined the mean minimum lethal temperature for tilapia to be 9.5ºC.

Low water temperatures can make tilapia more susceptible to parasites. Oldwage and van As (1987) suggest a rise in temperatures in early spring causes a surge in invertebrate numbers. As recovery from winter temperature stress occurs more slowly in tilapia than the surge in invertebrates, parasite load can contribute to the existing stress condition in the fish, leading to mortality.

As reported in Allanson et al. (1971), saline waters can enhance cold tolerance in tilapia. They found that tilapia did not lose orientation at 11ºC if maintained at a salinity of 5‰ due to reduced osmotic stress. The most southern natural populations of tilapia in South Africa occur in estuarine lagoons at Algoa Bay (33º50'S) (Whitfield and Blaber, 1979). The reproducing populations of tilapia survive in the small (0.6 ha), shallow (1m), saline (16-40‰) Kowie Lagoon in Eastern Cape Province, South Africa, where minimum water temperatures in winter fall to 9.5 ºC. Tilapia also persist in nearby small freshwater bodies where winter minimum water temperatures fall to as low as 10ºC (James and Bruton, 1992). Saline conditions in the southern Murray–Darling Basin are likely to facilitate overwintering of tilapia. However, in hypersaline conditions, the improved tolerance of low temperatures may be lost. In hypersaline conditions at temperatures below 15ºC and above 35ºC, salinity tolerance of tilapia is greatly reduced (Sardella et al. 2007). Winter fish kills (natural die-off due to cold temperatures) in the Salton Sea (44‰), California, are likely to be associated with the effect of temperature on salinity tolerance (Sardella et al. 2007).

The range of temperatures experienced in water bodies in south-east Queensland with existing tilapia populations can be seen in Table 1. Conservatively, a water temperature minimum of 10ºC can be viewed as indicating a location where tilapia are highly likely to survive the winter. Between 8-9.9ºC, there is still a reasonable probability that tilapia would survive winter, and below 7.9ºC, tilapia survival in the Murray–Darling Basin would be compromised. These figures are used to indicate tilapia survival in the rest of this report.

Minimum temperatures below 10°C have been recorded at a number of sites in south-east Queensland where tilapia populations appear to be breeding and surviving well. Whether tilapia are actually exposed to and withstanding these lower temperatures, or are using behavioural responses to find warmer pockets in these water bodies is unknown. However, it is likely some tilapia in south-east Queensland can survive less than 10°C, as seen in Arthington's (1991) report in which tilapia survived in a small pond where temperatures fell below 10°C in winter.

MINIMUM TEMPERATURES RECORDED IN MURRAY–DARLING BASIN WATERS

Comparing the recorded minimum water temperatures at sites in the Murray–Darling Basin will provide an indication of where Mozambique tilapia are likely to survive through winter. The Queensland part of the Basin contains a number of sites where the winter water temperature minimum remains above 10°C, with some sites being considerably warmer (see Table 2). Thus, winter survival of tilapia is likely. Most of these sites are large water bodies, such as weirs and reservoirs, or pools on major rivers. Smaller tributary streams and shallow water areas tend to have lower winter minima and tilapia would be less likely to survive winters in these locations. This report examined winter water temperature time series plots from some northern Basin sites (DERM data). These showed a run of warm water years (in which tilapia could survive) at many sites, with the occasional year during which temperatures dropped to potentially lethal levels. Therefore, the winter minima shown in Table 2 are not necessarily typical of every year and the lowest water temperatures appear to be associated with low water levels.

Most sites on the lower River Murray in South Australia also experience winter minima that tilapia could probably survive (see Table 3). Elevated salinities would also assist overwintering in South Australia, especially in the Coorong. In addition, parts of northern New South Wales and most of the Darling River also appear capable of supporting overwintering populations of tilapia. They could probably overwinter in the River Murray upstream to the Mildura-Merbein district.

Table 1: Temperature parameters of sites in south-east Queensland with existing tilapia populations

Somerset, Wivenhoe and North Pine Dam data are sourced from Seqwater, other data are sourced from the Department of Environment and Resource Management. Temperatures are given in °C.

Site	Min	Med	Max	Comments
North Pine River Youngs Crossing	7		30	May have some salt water intrusion on king tides.
South Pine River Drapers Crossing	12	22.3	28.2	
Caboolture River at upper Caboolture	10.9	20.85	28	
Brisbane River Savages Crossing	12.5	23	29.5	
Brisbane River Middle Creek	13	22	30	
Bremer River Walloon	11	22.5	30	
Wivenhoe Dam	13.5		30.5	
Somerset Dam	15		31	
North Pine Dam	16.4		28.4	Recorded at 1m depth.
Logan River McLean Pump Station	6		33	Most winters only fall to 9°C.
Maroon Dam	12	20	26	

Temperatures of rivers flowing from Victoria into the River Murray appear to be too cold in winter for tilapia survival (see Appendix I). Most of southern NSW may also be too cold to support overwintering tilapia. It is possible that there may be some pockets of warmer water, or some years with warmer temperatures, that may permit tilapia to overwinter in parts of southern or central NSW.

Sites with large volumes of water, like weir pools on the lower Murray are probably more resistant to chilling, hence, likely to assist tilapia survival. Groundwater inflows may also provide warm water pockets as winter refuges. Heat as a tracer has been demonstrated to be a robust method for quantifying surface water — groundwater exchanges in a range of environments, and groundwater tends to have a moderating influence on surface waters (Baskaran et al. 2009). Therefore, there are likely to be a mosaic of sites between Queensland and South Australia where tilapia may be able to overwinter.

Unfortunately, many of the automated water temperature data-logging sites are located on small gauging structures, or below major weirs and dams, rather than at larger water bodies. The water temperatures in these small shallow water bodies are much more likely to be colder in winter than adjacent large water bodies. For example, the minimum winter water temperature in the Condamine River at Warwick falls close to 7°C, whereas nearby Leslie Dam only falls to between 10 and 12°C (see Table 2). Tilapia would probably not survive winter at the Warwick site, but could survive at Leslie Dam. Water temperatures recorded downstream of the Chinchilla Weir pool showed that temperatures can fall below 6°C, but the weir pool itself is likely to be much warmer than the recording site; however, no data is available. Gil Weir, in the same region, only falls to 11°C (Table 2) in winter.

Water temperature data from large impoundments and weirs in the NSW section of the Basin could not be obtained for this report. It is probable that some of these larger water bodies would provide suitable temperatures for tilapia to overwinter. Nevertheless, some riverine sites in NSW were identified as places where tilapia could potentially survive (see Table 4). It is important to obtain data for the large water bodies throughout the Basin, as they could be potential overwintering sites and invasion strongholds for tilapia, from where they could spread to other areas. Other potential winter warm water refugia include artesian bore drains, which are already used by European carp.

Table 2: Temperature parameters of selected sites in the northern Basin

All Qld data are sourced from the Department of Environment and Resource Management except for Goondiwindi Roundabout Pond which is sourced from the Department of Employment, Economic Development and Innovation.

Site	Min	Med	Max	Comments
Leslie Dam buoy line	11.2	18.9	27.6	
Leslie Dam upper arm	10	20.6	26.6	
Leslie Dam central	12	17.5	27.5	
Gil Weir Dogwood Creek	11	22.8	33.9	
Beardmore Dam	11.5	16.4	25.8	Recorded over 18 months (2 winters and 1 summer), therefore median temp. is lower than if a second summer season was included.
Cotswold Weir	10.5	20.75	30	
Loudouns Bridge	10	21	30.7	
Coolmunda Dam	14.3	18.85	22.3	Autumn and winter data only.
Cunnamulla Weir	12	21.6	30.8	
Wyandra	10.3	21.1	30.6	
Moonie River Nindigully	11	22.7	34.8	
Glen Lyon Dam tail water	9.4	19	32	Tail water normally colder than dam.
Gowrie Creek Oakey	7	20	34	Small shallow system.
Macintyre River Goondiwindi	8	22.5	30.2	
Roundabout Pond Goondiwindi	14.5	23.1	37.3	Deep small water body — 18 months continuous data only.
Inglewood	9	21.35	30.5	
Cecil Weir	5	21.5	32.9	Low temperature recorded when dam water level was very low. Temperatures were usually higher.
Warrego River Augathella	9.5	20.25	33.1	
Upper Condamine Cowboy Crossing	6.7		17.1	Very few temperature records but tilapia unlikely to persist in upper catchment.
Spring Creek Killarney	6	17	26	High altitude area.
Kings Creek	8		27	Few records.
Emu Creek	4.3	20.5	30.5	Upper Condamine catchment.
Condamine River Chinchilla Gauging Station	5.7	20.1	30.7	Shallow pool in winter. Only 0.5% of readings were less than 8°C. In 50% years temperature remains above 10°C. Nearby Chinchilla Weir Pool is likely to be warmer.
Condamine River Warwick	7.1	19.7	33.8	Upper catchment.
Caiwarro Lagoon Paroo River	11.9	21	30	Limited data.

Table 3: Temperature parameters of selected sites in the lower River Murray, South Australia

All South Australian data are sourced from the Australian Water Data Infrastructure Project. http://e-nrims.dwlbc.sa.gov.au/awdip_client/

Site	Min	Med	Max	Comments
Coorong (Beacon)	9.3	18.5	28.3	These data were extrapolated from three-year daily continuous temperature graphs.
Coorong (Beacon 105, the mouth of the lakes)	11.3	20.7	29.8	
Katarapko Creek	9.8	20.3	31.8	
Lock 6	10.3	20.4	31.7	
Morgan No. 1 Pump Station	9.8	20.6	31.8	
Long Island/Murray Bridge	11.8	20.2	27.8	
Swan Beach	11.3	19.9	29.4	
Overland Corner	9.8	19.8	29.9	

Table 4: Temperature parameters of sites in the Murray–Darling Basin in New South Wales

All data are sourced from the NSW Office of Water. Most data are for the period 2005–2010, although earlier data have been used where these were unreliable. Data were extrapolated from continuous temperature graphs.

Site	Min	Med	Max	Comments
Murray River Biggara	1.5	15.4	29.4	
Murray River Albury	4.7	15.2	27.6	
Murray River Corowa	6.1	17.8	28.9	
Edward River Deniliquin	6.4	18.9	30.8	
Murray River Barham	7.8	19	29.5	
Murray River DS Hume Dam	7.3	16.7	26.7	
Edward River DS Stevens Weir	7	18.5	31.5	
Murray River DS Yarrawonga Weir	7.6	18.3	29.5	
Edward River at Leiwa	6.5	18.7	30.7	
Murrumbidgee at Wagga Wagga	5.6	17.9	30	
Murrumbidgee at Narrandera	5.6	18.5	31.5	
Murrumbidgee DS Burrinjuck	7.6	15.4	22.2	
Murrumbidgee Berembed Weir	6.2	18.5	30.6	
Murrumbidgee Balranald Weir	7.3	19.1	30	
Lachlan River Cowra	4	17.8	31.2	
Lachlan River Forbes	6.6	18.4	32.3	
Lachlan River at Booligal	5.2	19.3	32	
Lachlan River at Condobolin	6.6	19.8	33.2	

Site	Min	Med	Max	Comments
Lachlan River at Lake Cargelligo	7.4	20	32.1	
Abercrombie River at Abercrombie	3.5	17	31	
Lachlan River at Hillston Weir	7.5	20.1	33	
Murray River at Mallee Cliffs No. 1 DS	9	19.8	31.4	50% of winters exceed 10°C.
Murray River at Mallee Cliffs No. 2 US	8	19.8	31.5	
Murray River at Collingan Pontoon	8.7	20	30.4	2 years of data only.
Murray River at Mallee Cliffs upstream Pontoon	9.8	19.8	32.1	
Murray River at Chaffey's Graveyard Pontoon	8.7	20	30.5	2 out of 3 winters exceed 10°C.
Murray River Merbein Pontoon	9.5	18	31.8	50% winters exceed 10°C.
Murray River at Curlwa Pontoon	9.1	20.2	31.2	2 out of 3 winters exceed 10°C.
Barwon River at Mungindi	8.1	21	34.4	60% of winters exceed 10°C.
Macintyre River at Holdfast	8	22	40	Most summers do not exceed 32°C.
Macintyre River at Inverell	5.2	18.4	32	
Dumaresq river at Glenarbon Weir	7.4	20.5	34.3	
Gwydir River at Yarraman Bridge	9.5	22.3	38.5	
Mehi River at Bronte	5	19.2	38.5	
Peel River US Paradise Weir	6.6	20	39	
Namoi River at Goangra	5	21.2	35.5	
Peel River DS Chaffey Dam	6.5	18	31	
Namoi River at Bullawa	6.5	19.7	34.5	
Castlereagh River at Hidden Valley	3.5	20	39	
Castlereagh at Gungalman	5	21.5	38	Not very reliable plot. Possibly an ephemeral pool that dries out.
Macquarie River at Dubbo	7.5	18	30.2	
Macquarie River at Warren Weir	7.5	18.5	32	80% of winters above 8°C; 60% above 9°C, 20% above 10°C.
Macquarie River at Carinda	5.3	21.2	35	
Bogan River at Gongolgon	8.5	21.5	34.5	
Macquarie River at Bruinbun	3.8	19.2	34	
Macquarie River DS Burrendong Dam	7.5	17	31	
Barwon River at Walgett	7.9	20.6	32.5	90% of winters exceed 8°C; 70% exceed 10°C. Should be treated as potential invasion site.

Site	Min	Med	Max	Comments
Barwon River at Brewarrina	10.3	21.3	34	
Culgoa River at Brenda	6.6	19.1	31.8	Data logger appeared unreliable.
Barwon River at Geera	7.7	20.4	34	50% winters exceed 8°C; 25% exceed 10°C.
Warrego River at Fords Bridge	4.8	19.2	34.6	Highly variable. Probably shallow pool.
Darling River at Louth	7.5	22.3	35.6	50% winters exceed 10°C.
Darling River at Pooncarie	7.7	19.8	32	Logger not reliable. 4 out of 5 winters exceed 8°C.
Darling River at Burtundy	6.4	19.5	34.4	
Darling River at Wilcannia	8.1	22.3	35	
Darling River at Menindee US Weir 32	8.6	20.4	32.4	
Outlet channel at Lake Cawndilla	8.6	18.3	29.2	
Darling River DS Dead Horse Creek	10	22.4	35.8	
Darling River at Glen Villa	8.1	21.5	36	85% winters exceed 10°C.
Darling DS Weir 19A	7.7	21.5	38.5	
Darling River at Myandetta	8.1	21.2	34.2	
Darling River at Warraweena	8.4	21.1	37	

USING NATIVE FISH DISTRIBUTIONS TO ESTIMATE THE POTENTIAL RANGE OF TILAPIA IN THE MURRAY–DARLING BASIN

The temperature tolerances and distribution of certain Australian native fish species could also provide insights into the potential distribution of tilapia within the Murray–Darling Basin. The native Australian catfish *Neosilurus hyrtlii* has low temperature tolerances of 8–12°C (Lintermans, 2007), which is very similar to the lower temperature tolerances reported for tilapia, although records reported in Wohlfarth and Hulata (1983) suggest tilapia may be marginally more cold tolerant. Based on a distribution map in Lintermans, *N. hyrtlii* inhabits the slopes and lowland areas of the Condamine–Balonne, Warrego, Nebine, Paroo and upper Darling system south to the Menindee Lakes.

Spangled perch, *Leiopotherapon unicolor*, is another Basin species with a broad tropical and sub-tropical distribution in Australia. Its lower temperature tolerances range between 4.1 and 7.2°C (Beumer, 1979), which is more cold tolerant than both tilapia and *N. hyrtlii*. As would be expected, *L. unicolor* has a somewhat broader distribution than *N. hyrtlii* in the Basin. Mapping data in Lintermans (2007) shows that this species occurs in the same catchments as *N. hyrtlii*, but it also occurs in the Border Rivers and catchments south to Condobolin. It is also found further upstream in the Condamine catchment than *N. hyrtlii*. If the distributions of *N. hyrtlii* and *L. unicolor* are temperature limited in the Murray–Darling Basin, then the range of these species is potentially a good predictor of the potential areas into which tilapia may spread.

It could be expected that tilapia may be able to colonise a similar range in the Basin to that of *N. hyrtlii* or a range between that of *N. hyrtlii* and *L. unicolor*. With human- or flood-assisted dispersal, some of the lower reaches of the River Murray system in South Australia may be colonised by tilapia as well. Temperatures in the lower Murray weir pools remain above lethal levels for tilapia throughout winter (see Table 3) and parts of the Gwydir River in NSW, lower Murray in NSW and the Border Rivers may also be suitable (see Table 4).

CORE RANGE OF THE MURRAY–DARLING BASIN LIKELY TO BE COLONISED BY TILAPIA

Recorded winter temperature minima in the Murray–Darling Basin are outlined in Figure 2, showing the potential core region that could be colonised by tilapia. The potential core range of tilapia is similar to the current catfish *N. hyrtlii* range, but occupies a slightly larger geographical area. As noted above, temperature data for large impoundments in northern New South Wales are lacking; however, it is likely that some of these water bodies may also provide suitable winter temperature minima for tilapia in the eastern slopes of the northern Basin.

Outside of the core distribution area indicated on the map it is possible that there may be warm water refugia where tilapia could overwinter (particularly in the lowlands), from where they could temporarily expand their range each summer. It is also possible that tilapia may have temporary expansions beyond the core distribution area in warmer years. The core distribution area represents about 50% of the Murray–Darling Basin. With global warming this predicted range could expand into southern areas. An increase in winter minima of around 2ºC would enable tilapia to overwinter in most of the lowland areas of the Murray–Darling Basin (Figure 3) (see section on climate change later in this document).

UPPER THERMAL TOLERANCES

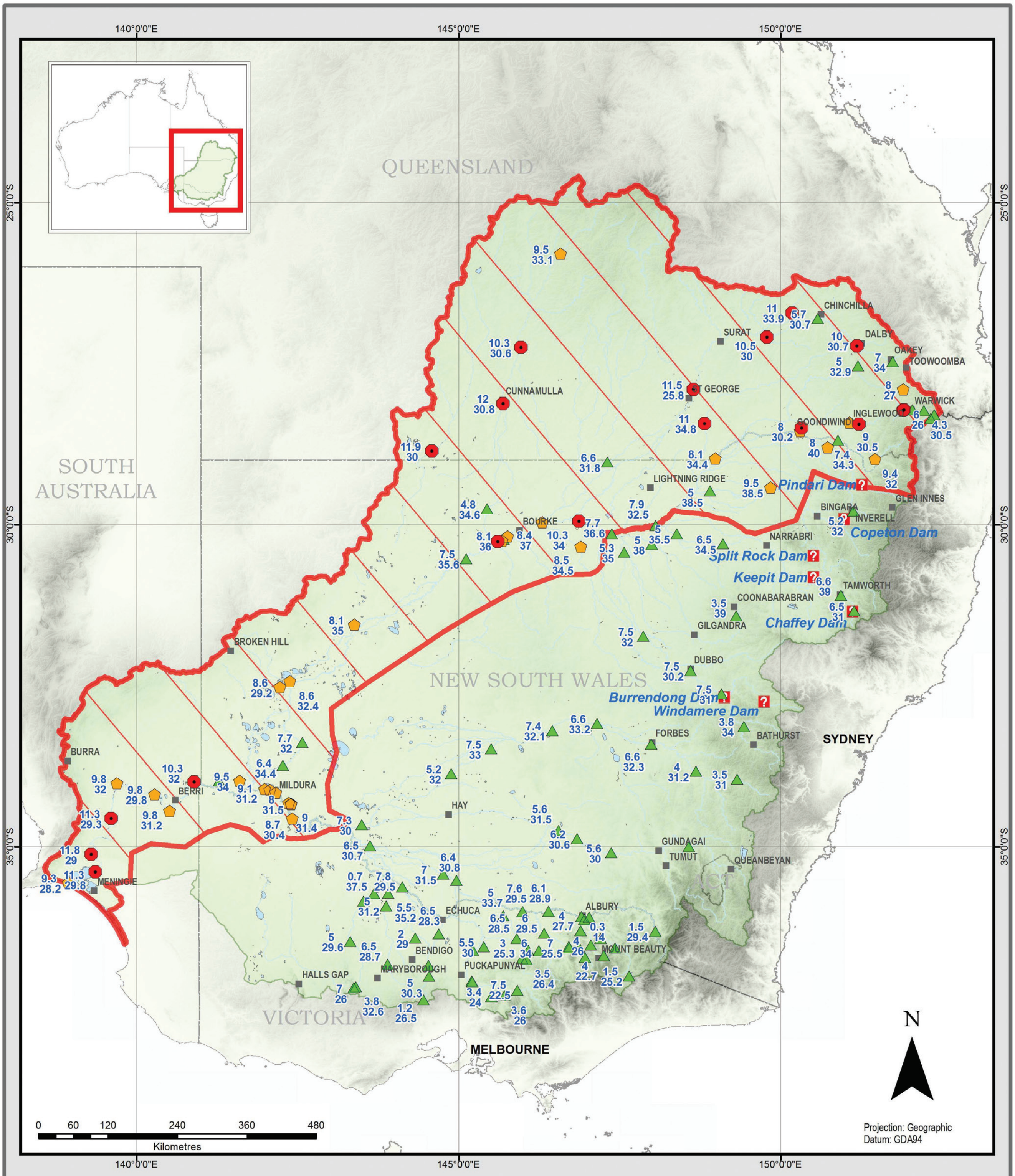
The maximum temperatures in which tilapia survive have been reported to range between 38ºC and 42ºC (Wohlfarth and Hulata, 1983; Allanson and Noble, 1964; Kirk, 1972). It can be seen from Table 2 that upper thermal maxima will probably not be a limiting factor for tilapia in the Murray–Darling Basin. Temperatures greater than 35ºC lead to osmotic stress for tilapia in hypersaline conditions (Sardella et al. 2007) but the occurrence of both hypersaline waters and water temperatures above 35ºC would be limited to a few shallow hypersaline lakes in summer. This would have little impact on the potential distribution of tilapia in the Basin.

BREEDING TEMPERATURES

Wohlfarth and Hulata (1983) report that most tilapia species do not spawn below 20ºC and state that only one species, *Tilapia sparrmanii*, is an exception. However, James and Bruton (1992) report that in Eastern Cape Province, South Africa, spawning normally commences in November when temperatures exceed 18ºC. The duration of the spawning season in the Eastern Cape ranges from three to five months per year and tilapia can produce up to five broods over a 133 day period (James and Bruton, 1992). Eastern Cape Province occupies a similar latitudinal range to the central Murray–Darling Basin, so a similar breeding season is probable in that area of the Basin. However, Arthington and Milton (1986) state that in south-east Queensland, breeding occurs for six to seven months of the year when the water temperature

Figure 2: Predicted core range of tilapia in the Murray–Darling Basin

Green symbols indicate sites likely to remain tilapia free, orange symbols represent sites that could be overwintered by tilapia and red symbols indicate sites where overwintering is highly likely. Question marks denote some large water bodies for which there are no temperature data. These large water bodies are likely to be warmer than surrounding sites. The outline on the map suggests the potential area that could be invaded by tilapia based on available data. Summer temperatures are suitable for breeding throughout this area and also in most of the Basin outside this area.



Data Sources:

Murray-Darling Basin Boundary:
Derived from Australian River Basins, 1997

Localtities:
Commonwealth of Australia, Geoscience Australia

Rivers:
Commonwealth of Australia, Geoscience Australia

Waterbodies:
Commonwealth of Australia, Geoscience Australia

State and Territory Boundaries:
Commonwealth of Australia, Geoscience Australia

Monitoring Sites:
Compliled from data supplied by the various State Government agencies.

PRODUCED BY:
Freshwater Habitat Unit,
Habitat and Assessment,
Fisheries Queensland, Brisbane. 2010
QFSDD Ref: 1811

Legend

Temperture Min/Max

Min

- ▲ 0.0 - 7.9
- ⬟ 8.0 - 9.9
- ● >= 10.0
- ? NO DATA
- ■ Towns/Localities
- Endangered_Area
- RIVERS
- WATERBODIES
- MURRAY-DARLING BASIN

MURRAY-DARLING BASIN
Native Fish Strategy Funded Project
Economic Impact Analysis of Tilapia
Water Tempature Monitoring

Australian Government

MURRAY–DARLING BASIN AUTHORITY

Queensland Government

Printing Date: Tuesday, 10 May 2011
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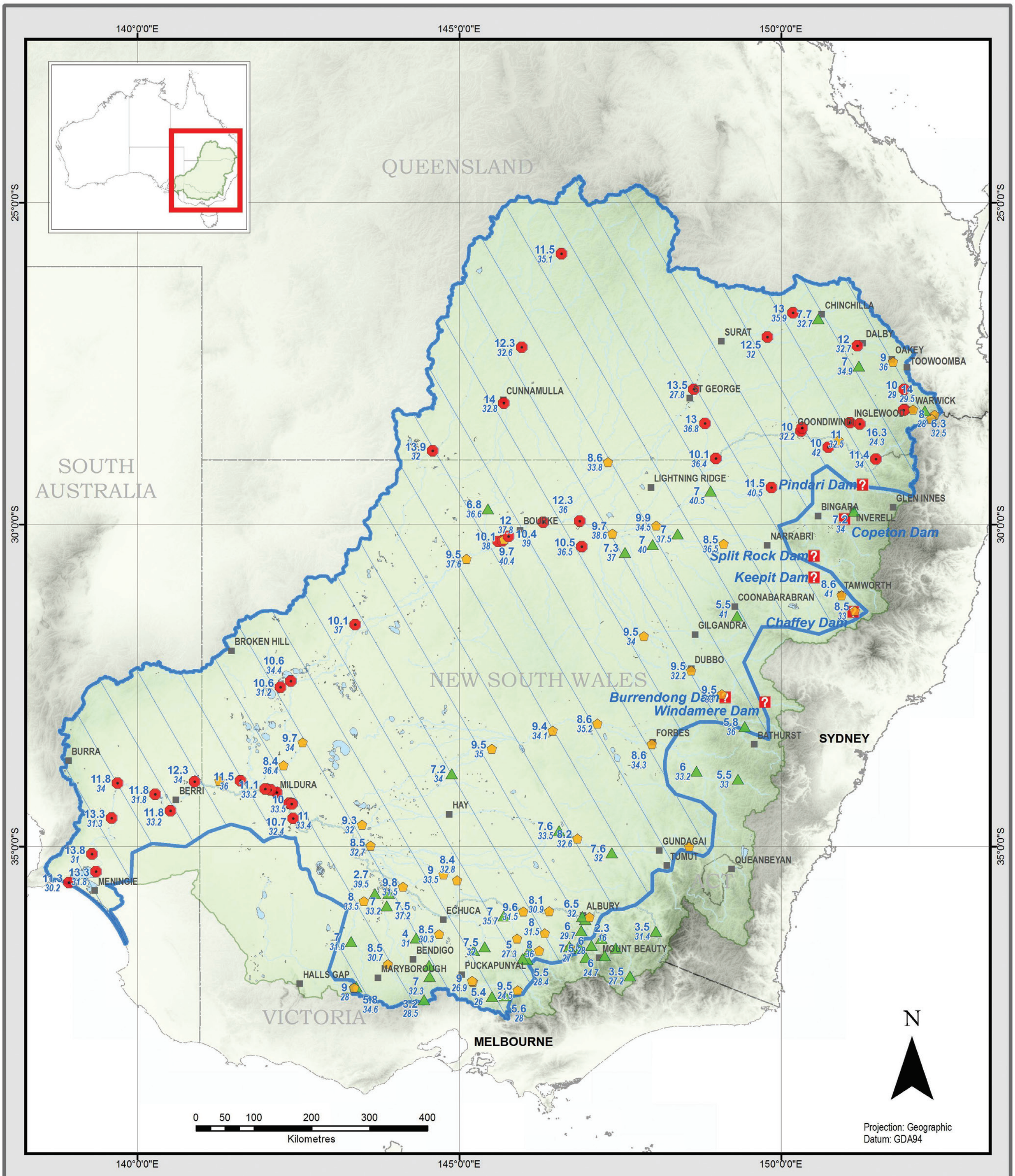

Data Sources:

Murray-Darling Basin Boundary:
Derived from Australian River Basins, 1997

Localtities:
Commonwealth of Australia, Geoscience Australia

Rivers:
Commonwealth of Australia, Geoscience Australia

Waterbodies:
Commonwealth of Australia, Geoscience Australia

State and Territory Boundaries:
Commonwealth of Australia, Geoscience Australia

Monitoring Sites:
Complied from data supplied by the various State Government agencies.

PRODUCED BY:
Freshwater Habitat Unit,
Habitat and Assessment,
Fisheries Queensland, Brisbane. 2010
QFSDD Ref: 1811

Legend

Temperture Increase 2°C

NEWMIN

- ▲ 0.0 - 7.9
- ⬟ 8.0 - 9.9
- ● >= 10.0
- ? NO DATA
- ■ Towns/Localities
- Endangered_Areaplus2
- RIVERS
- WATERBODIES
- MURRAY-DARLING BASIN

MURRAY-DARLING BASIN
Native Fish Strategy Funded Project
Economic Impact Analysis of Tilapia
Water Tempature SCENARIO
(MIN 2°C RISE)

Australian Government

MURRAY–DARLING BASIN AUTHORITY

Queensland Government

Printing Date: Tuesday, 10 May 2011
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exceeds 23ºC. A study by Subasinghe and Sommerville (1992) of artificially incubated eggs and yolk sac fry of Mozambique tilapia found that the upper lethal temperature for fertilised eggs was above 40ºC and the lower lethal limit was between 11ºC and 17 ºC. Yolk sac fry survival was less than 60% at 20ºC but was 100% above 24.3ºC. The lower lethal temperature for yolk sac fry was between 17 ºC and 20ºC.

Figure 3: Predicted tilapia distribution in the Murray–Darling Basin assuming an increase of 2ºC in water temperature

Green symbols indicate sites likely to remain tilapia free, orange symbols represent sites that could be overwintered by tilapia and red symbols indicate sites where overwintering is highly likely. Question marks denote some large water bodies for which there are no temperature data. These large water bodies are likely to be warmer than surrounding sites. The outline on the map suggests the potential area that could be invaded by tilapia based on available data. Summer temperatures are suitable for breeding throughout this area and also in most of the Basin outside this area.

If the minimum breeding temperature of 18ºC for tilapia in the Murray–Darling Basin is accepted, then based on median water temperatures from Tables 2, 3 and 4, tilapia could breed in the northern Basin for more than half the year. If the more conservative temperature estimate of 20ºC is accepted, a breeding season of at least six months is still probable at most northern Basin sites. If Arthington and Milton (1986) are correct, and breeding in south-east Queensland tilapia only occurs at 23ºC and above, then the potential northern Basin breeding season is likely to be between four to six months in length. Even the southern Basin experiences summer water temperatures high enough for tilapia to breed. Excluding highland areas and those subject to cold water thermal pollution, tilapia could breed successfully at most sites in the Basin. However, as outlined above, winter survival would be unlikely in southern NSW and Victoria. If a minimum breeding temperature of 20ºC is correct, then the breeding season in the lower Murray in South Australia is likely to be four to six months. If the minimum breeding temperature is 23ºC, then the breeding season in the lower Murray is likely to be three to five months. Between four and six broods per year could be expected to be produced by tilapia in the Basin. Therefore populations could be expected to increase rapidly. Further details on reproduction are provided in later sections of this report.

EFFECT OF TEMPERATURE ON SEX DETERMINATION

Temperature early in the life cycle appears to affect the sex of tilapia. Fry reared below 20ºC (until first feeding stage) were found to have a sex ratio strongly skewed towards males (89% males), demonstrating environmental sex determination (Mair et al. 1990). Therefore, early in the breeding season there is likely to be a surplus of males produced. These early season males will have a longer growing season and are likely to be larger than other males spawned later in the same year, thereby giving them a territorial advantage in the next breeding season. Early season temperature effects might be expected to generate a population sex ratio imbalance with an overall excess of males. However, if such males are a result of environmental modification of genotypic sex (sex reversal), this would be compensated by an excess of females resulting from crosses involving these delta males (Mair et al. 1990).

In contrast to the results of Mair et al. (1990), Wang and Tsai (2000) found that Mozambique tilapia reared before ten days old at a temperature of 20ºC produced a high proportion of females, whereas a high proportion of males was induced by elevated temperatures after ten days old. Wang and Tsai (2000) also found that tilapia larvae exposed to elevated temperatures (28ºC and 32ºC) before five days old had a greater proportion of deformities (bent vertebral spines).

FEEDING TEMPERATURES

Most tilapia species cease feeding and growth at water temperatures below 15ºC (Wohlfarth and Hulata, 1983). Mozambique tilapia cease feeding between 15ºC and 16ºC (Kelly, 1956; Dendy et al.1967; Wohlfarth and Hulata, 1983). Within the northern Basin tilapia could be expected to feed for at least 9–10 months of the year and at some sites they could feed almost year-round. In South Australia, feeding may cease over most of winter. In areas that could potentially be occupied by tilapia in the Basin, native fish species could only be expected to be free from competition for food resources with tilapia over a two to three month period at best.

OTHER PHYSICO-CHEMICAL PARAMETERS

Tilapia have broad environmental tolerances, such as salinity (0-120‰), pH (3.7-10.3), ammonia (up to 32 mgL^{-1}), low oxygen levels (down to 20% saturation) and turbid and polluted waters. These parameters are covered well in the review by Russell et al. (2010). The expansion of tilapia within the Basin is unlikely to be limited by any of these parameters.

One way tilapia are able to cope with low oxygen levels is to supplement oxygen requirements by gulping air (Maruyama, 1958; Senguttuvan and Sivakumar, 2002). Their ability to aestivate in wet river sands to escape periods of drought (Donnelley, 1978; Minshull, 2008) would also give them an advantage in recolonising rivers following drought and could lead to tilapia dominating ephemeral river systems in the Basin.

Figure 4: *Tilapia nests exposed by falling water levels (Photograph: John Russell)*

Tilapia's tolerance to low dissolved oxygen is well documented. In the closely related Nile tilapia *O. niloticus*, gill structure (high numbers and length of the gill filaments and high frequency of the secondary lamellae) allows this species to exchange gas very efficiently (Fernandes and Rantin, 1986). In addition, the high affinity of its haemoglobin to oxygen (Verheyen et al. 1985) enables Nile tilapia to be very tolerant to very low dissolved oxygen concentrations (Welcomme, 1969). Chervinski (1982) reported that Nile tilapia could tolerate concentrations as low as 1 mgL^{-1}. It is likely that similar adaptations assist Mozambique tilapia to tolerate low oxygen levels. However, it is also reported that prolonged exposure to low dissolved oxygen reduces growth in Nile tilapia (Rappaport et al. 1976; Chervinski, 1982) and this results in high mortality (Coche, 1982). Similar effects could be anticipated for Mozambique tilapia.

Reproduction

Many fish that become successful invaders exhibit efficient reproductive strategies and tilapia is no exception. This species is fecund and can adapt its reproductive strategies in response to its environment, maturing very rapidly and at small sizes under stressful conditions. Males aggressively defend nests and the offspring also have a good chance of survival with females providing a high level of parental care for young.

NESTING AND PARENTAL CARE

Tilapia males build circular nests in sandy or muddy substrates (see Figure 4). These nests are usually in clusters and are used as mating arenas or leks by the males (Fryer and Iles, 1972; Bruton and Boltt, 1975). Males attract females to nests where spawning takes place, after which the female collects eggs and sperm into her mouth (Fryer and Iles, 1972). Further details on spawning and mating behaviour can be found in the review by Russell et al. (2010).

A wide range of environmental factors influences both the shape and depth at which tilapia builds its nests (James and Bruton, 1992). Some of these include the substrate (bottom surface) material, slope, turbidity and the depth profile of the lake. Depending on the reproductive strategy adopted, tilapia can construct simple excavations made in very shallow water (30–50 cm), with some nests not clearly defined.

In other cases tilapia construct carefully built, symmetrical nests with a smooth clean base. Nesting frequently occurs in shallow water less than 100 cm deep, but can occur at depths up to 8.5 metres. Diameter of nests can range from 25–185 cm (Bruton, 1979; James and Bruton, 1992).

The spawning frequency of tilapia may be influenced by the prevailing physical, chemical and environmental conditions (James and Bruton, 1992), including water levels (Bruton, 1973). Similarly, the size and quantity of eggs produced at any one time varies significantly with the body size of the breeding individuals as well as the environmental conditions. The egg size of tilapia has been reported to vary from 2 to 3.5 mm (Peters, 1963; Bruton, 1979; Trewavas, 1983; De Silva, 1986).

Tilapia in the *Oreochromis* genus (including Mozambique tilapia) display mouth brooding behaviour associated with parental care. This includes incubation of eggs and nursing larvae in the mouth of the parent (Tacon et al. 1996). Larvae are carried in the mouth of the female until the yolk sac resorption stage (i.e. the yolk sac remains attached to the larval fish for a period after hatching until it is reabsorbed). Parental care also continues after the young are released from the mouth with the female guarding her offspring. The mother may still continue to take the young into their mouth for protection during the night or in the presence of danger (Keenleyside, 1991). However, parental care and its associated behaviour significantly changes at the end of the brooding period at which time the parents start to display aggressive and cannibalistic behaviour towards the fry (Tacon et al. 1996).

The duration of parental care is important in terms of the time between two spawning periods (interspawning interval). It seems that the interspawning interval extends if the spawning and hatching is successful, allowing the mother to spend a longer time caring for her young. On the other hand, the interspawning interval shortens if spawning is not successful (e.g. due to lack of fertilisation or loss of the brood). Gautier et al. (1993) successfully modified the interspawning interval in the closely related species *O. niloticus*. They were able to artificially modify the duration of maternal care by experimentally promoting the adoption of foreign broods of various ages.

Tacon et al. (1996) have shown that the gonadosomatic index (weight of ovaries relative to total body weight) in non-incubating females

Figure 5: *Stunted tilapia mature at only a few centimetres in length (male: top, female: bottom) (Photograph: courtesy of DEEDI).*

increases (within 15 days after spawning) a lot faster than for incubating females (within 27 days after spawning). This indicates that the non-incubating females develop eggs and become ready for the next spawning sooner. Cichlid fish, including Mozambique tilapia, exhibit a type of development called 'group synchronous type follicular development' (De Vlaming, 1974), which contributes to the prolific reproduction ability of tilapia species. This type of development means that females can have oocytes (immature eggs) at three different development stages present in the ovary at the same time. When the first 'batch' of oocytes is ready to be released, development

Figure 6: *A non-stunted female Mozambique tilapia approximately 28 cm in total length. Note tilapia yolk sac larvae expelled from the brooding mouth. (Photograph: Keith Chilcott).*

Stunting

Tilapia can sexually mature at an early age when environmental conditions become less favourable. Some of these conditions might include reduced productivity, overcrowding or harsh abiotic conditions. In these situations Oreochromis spp. divert energy expenditure and investment from somatic (general) growth to reproduction, leading to stunting (Siraj, et al. 1983; Galman et al. 1988; De Silva and Radampola, 1990). Mozambique tilapia are capable of maturing at three and a half months of age under unfavourable conditions (Elliot, 1955). In south-east Queensland, early sexual maturity at around 3 months was observed by DEEDI biologists for O. mossambicus in farm dams where water quality and densities are not very favourable. Its ability to stunt gives tilapia the capacity to rapidly dominate waterways and build up very dense populations. Stunted male and female tilapia are shown in Figure 5. For comparison a non-stunted female is shown in Figure 6.

Stunting is a very important phenomenon in tilapia, and is a feature of the populations in the ephemeral Gascoyne River in Western Australia (Morgan, et al. 2004). In the western catchments of Queensland, rivers shrink to waterholes where native fish species aggregate and wait for the next rainy season for dispersal and reproduction. In drought periods, when most native fish species do not breed, but conserve resources whilst waiting for the rain, tilapia can continue to reproduce (in warmer months). Under these stressful conditions, tilapia will adopt a strategy of early maturation at small sizes. Therefore, tilapia have the potential to dominate ephemeral rivers in the northern Murray–Darling Basin and greatly impact the ecosystems in drought refugia.

Table 5: Age, and length at sexual maturity (Lm50) (where 50% of individuals reached maturity) for tilapia in north Queensland. Average length of all females in the populations is also shown (from Russell, et al. 2009).

Location	Male tilapia		Female tilapia		
	Age in years at 50% maturity	Lm50 (mm)	Age in years at 50% maturity	Lm50 (mm)	Average length (± 95% confidence interval) (mm)
Tinaroo Falls Dam	2.6	380.7	2.4	331.0	341.6 (335.2–348.1)
Paradise Palms	2.2	278.1	2.0	244.0	258.5 (253.9–263.1)
Herberton Weir	1.4	188.9	1.6	155.5	177.5 (171.3–183.7)
Kewarra Beach Drain	0.5	113.8	0.5	93.3	111.68 (106.1–117.3)

of the second and third batches is already underway. This means that new batches are ready for the next spawning much sooner than if they were 'starting from scratch'.

ADAPTABLE REPRODUCTIVE STRATEGIES

Tilapia exhibit flexible reproductive strategies in response to environmental stressors; this enables them to achieve reproductive success even under difficult conditions. They can modify their extent of parental care, alter energy expenditure on growth by re-directing it towards reproduction (producing stunting) or shorten the period of time between successive spawnings to enhance their reproductive success.

Providing parental care is considered to be a significant investment towards guaranteeing the survival of the offspring (Sargent et al. 1987). However, this results in substantial energy cost which impacts on the subsequent reproduction cycle (Williams, 1966). Such energy expenditure can be compensated for by either reducing the growth of incubating females (stunting) (Little et al. 1993) or extending the interspawning interval (period of time between spawning) (Mrowka, 1987; Smith and Haley, 1988; Smith and Wootton, 1994).

Mozambique tilapia is matched by very few fish for the diversity of habitats it can colonise and the range of phenotypes it can form (James and Bruton, 1992). A phenotype is the observable physical or biochemical characteristics of an organism, as determined by both its genetic makeup and environmental influences. Mozambique tilapia can adopt an 'altricial' strategy (early maturation at small size) when environmental conditions are harsh or a 'precocial strategy' (late maturation at large size) when conditions are more favourable (James and Bruton, 1992). An altricial strategy can be defined as a trend towards earlier maturation, increased fecundity, smaller eggs, and an extended breeding season with reduced parental care. However, care will not be completely lacking but may involve more rudimentary nest construction by males (James and Bruton, 1992). In benign environments where resources are plentiful, tilapia may adopt a precocial strategy, in which fish delay maturation and have reduced fecundity, but larger eggs and increased longevity with high investment in individual young (James and Bruton, 1992).

Where the climate is more temperate, it seems reproduction is more seasonal and closely tied to seasonal temperature fluctuations and water levels (Lowe-McConnell, 1975; De Silva, 1985). However, Lowe-McConnell (1982) indicated that tilapia in lacustrine (non-flowing waters, e.g. a lake, billabong or waterhole) tropical waters may breed irrespective of flooding. Good feeding conditions enable tilapia to continue somatic growth after maturity. This helps fish to attain a large body mass which in turn directly influences fecundity (James and Bruton, 1992). On the other hand, as already noted previously in this paper, if the reproductive behaviour consumes most of the energy ingested, the growth of tilapia may be adversely affected.

Outlined in Table 5 are comparative age and size at maturity for different populations of tilapia. It shows data from north Queensland populations where age and size at maturity are greater in the relatively benign and productive habitats of Tinaroo Falls Dam and Paradise Palms, compared to the less productive Herberton Weir and harsh conditions of the Kewarra Beach drain (Russell et al. 2009).

FECUNDITY

Tilapia fecundities recorded in Eastern Cape Province populations in South Africa will be used in this report, as populations occupy a latitudinal range that corresponds to the Murray–Darling Basin. Depending on the water body, these populations mature at between one and three years of age and have a reproductive lifespan of six to seven years. Typical clutch sizes ranged from 376 to 3,113 eggs, with the smaller clutch sizes belonging to smaller earlier maturing fish (age 1+). These clutch sizes correspond to relative fecundities of 9,400 and 3,697 eggs per kg of body weight respectively (James and Bruton, 1992). Egg number per unit of body mass was found to be higher in the earlier maturing fish and egg sizes were smaller in the more fecund populations.

Pond-based studies of tilapia in the Eastern Cape indicated that up to five broods per female could be produced in a 133 day period (James and Bruton, 1992). In the northern Basin, and even in more southern parts of the Basin, the median annual water temperatures exceed 20°C at many sites (Tables 2, 3 and 4). Therefore, the breeding season of tilapia is likely to be at least six months (180 days), meaning more than five broods could be produced per female per breeding season.

Russell et al. (2010) reported relative fecundities for tilapia in north Queensland ranging from 2,431 to 24,238 eggs per kg of body weight. The latter extremely high relative fecundity was recorded for very early maturing (0+) stunted populations. Stunted earlier maturing populations (1+ or 0+) of tilapia would appear to be a likely scenario in waterholes in the northern ephemeral rivers of the Basin, whereas later-maturing large fish are more likely to be prevalent in larger weir pools and impoundments.

INBREEDING

Inbreeding can become a problem in cultured tilapias as it is in other cultured fish. Species such as Atlantic salmon, brook trout, chinook salmon, coho salmon and rainbow trout (Tave, 1993; Wang et al. 2002; Fjalestad, 2005) have shown that closely related individuals breed with each other. Potentially, inbreeding could also be a problem for invasive species with small founder (establishing) populations. These populations can result in more closely related breeding pairs which increases the chance of recessive deleterious traits appearing in their offspring. The most frequently observed problems associated with inbreeding is the reduction of reproductive capacity or physiological efficiency, which is known as inbreeding depression (Falconer and Mackay, 1996; Wang et al. 2002). It was reported in Nile tilapia (which are closely related to Mozambique tilapia) that inbreeding results in reduced reproductive success in both males and females (Fessehaye et al. 2009).

Rapid inbreeding such as full-sibling matings can have a negative impact on the success of the following generations (Bentsen and Olesen, 2002). However, it has been shown in pigs that mild inbreeding presents the opportunity for selection to act against fixation of undesirable genes and avoids inbreeding depression (Pirchner, 1983). Reproductive problems associated with inbreeding are mainly due to reduction in the size of a breeding population (Sonesson et al. 2005).

The question arises: does a small founder population of tilapia in the Murray–Darling Basin means that tilapia should be ignored as a threat? The answer is no. However, intervention during the early founder stages of a population, before there is much opportunity for selective pressure to take effect, would have a greater chance of success. If inbreeding is a problem, then how do biological invasions succeed? The answer appears to be a genetic paradox as many invasive species are successful despite having apparently small founder populations. There are a number of explanations as to how tilapia overcome inbreeding and problems of low genetic diversity. One explanation is high migration rates; where repeated introductions occur low genetic diversity is overcome. Kolbe et al. (2004) provide evidence for this scenario with the invasive brown inole lizard. Similar arguments have been put forward to explain the success of introductions of the house mouse (Frankham, 1997), and starling and sparrow (Sakai et al. 2001). If this is the case, then vigilance in preventing multiple translocations of tilapia across the Great Dividing Range into the Basin is essential.

However, Perez et al. (2006) argue that high migration rates with repeated introductions cannot explain the success of all invasions. They provide evidence that a number of invasions have been successful from single introductions with small founder populations. Translocation of a small number of tilapia from a farm dam in south-east Queensland to the Basin could fit this paradigm. Perez et al. cite the invasion of a lake in Venezuela by tilapia as an example that was responsible for the extinction of 13 out of 23 native fish species in the lake. This tilapia population was derived from just 17 individuals translocated from Trinidad. This single introduction has also resulted in the colonisation of a river system where 6 native fish species were eliminated. Perez et al. contend that these tilapia would have been through at least four bottle necks before reaching Venezuela. They suggest that successful invaders not only modify their environment, but also suffer genetic modifications under the influence of the new environment.

It appears that inbreeding has not hindered successful biological invasions by tilapia in the past, or prevented them from having deleterious impacts. Therefore, the potential for tilapia to inbreed in the Basin cannot be used as an excuse for complacency or a 'do nothing' approach in preventing tilapia incursions into the Basin. It is better to prevent incursions or, failing that, to detect them in an early enough stage to permit their eradication; these options are the only ways that tilapia can be from prevented from colonising the Basin.

Other important biological attributes of tilapia

ABILITY TO DISPERSE

Rapid spread of Mozambique tilapia through the Murray–Darling Basin is plausible if it is introduced to these waterways. Experiences in north Queensland and Western Australia have both demonstrated rapid dispersal of tilapia. This rate of spread is exacerbated where human-assisted dispersal is combined with the natural abilities of tilapia to move up and downstream of an introduction site.

Tilapia has been found in the Burdekin River system, one of the largest catchments on the east coast of Queensland. Veitch et al. (2006) found it had dispersed both upstream and downstream from sites in the Burdekin River where it had been introduced, with the spread being more rapid upstream than downstream. Tilapia were found at sites spread over more than 500 km of waterway within two years of their initial discovery. This rapid spread was attributed to a combination of natural and human assisted dispersal (Veitch et al. 2006). By February-March 2009, tilapia had colonised the whole Burdekin catchment, reaching the mouth only five years after their initial discovery in Keelbottom Creek, an upper tributary (Malcolm Pearce, pers. comm.). There was strong evidence that humans assisted the dispersal of tilapia in the catchment. Natural rates of dispersal were up to 70 km per year from infestation sites (Malcolm Pearce, pers. comm.).

In Western Australia, tilapia was introduced near the mouth of the Gascoyne River at Carnarvon, spreading to most of the accessible length of this arid zone ephemeral system within ten years (Arthington and Blühdorn, 1994). The Gascoyne River is 834 km in length (Geoscience Australia, 2009) and has a catchment area of 67,700 square km (Chanson, 2004). The rate of infestation of suitable catchments is predicted to occur in a similar timeframe.

Migration of native fish and introduced species (such as European carp) is an important phenomenon in the Murray–Darling Basin. The potential impact of tilapia on the operation and efficiency of fishways and for infrastructure currently used to manage European carp (e.g. separation cages) is an important question. However, there is very little published information on potential migrations that tilapia might undertake. Tilapia have been known to migrate and observed accumulating below a weir during a flow event in South Africa (Cambray, 1990). There is no published information referring to tilapia using fishways in Australia; however, this is mainly a reflection of fishways monitored to date, which were all outside the known distribution of tilapia at the time of monitoring. There is no published information on tilapia using fishways outside of Australia either; however, in 2011 tilapia was recorded moving upstream through a fishway on the Logan River in south-east Queensland (David Roberts, pers. comm.) but details of this are yet to be published. Tilapia behaviour in a fishway remains an unknown at this stage; therefore, no conclusions are drawn in this report as to how they may impact on native fish using fishways or the operation of carp management infrastructure.

HABITAT PREFERENCES

Tilapia are able to tolerate a broad range of freshwater and saline habitat types in Australia, from severely disturbed to relatively pristine (Arthington and Blühdorn, 1994). They have been recorded in ephemeral rivers, reservoirs, lakes, ponds, farm dams, rivers, creeks, drains, swamps, salt lakes and tidal areas (Allen et al. 2002; Morgan et al. 2004; Russell et al. 2010). Tilapia appear to be well adapted to ephemeral systems (Donnelley, 1978; van der Waal, 1998; Minshull, 2008) and can dominate pools and waterholes in ephemeral waterways (Morgan et al. 2004; Minshull, 2008). They are often found in flowing waters, although they do display a preference for pools and low flow areas (Pienaar, 1968; Gaigher, 1973; Whitfield and Blaber, 1979). In the Limpopo River system (South Africa and Mozambique), tilapia occur from an elevation above 900 m down to sea level, but are more common in the lower and middle reaches and most prevalent in pools of both perennial and annual rivers (Gaigher, 1973).

Cooper and Harrison (1992) found that in summer, males move from deeper water areas to shallows, where they construct mating pits or nests. The preferred nesting habitats were shallow vegetated terraces. In reservoirs in Sri Lanka, tilapia nests are mostly constructed in shallow waters in or near coves and bays (De Silva and Sirisena, 1988).

Juvenile tilapia can be plastic (adaptable/changeable) in their use of habitat. In Lake Sibaya, South Africa, juveniles have been observed to move daily from deep offshore waters to feed in shallow littoral (shoreline) areas. When the littoral zone was free of debris, juveniles visited this zone only during daylight. With a rise in lake level and accumulation of debris in the littoral zone, juvenile tilapia were abundant in the littoral zone only at night. When marginal grasslands were flooded, juvenile tilapia occupied this habitat (where potential fish predators did not occur) in preference to other areas (Bowen and Allanson, 1982). James and Bruton (1992) also noted plasticity in habitat use by juvenile tilapia in small dams in South Africa. In a small dam where the piscivorous bass *Micropterus salmoides* was present, young tilapia were released into shallow marginal areas by the adults and larger juveniles fed amongst aquatic vegetation (*Potamogeton pectinatus*) to avoid predation. In a nearby dam without any large piscivorous fish, juvenile tilapia were released by adults into warm surface waters adjacent to reed beds (*Typha capensis*). The larger juveniles used the warm shallow areas among the reed beds for feeding and cover from predatory birds. In winter, all tilapia in the dam sought refuge in deeper waters at the edge of, or amongst, the aquatic vegetation.

DIET

Tilapia have adaptable dietary habits. Although they primarily feed on detritus, algae, macrophytes and other organic matter (Jameson 1991; Arthington et al. 1994; Silva et al. 2001; Ujjania et al. 2001; Weliange and Amarasinghe, 2003; Morgan et al. 2004; Russell et al. 2010) they are also known to be adaptable in their dietary choices (Bowen and Allanson, 1982; Arthington et al. 1994; Russell, et al. 2010). For example, in Sri Lanka, diets of tilapia in nine reservoirs ranged from herbivory to total carnivory (De Silva et al. 1984). A study of diets of tilapia in 12 Sri Lankan lakes also found seasonal variation in diets, as well as variation between lake populations (Maitipe and De Silva, 1985). Detritivory was common in the Sri Lankan wet season whereas phytoplanktivory (algal plankton-based) dominated in the dry season (Maitipe and De Silva, 1985). Bowen and Allanson (1982) also noted that changes in the diets and habitat use of tilapia in a South African lake coincided with fluctuations in water levels in the littoral zone.

Changeable diets have also been observed in Mozambique tilapia in Australia. In 2005, adult tilapia in North Pine Dam and Wivenhoe dams in south-east Queensland were found to consume mostly periphyton (aquatic organisms, such as certain algae, that live attached to rocks, macrophytes or other surfaces), benthic algae and detritus carbon sources. There was minimal contribution to their diet from other higher level consumers (e.g. snails, shrimp, forage fish). As their diet was dominated by these primary energy sources, they were positioned low in the food web. In 2006, 2007 and 2008, following a period when macrophytes were absent from North Pine and Wivenhoe Dams, tilapia diets shifted to rely on detritus and snails with other contributions from zooplankton, crustaceans and various other algae sources (David Roberts, pers. comm.). Similarly, in an urban drain in Cairns, when few food sources were available, tilapia preyed on snails (Russell et al. 2010). This indicates a degree of diet flexibility when preferred food sources are not available, and demonstrates tilapia can adapt to alternative food sources.

Tilapia show some shifts in dietary preferences with growth. In Hartbeespoort Dam in South Africa, small fish fed mainly on zoobenthos and zooplankton. Tilapia over 4 gm body weight fed increasingly on *Microcystis aeruginosa* (a species of blue-green algae) and detritus and these food sources also dominated the diets of fish over 8 gm body weight. Some cannibalism was also encountered in fish up to 64 gm in the summer months. The ratio of gut length to fish length increased as fish grew, indicating an adaptation from a carnivorous to phytoplanctivorous and detritivorous diet with increasing size (de Moor et al. 1986).

Studies on the closely related Nile tilapia (*O. niloticus*) show a similar trend. Its feeding habits change from carnivorous to omnivorous at a size of around of 2–3 cm standard length (SL), and it becomes a phytoplanctivorous filter feeder at around 6–7 cm SL (Yada, 1982; Getachew, 1987). At the adult stage Nile tilapia consumes blue-green algae as its main food source (Moriaty and Moriaty, 1973a and b; Yada, 1982; Getachew, 1987). Changes in diet between larval and adult tilapia could be due to a variety of factors including changes in the ability of tilapia to catch and process phytoplankton, the increase in buccopharyngeal (mouth and throat) mucus cell numbers and their activity, and further development of the digestive tract (Drenner et al. 1984; Northcott and Beveridge, 1988; Sanderson et al. 1996). These differences also affect the type of phytoplankton larval tilapia can consume. For example, Lu et al. (2004) have shown that larval tilapia consume more *Spirulina* than *Chlorella* and *Euglena*, which changes with the development of the larvae.

The cell wall of plant tissue generally acts as a barrier for digestion. However, it can be broken down by gastric acid which reduces the stomach pH to around 1 in adult *O. niloticus* (Moriaty and Moriaty, 1973a and b). Secretion of low pH gastric acid increases in larval tilapia with age, resulting in different digestibility for different alga as each species has a cell wall with a different degree of strength. The ability to digest and uptake nutrients from different algae species with increasing age is probably related to the increasing intestinal length (Lu et al. 2002), and the differences in bioavailability of nutrients contained in the algae and the cell structure of different algae species. The highly acidic stomach of *O. mossambicus* also enables fish prey to be digested rapidly, certainly within 24 hours, but most probably within one hour (Doupé and Knott, 2010). This means piscivory (fish consumption) could be underestimated in tilapia.

CANNIBALISM

Cannibalism is known in tilapia (de Moor et al. 1986; Ellis and Watanabe, 1994; Ellis et al. 1993). Tilapias from the *Oreochromis* genus seem to be primarily subject to cannibalism associated with difference in size; typically, larger individuals will prey on smaller ones. This seems to particularly be the case in the Nile tilapia which has low fecundity and an asynchronous reproductive cycle. This results in production of several batches of fry over a breeding season and thus different hatching times and a wide size range of juveniles (Fessehaye et al. 2006). Mozambique tilapia also produces a number of broods in a breeding season, so similar patterns in size range can be expected. The aggressive behaviour of the genus also exacerbates cannibalism associated with the size differences.

Cannibalism may also occur due to a number of behavioural and size-related factors (Fessehaye et al. 2006). Behaviour-related cannibalism may be a result of low food availability, high population density, lack of refuge/shelter availability, water clarity, light intensity, feeding frequency and availability of alternative prey (De Angelis et al. 1979; Fox, 1975; Hecht and Appelbaum, 1988; Katavic et al. 1989). The incidence of cannibalism is affected by the population density (Hecht and Pienaar, 1993) where availability of food significantly influences the incidence of cannibalism (Fessehaye et al. 2006). This is the case not only in adult tilapia but also in tilapia fry (Macintosh and De Silva, 1984).

Cannibalism and general predatory behaviour are also considered to be related to gape size (how far the mouth can open) (Hambright, 1991).

Although there is a strong relationship between predator and prey size on the rate of cannibalism in Nile tilapia *O. niloticus* (Fessehaye et al. 2006), there are some cases where tilapia have been observed attacking and attempting to eat individuals of its own kind and other species that are larger than its own gape size. Cannibalism by Mozambique tilapia further demonstrates the potential for this species to exhibit piscivory and suggests possible impacts on Basin native fish species from tilapia predation.

Climate change and its potential influence on tilapia in the Murray–Darling Basin

In most aquatic habitats, especially inland catchments such as the Murray–Darling Basin, native species have evolved for a fluctuating climate and periods of drought (Commonwealth of Australia, 2009). Despite this may, many could be vulnerable to climate change as they are already under stress from the negative effects of human activities, such as altered landscapes through vegetation clearing, introduced pests and weeds, overcommitted water resources, widespread use of fertiliser and other chemicals, changed fire regimes, urbanisation, mining, and over-harvesting.

It is estimated that climate change will increase global air and water temperatures and so simultaneously reduce freshwater availability through a decline in normal rainfall (Garnaut, 2008). In the second half of the twentieth century, the impact of climate change appears to have resulted in a rise of air and water temperatures in Australia that is higher than the global average (Garnaut, 2008), thus affecting already stressed Australian aquatic ecosystems and reducing their adaptive capacity. Australia's annual mean temperature has increased by 0.9^{0}C since 1910 (CSIRO and BoM, 2007). Increased temperatures will favour expansion of the distribution of northern fish species southwards (therefore

The Commonwealth of Australia (2009) has identified some key adaptive measures to reduce the impact of climate change on Australian ecosystems. These measures are also relevant to limiting the further spread of tilapia and minimising additional impacts should this noxious species enter the Murray–Darling Basin.

Maintaining well-functioning ecosystems

It is considered that the single most important adaptation strategy is the maintenance of well-functioning ecosystems. Although there will be some shift from the current ecosystem functions due to temperature rise, a well-functioning ecosystem will give native fish species a better chance to maintain healthy populations. In a well-functioning ecosystem, tilapia generally put more energy into growth rather than reproduction (i.e. they do not stunt) and populations are less dense. Thus tilapia populations are likely to be smaller and the impact on native fish populations less.

Protecting a representative array of ecosystems

The principle of representativeness of all biodiversity in appropriately managed systems remains essential. However, under a rapidly changing climate, the purpose may be to represent as many different combinations of underlying environments and drivers, rather than specific arrays of current species. To be effective, protected areas have to be kept free from any human-initiated impacts and pest flora and fauna, including alien fish species such as tilapia.

Removing or minimising existing stressors

Climate change magnifies the effects of many existing stressors, which continue to threaten Australia's biodiversity. Accelerating the control or elimination of existing stressors offers an extremely low-risk, high-payback starting point in

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favouring southern expansion of tilapia), reduce refuge capacity of waterholes during dry seasons and drought periods, and accelerate the demand for freshwater during rejuvenation of terrestrial vegetation (DPIF, 2008).

The impacts of climate change, in addition to increasing the temperature, may also include a reduced capacity of freshwater fish habitats to sustain existing fish populations and biodiversity as rainfall patterns change. Although changes in rainfall patterns due to climate change are difficult to predict, all models indicate that there will be 5–10% less rainfall throughout the year in the Basin, except in summer months in the northern Basin (EPA, 2008). Impacts of declined rainfall on freshwater habitats will be most pronounced in areas where water resources are used for agricultural, urban and industrial purposes. Reduced rainfall will result in quicker drying of important habitat areas after a rain event due to increased evaporation resulting in increased aridity and the severity of droughts. This will lead to a loss of habitats in critical areas (DPIF, 2008; EPA, 2008).

Effects of climate change include a reduction in water quality and declined food availability in isolated refugia and waterholes that will occur more often and be more widespread. These conditions are likely to be unfavourable to native fish species and have a negative impact on them. On the other hand, tilapia will withstand such conditions more easily than many native fish. As mentioned earlier, tilapia is a very resilient fish species and can tolerate extreme environmental conditions including low dissolved oxygen, high ammonia, high salinity and high turbidity levels. It can also change food preference to adapt to the prevailing conditions. Increasing water temperatures will only expand the potential population range of tropical pest species including tilapia, and assist their spread southwards within the Basin in the long term.

building resilience of natural systems to climate change. This includes providing enough freshwater for the environment when it is needed most, making sure water quality does not deteriorate due to agricultural, urban and commercial activities, and preventing erosion of banks and degradation of in-stream habitats. These actions will give native fish species better chances of surviving impacts of climate change. Removing or minimising existing stressors will also improve aquatic habitat, thus reducing the chance of tilapia stunting and preventing them from rapidly building up numbers.

Building appropriate connectivity

With increasing pressure on species to migrate in response to a changing climate, there needs to be greater focus on achieving appropriate types of aquatic connectivity to give space for native fish species to self-adapt. However, for connectivity to work most efficiently there has to be sufficient flows of good quality water to re-connect separated habitats and inundate crucial new aquatic habitat. Although it is probable that connectivity assists the dispersal of alien fish species such as tilapia, it benefits native fish populations more by aiding migration to refugia, providing better habitats, maintaining biodiversity and improving water quality and productivity. Connectivity should also decrease the potential for stunting of tilapia as improved aquatic habitats will encourage them to spend most of their energy on growth rather than reproduction.

Identifying and protecting refugia

There is a need to ensure that key sites likely to provide refugia in the face of climate change are identified and included in reserves, or otherwise managed to protect their values.

Reported and potential impacts of tilapia

IMPACTS RECORDED ON AUSTRALIAN NATIVE FISHES

Despite the relative dominance of tilapia in a number of Australian waterways, there is comparatively little information available on their impacts (Arthington, 1989; Russell et al. 2010). Critically, there is a lack of studies before and after the establishment of tilapia (Arthington and Blühdorn, 1994), so most impacts are inferred from observations of tilapia diets, dietary overlaps or more recently from microcosm studies (Doupé et al. 2009a and b). This section examines some of the key work done on this subject in Australia to date.

Arthington et al. (1994) found that there was distinct partitioning of food resources between tilapia, spangled perch *Leiopotherapon unicolor* and freshwater catfish *Tandanus tandanus* in North Pine Dam in south-east Queensland. The diet of tilapia was shown to be mainly herbivorous but included minor consumption of invertebrates and high use of phytoplankton. They concluded that mature tilapia and these native species probably did not compete for food resources due to different foraging strategies. However, this study commenced after tilapia colonised the dam, so whether the presence of tilapia forced any dietary shifts in the native species is unknown. Arthington et al. (1994) noted that tilapia and spangled perch consumed different parts of *Hydrilla verticillata* plants. Although not actually competing for food this grazing may affect plant health and thus indirectly reduce availability to the spangled perch. This study also did not examine dietary overlaps between juvenile tilapia and the two native species.

The diet of juvenile tilapia in the Chapman River and mature fish in the Gascoyne River in Western Australia were found to be predominantly detritus/sand/biofilm based. Juveniles in the Gascoyne River also consumed a high proportion of aquatic insects. This diet only overlaps significantly with that of the Murchison River hardyhead *Craterocephalus cuneiceps*. Other native fish in these systems ingest little if any detritus/sand/biofilm (Morgan et al. 2004).

Native species may be affected during the tilapia breeding season. Morgan et al. (2004) observed that during the breeding season, male tilapia become particularly aggressive when guarding their nests. These nests often covered over 80% of the shallows in the Gascoyne River and were vigorously guarded by their incumbent males. Tilapia were easily the largest species found in the river and they excluded native species from large areas of the river through their aggression and nest building, reducing the habitat available to native fish. Morgan et al. (2004) concluded that tilapia must have serious deleterious effects on native fish and were particularly concerned about effects of tilapia during periods of drought when most of the region's rivers become dramatically reduced to small, disconnected pools.

Similarly, in its native range in Zimbabwe, Mozambique tilapia are the dominant species in terms of biomass in dry season pools (Minshull, 2008). A large number of the Murray–Darling Basin's rivers and streams are ephemeral and contract to pools in drier periods. Based on evidence from the Gascoyne River in Western Australia (Morgan et al. 2004) and from its native range, tilapia has the potential to dominate drought refuge pools in the Basin. If they are also able to aestivate in wet river sands, as previously noted, this could further promote the dominance of tilapia in ephemeral systems.

Although tilapia are predominantly detritivores and herbivores (Arthington et al. 1994; De Silva et al. 2001; Morgan et al. 2004), they are omnivorous and have very adaptable diets to make use of available resources (Russell et al. 2010; Cooper and Harrison 1992, and Ujjania, et al. 2001). Overseas evidence corroborates tilapia's dietary adaptability, including De Silva et al. (1984) who report that tilapia in Sri Lanka feed on fish and invertebrates in some lakes. The potential of tilapia for piscivory means that tilapia could impact more directly on some native Australian fish species than previously thought.

Microcosm (tank or small enclosure) experiments by Doupé et al. (2009b) recently demonstrated the potential for tilapia to prey upon juvenile native Australian fishes. Species consumed in these experiments included members of genera that occur in the Basin, such as *Melanotaenia*, *Hypseleotris*, *Craterocephalus*, *Nematalosa* and *Ambassis*. Similarly, Arthington and Blühdorn (1994) noted evidence that tilapia consume rainbowfish (*Melanotaenidae*) and gudgeons (*Eleotriidae*) in sub-tropical impoundments in Australia. Doupé and Knott (2010) observed that fish prey was rapidly digested by tilapia, sometimes within an hour. This could lead to an underestimation of the degree of piscivory by tilapia. Arthington and Blühdorn (1994) suggested that consumption of fish and aquatic invertebrates may be higher in water bodies with low primary productivity. This situation could possibly apply to some of the turbid waterholes in the Basin.

Further microcosm experiments by Doupé et al. (2009a) also suggest that tilapia can significantly reduce breeding success in Australian eastern rainbowfish *Melanotaenia splendida splendida*. These experiments need to be treated with some caution as the species are tested in artificial circumstances – confined and in close proximity. However, there is also some supporting evidence from a field situation that tilapia may have impacted on the breeding success of a species of rainbowfish in New Guinea (Crockford, 1999; Crockford, 2001), which concurs with the microcosm experiment results.

IMPACTS RECORDED ON FISH FAUNA FROM OUTSIDE AUSTRALIA

Some authors suggest that there is little substantiated evidence for impacts of tilapia species (*Oreochromis* spp.) on freshwater fish biodiversity. They state that impacts are only mild to moderate and they also suggest the benefits of introduction of tilapia as a food source outweigh the negatives (e.g. Fernando et al. 2002 and Arthur et al. 2010). For example, in Sri Lanka tilapia have mainly become established in reservoirs, where they contribute to fish production and they have not established in the rivers (Fernando et al. 2002). Despite the benefits of some tilapia fisheries in the tropics, there are also examples of negative impacts of tilapia on native fish communities from various locations around the world.

Pacific

In Papua New Guinea, Mozambique tilapia has been implicated in the decline of a species of rainbowfish: the Lake Wanam fasciata (*Chilatherina fasciata*). Lake Wanam became dominated by tilapia, whilst the once common *C. fasciata* became extremely rare. One possible mechanism causing this decline is that the nesting habits of tilapia may have disrupted the bottom-spawning habitat of *C. fasciata* (Crockford, 1999; Crockford, 2001).

In Fiji, native freshwater fishes are also significantly affected by tilapia. On average, stream networks with established *Oreochromis* spp. populations were found to contain 11 fewer species of native fish than intact systems. The species that disappeared were mostly species of amphidromous (species that migrate between freshwater and the sea for purposes other than breeding) gudgeons (*Eleotridae*) and gobies (*Gobiidae*) (Jenkins et al. 2010). These families also occur in Australian freshwaters.

Asia

De Silva et al. (2004) make a case that, in Asia, although tilapia have been associated with adverse impacts, it is environmental degradation that has been more responsible for adverse impacts than tilapia. This includes land-based activities, overfishing and changes in hydrological regimes. They also point out the benefits to food production that tilapia have brought to the region. It may well be the case that other activities have had a greater impact on biodiversity, but it could also be argued that pest fish species further exacerbate impacts in degraded ecosystems.

In India, a network model of trophic interactions in a reservoir was used to quantify matter and energy flows in order to study the impact of invasive fishes in the system. This study found that Mozambique tilapia adversely affected indigenous catfishes (Feroz Khan and Panikkar, 2009). Also in India, the yield of native Indian major European carps declined significantly following the introduction of Mozambique tilapia to Powai Lake. The introduction caused considerable changes in the growth pattern of Indian major European carps, ultimately reducing the productive potential of the lake by 67% (Bhagat and Dwivedi, 1988).

In the Philippines, Mozambique tilapia is established in brackish water farms, rivers, swamps, and rice fields throughout the country. There is some debate over whether they are a causal agent in the (localised) extinction of the endemic goby, the sinarapan (*Mistichthys luzonensis*) (Pullin et al.1997, reported in Canonico et al. 2005). Although tilapia may prey on sinarapan, it has been suggested that overfishing and barriers to migration could be more significant contributing factors to the sinarapan's decline (De Silva et al. 2004).

Central America and South America

In a lagoon in Yucatan, Mexico, Mozambique tilapia caused a shift in habitat use in two out of five native *Cyprinodon* species. These fish species were segregated by habitat use but the introduction of tilapia forced two species, *C. maya* and *C. labiosus*, into habitat occupied by *C. beltrani* (Fuselier, 2001). This has put the *Cyprinodon* species at risk of extinction and caused a significant perturbation of the conditions that gave rise to the speciation of this group of fish (Fuselier, 2001).

Russell et al. (2010) cite two Spanish language references (Aguilera and Carvajal 1976; Perez et al. 2003) that implicate tilapia in the loss of 13 fish species from an estuary and 6 fish species from a river in Venezuela. A review article by Canonico et al. (2005) cites impacts of introductions of other tilapia species outside their natural range on native fishes in the USA, Africa, and southeast Asia. Impacts included reduction in biomass and abundance of native species, destruction of native fish habitat and hybridisation with related species (Africa only) and transfer of parasites.

Mozambique tilapia invasion of Lake Nicaragua

Three African *Oreochromis* species, including *O. mossambicus* were introduced into Lake Nicaragua between 1983 and 1984. Interest in building an inter-oceanic canal through Lake Nicaragua in the 1980s stimulated research on the lake ecosystem, resulting in the collection of important baseline data prior to tilapia introductions (McKaye et al. 1995). No tilapias were collected in Lake Nicaragua during a Soviet study in 1983, but by 1987–88, fishermen began reporting tilapia catches. The fishermen correlated these catches with a decline in native cichlid catches, and this correlation was confirmed with data collected by McKaye et al. (1995). By 1990, in areas where tilapia had only just established, catch rates of fish were 1.8 times higher than areas where tilapia were already abundant. Biomass of native cichlids declined by 80% by the early 1990s (McKaye et al. 1995).

Tilapia species have now spread to other lakes and catchments in Nicaragua (McCrary et al. 2007). They may be edging out molluscivores from the Lake Apoyo, thereby promoting population instabilities and propagation of infections of parasitic trematodes (flatworms). Tilapia have been blamed for an outbreak of blindness in native cichlids in Nicaraguan waters, caused by the introduction of a trematode infection. It is also suggested that tilapias have eliminated preferred breeding habitats of some native fishes (McCrary et al. 2007).

IMPACTS ON HABITATS AND WATER QUALITY

The possible impact of tilapia on aquatic vegetation in the Murray–Darling Basin is difficult to assess. However, there is some evidence that suggests detrimental effects are possible. Impacts on water quality in the presence of tilapia have been documented elsewhere in Australia and are likely to occur in the Basin.

Impacts of herbivorous or omnivorous fish species on the aquatic plants could be categorised as either by feeding on plants or by uprooting plants (Piepho and Alkämper, 1991; Haroon and Pittman, 1997; Rothuis et al. 1999). While the activity of bottom feeding fish species, such as European carp, results in plants being uprooted, species such as tilapia impact on plants by feeding directly on them. Tilapia are known to graze on macrophytes (Arthington et al.1994; Costa-Pierce, 2003), and microcosm experiments by Doupé et al. (2010) have demonstrated that tilapia can significantly impact on the weight of native Australian macrophyte species. However, the impact of tilapia on macrophyte biomass has not been evaluated in a field situation in Australia. Elsewhere, tilapia has been introduced to waterways to control aquatic weeds (Costa-Pierce 2003), so potentially they could have negative impacts on aquatic plants in the Basin. In addition, observations of small lagoons in South Africa found that the nest building and lekking activities of tilapia are capable of uprooting macrophytes and reducing bank stability (Cooper and Harrison, 1992). Tilapia species have eliminated beds of the macrophyte *Chara* sp. in Lake Apoyo, Nicaragua, depriving native cichlids of nursery and preferred breeding habitats (McCrary et al. 2007).

The impact of tilapia could further compound existing impacts from European carp on native macrophytes in the Basin. Frei at al. (2007) have demonstrated that European carp and Nile tilapia together are very effective in removing weeds from rice fields, significantly reducing costs associated with controlling weeds in rice fields manually or by using herbicides. This suggests that a combination of both European carp and tilapia in the Murray–Darling Basin could have a major negative impact on native macrophytes. This in turn could impact on native fish species (such as olive perchlet *Ambassis agassizii*) that use macrophyte beds as spawning or nursery habitat (Hutchison et al. 2008; Lintermans, 2007).

Although tilapia are known to consume phytoplankton, including blue-green algae (Jameson, 1991), they can also promote phytoplankton and blue-green algal blooms. These blooms can be promoted through resuspension of phosphates by tilapia's activity (Wang et al. 2000). Starling et al. (2002) demonstrated a link between high *O. niloticus* and *Tilapia rendalli* biomass in a tropical reservoir in Brazil and the subsequent increases in total phosphorus, chlorophyll *a*, and cyanobacteria (blue-green algae) concentrations. Given the high biomass that Mozambique tilapia can reach in impoundments, there is real potential for them to adversely affect water quality. This could result from the recycling of nutrients by excretion due to their dietary habit of feeding on detritus and other primary production (David Roberts, pers. comm.). Compared to other phytoplankton-consuming fish species such as European carp, tilapia have a much higher potential to cause eutrophication (pollution of waterways through nutrient enrichment) (Datta and Jana, 1998). Grazing on blue-green algae by tilapia may lead to a short term initial decline in blooms; however, these are likely to be followed by an increase due to nutrient enrichment from tilapia defecation (Datta and Jana, 1998).

Being a fish of sub-tropical/tropical origin, tilapia is also subject to winter fish kills under colder water temperatures. This has been recorded in a number of temperate locations, including Australia (Cochrane, 1986; James and Bruton 1992; Sardella et al. 2007; Russell et al. 2010). Large kills of tilapia have been a relatively frequent occurrence in south-east Queensland dams managed by Seqwater, during the winter when water temperatures decline. Data collected to date indicates that this coincides with minimum water temperatures below 16°C, particularly in the surface waters and shallower reaches. These kills have occurred across a range of locations including North Pine, Wivenhoe, Kurwongbah and Leslie Harrison Dams (David Roberts, pers. comm.). Therefore, if tilapia establish in the Murray–Darling Basin, winter fish kills appear likely to happen. These kills can be quite large, with fish clean-ups around the more accessible recreation points in south-east Queensland often totalling more than a tonne of fish. It often takes several days to weeks to remove dead fish. Clean-ups of only around 10% of the lake shorelines have recovered several tonnes of fish. Past examples highlight the high biomass tilapia can attain in impoundments. By the nature of this high biomass, fish kills of this magnitude have a real potential to exert various negative impacts on water quality. Water quality monitoring during these kills suggests spikes in dissolved inorganic nutrients occur shortly after the onset of the kill (David Roberts, pers. comm.).

Greiner and Gregg (2008) quote a representative of North Queensland Water who stated:

> Following a flood release from Ross River Dam, large numbers of tilapia congregate below the dam stilling basins, rapidly reducing DO [dissolved oxygen] levels and causing fish kills. These fish have to be removed from the stilling basins and adjacent water holes to reduce public health concerns. The loss of tilapia is not of concern, but the loss of native species and the environmental (public) impact of large mass of decaying fish is undesirable.

In the Basin, large kills of tilapia in irrigation channels, rivers and other waterways could potentially block up water intake pipes for irrigation systems. Decaying fish could potentially deplete water of oxygen, leading to further fish kills, but of native species.

DISEASES AND PARASITES

Within Australia, there are no confirmed cases of tilapia passing on diseases or parasites directly to Australian native fishes in the wild (Russell et al. 2010). A disease, *Bohle iridovirus* (BIV), originally isolated from the ornate burrowing frog *Lymnodastes ornatus* is thought to cause spinning tilapia (ST) syndrome (Ariel and Owens, 1997). This syndrome was observed in tilapia at a disease laboratory in Townsville, Australia. The histology of infected tilapia matched that of the virus when viewed by scanning electron-microscope, but viral isolation was not successful. Tilapia with ST syndrome were fed to barramundi fingerlings and the barramundi that consumed the ST syndrome fish exhibited classical BIV pathology. Ariel and Owens (1997) concluded that tilapia could carry BIV into naïve (not previously exposed) populations of fish and amphibians along waterways of northern Australia. Tilapia *O. mossambicus* have been successfully artificially infected with nodavirus (Skliris and Richards, 1999) and could therefore be potential carriers of nodaviruses. Translocation of tilapia from east coast catchments to the Basin could potentially be a means for nodavirus to enter the region.

In a study of 28 freshwater fish species in Taiwan, fourteen parasitic trichodinid (worm) species were recorded. Four trichodinids were of African origin and so it is probable that the African species entered Taiwan on tilapia (Basson and Van As, 1994). Some exotic trichodinid parasites have been found in Australia; *Trichodina c.f. acuta* was found on *Poecilia reticulata* (guppy) near Walkamin in north Queensland (Dove and O'Donoghue, 2005). Although not yet recorded from tilapia in Australia, tilapia has been recorded as a host for *T. acuta* elsewhere (Dove and O'Donoghue, 2005). Dove and O'Donoghue (2005) recorded *T. heterodentata* from various native fish species (gudgeons, golden perch, olive perchlets, galaxiids) and exotic species (European carp, live bearers and tilapia), from various sites in eastern and northern Australia, including some sites in the Basin. This parasite is endemic to Africa (Basson and Van As, 1994) and possibly entered Australia with tilapia. However, its occurrence over 1,000 km from known infestations of tilapia suggest that other vectors (organisms that transmit disease), such as eastern gambusia *Gambusia holbrooki*, may also have been involved in the spread of this parasite to Australia (Dove and O'Donoghue, 2005). Dove and O'Donoghue even speculate that the parasite could have a natural Gondwanan distribution. Trichodinid parasites can cause chronic dermatitis and loss of condition in fish, and when infestation loads are high, fish mortality can occur (Barker et al. 2002).

Various other parasites and diseases have been recorded from tilapia. These include nematodes (Boomker, 1994), monogeneans (Aragort et al. 1997), trematodes (Aragort et al. 1997), flagellates (Kuperman et al. 2002), branchiurans (Webb, 2008), helminths (Barson et al. 2008; Moyo et al. 2009) and the bacterium *Vibrio anguillarum* (Bhanumathi et al. 2010). The branchiuran recorded by Webb that was infecting tilapia (near Townsville north Queensland) was actually an Australian native species. Jiménez-García et al. (2001) recorded African monogenean species infecting native cichlids in Mexico. The source of these monogeneans was believed to be Nile tilapia *O. niloticus* and/or *O. aureus*. Conversely, some monogeneans from American cichlid species were found to infect the African tilapias.

It can be concluded that tilapia are a potential host for a diverse range of parasites and diseases. Although considered a very low risk, there is potential for tilapia to be a vector for transferring African parasites to native fish species. Of higher concern is the potential risk of spreading endemic diseases and parasites from north-east drainages into the Basin.

POTENTIAL IMPACTS OF TILAPIA ON NON-FISH FAUNA

There is virtually no information in the literature regarding impacts of tilapia on non-fish fauna. We know from information on tilapia diets (reviewed in this paper) that they do consume invertebrate prey, including shrimp, aquatic snails and zooplankton. Therefore, it is conceivable that tilapia may impact on the abundance of some invertebrate species. Invertebrates are a highly diverse group, so predicting which species would be impacted by tilapia in the Basin would be purely speculative.

As to the potential impacts of tilapia on aquatic mammal, reptile, and amphibian fauna, again this remains a knowledge gap as no impacts have been reported in the literature. Potentially tilapia could be a food source for turtles or, alternatively, they may compete with turtles for some invertebrate foods. Similarly tilapia may compete with platypuses for some invertebrate foods. However, in the Basin, the range of platypuses is unlikely to overlap significantly with the potential range of tilapia, as platypuses are confined to more eastern and southern areas of the Basin (Grant, 2007), which are less likely to be colonised by tilapia.

The impacts on amphibians by tilapia have not been reported, although Ariel and Owens (1997) concluded that tilapia could carry BIV into naïve populations of poikilotherms (fish and frogs) along waterways of northern Australia. Therefore it is possible tilapia could be vectors of BIV into frog populations in the Basin and possible that they could prey on the tadpoles of some frog species.

ASSESSING POTENTIAL IMPACTS OF TILAPIA ON MURRAY–DARLING BASIN FISH

Impacts of tilapia on fish are much better documented than impacts on other species groups. Existing knowledge of the diets and ecology of many Basin native fish species also makes it possible to make informed assumptions as to the possible impacts of tilapia on Basin fish.

Tilapia currently co-exists with a number of native species in south-east Queensland that are also common to the Basin. Whether tilapia has impacted on any of these species is uncertain, as there have been no before-and-after studies. Nevertheless, the Basin is an ecosystem under stress, and many native species are already in decline. Invasion of tilapia into the Basin would add an additional stress factor that could push some of the more stressed fish populations closer to localised extinction. The capacity for tilapia to continue breeding during periods of drought and sub-optimal environmental conditions (James and Bruton, 1992; Russell, et al. 2010), their capacity to aestivate in sandy river beds (Donnelley, 1978; Minshull, 2008) and to dominate ephemeral systems (Morgan et al. 2004; Minshull, 2008) suggests that the impact of tilapia could be more severe in the northern regions of the Basin than in adjacent coastal catchments.

Potential impacts on native species in the Murray–Darling Basin by tilapia are likely to be related to:

- dominance of drought refugia by tilapia
- competition for food resources
- predation of small native fishes and juvenile fishes by tilapia
- aggressive exclusion of native fish from shallow waters during the tilapia breeding season
- disturbance of native fish spawning and nursery habitats due to the nest building activities of tilapia and grazing on native macrophytes.

Key aspects of the biology of tilapia and the biology of native freshwater fish species in the Basin is summarised in Table 6. This table is used as a basis to predict possible interactions between native fish species and tilapia, therefore identifying possible impacts of tilapia on native fish in the Basin.

Native fish of the Murray–Darling Basin most at risk from tilapia

Olive perchlet *(Ambassis agassizii)*

Murray–Darling rainbowfish *(Melanotaenia fluviatilis)*

Bony bream *(Nematolosa erebi)*

Hyrtl's tandan *(Neosilurus hyrtilii)*

Flathead gudgeon *(Philypnodon grandiceps)*

Dwarf flathead gudgeon *(Philypnodon macrostomus)*

Desert rainbow fish *(Melanotaenia splendid taetei)*

Silver perch *(Bidyanus bidyanus)*

Freshwater catfish *(Tandanus tandanus)*

Rendahl's tandan *(Porochilus rendahli)*

South Australian populations considered vulnerable to tilapia

Murray River hardyhead *(Craterocephalus fluviatilis)*

Southern purple spotted gudgeon *(Mogurnda adspersa)*

Western blue spot goby *(Pseudogobius olorum)*

Lagoon goby *(Tasmanogobius lasti)*

Common galaxias *(Galaxias maculatus)*

Flat-headed galaxias *(Galaxias rostratus)*

Southern pygmy perch *(Nannoperca australis)*

Yarra pygmy perch *(Nannoperca obscura)*

The assessment of possible interactions between native fish and tilapia considered:

- the current status of the native species in the Basin
- likely overlap of native fish and tilapia ranges if tilapia invade
- probability of predation by tilapia
- potential loss of nursery and spawning habitat
- degree of dietary overlap.

Some native species could be potential predators of tilapia. Golden perch are a widespread potential predator of tilapia, but based on the isotopic and gut content work done to date, it would seem that there is minimal predation of tilapia from stocked golden perch in Seqwater impoundments (David Roberts, pers. comm.). However, spangled perch are known to consume small juvenile tilapia in north Queensland (Russell et al. 2010). Spangled perch are widespread in the northern Basin and may help reduce tilapia recruitment in some situations. Murray cod are a large predator that could probably consume both adult and juvenile tilapia, but their preference for tilapia is currently unknown. Trout cod are unlikely to overlap with the range of tilapia if they ever invade the Basin, so will not have any influence on an invasion.

There are a number of large native predatory fish present in north Queensland. These include barramundi, eels, sleepy cod, tarpon, fork-tailed catfish and various grunter species, of which some species undoubtedly prey on tilapia at times. However, tilapia has still managed to colonise north Queensland waters in the presence of such predators. Similarly in south-east Queensland, tilapia have established in impoundments with high densities of predatory fish, including stocked Australian bass and golden perch, and wild populations of long-finned eels and fork-tailed catfish.

Webb (2003) concluded juvenile and sub-adult tilapia remained in refuge habitats inaccessible to large predators until they were large enough to join adult schools in more open water. At this stage, these fish were effectively too deep-bodied and spinous to be selected as prey, even by large, gape-limited predators such as barramundi. Experimental studies showed that piscivorous fishes, irrespective of foraging mode, were functional rather than taxonomic predators, eating non-indigenous fishes if available. In the absence of cover, predators selected slow, soft-finned and narrow-bodied fish as prey in preference to fast, evasive, deep-bodied fish with spines (tilapia) (Webb, 2003). Nevertheless, recent gut flushing surveys of barramundi in rivers near Cairns have shown that they do prey on tilapia at times (John Russell, pers. comm.). Potential for predation of tilapia by Murray cod therefore cannot be discounted.

It is too difficult to predict whether tilapia may have adverse impacts on top-order predators in the Basin. If there are food chain/web–flow effects, then this could reach as high as golden perch and Murray cod. In situations where tilapia stunt and attain high densities, indirect food chain effects could potentially lead to either reduced abundance of Murray cod and golden perch or reduced physical condition of these species. Predation of Murray cod and golden perch eggs and larvae by tilapia cannot be ruled out. Direct competition with juveniles of these species when tilapia are in high densities can also not be ruled out. Whether or not tilapia impact on these species directly, it is also likely that tilapia may impact on angler enjoyment in fishing for these species through bait stealing.

Table 6: Comparison of the biology of tilapia *O. mossambicus* and fish species native to the Murray–Darling Basin

Species in bold text are those thought to be more likely adversely impacted by tilapia. Sources: Wager and Unmack (2000); Allen et al. (2002); Moffatt and Voller (2002); Pusey, et al. (2004); Lintermans (2007); Hutchison et al. (2008); Crook et al. (2010); Russell et al. (2010) and references therein.

Species	Spawning habitat	Spawning season	General habitat preferences	Diet	Temperature range	Maximum size	Comments
Mozambique tilapia *Oreochromis mossambicus*	Builds lekking nests on sloping banks, amongst aquatic vegetation. Mouth brooder.	Spring to autumn when water is above 18–20°C.	Plastic in habitat preferences. Prefers slow flowing waters, tolerates wide range of salinities.	Omnivore. Includes macrophytes, phytoplankton, detritus, zooplankton, aquatic insects and small fish. Plastic behaviour. More likely to be a predator in low productive environments.	8–39 °C	45 cm	Can dominate dry season pools. Can aestivate in sandy river beds. Has plastic breeding behaviour, switching to early maturation and stunting under harsh conditions.
Olive perchlet *Ambassis agassizii*	Lays adhesive eggs on aquatic macrophytes and rocks. May actively migrate to lagoons.	Spring to autumn.	Pools of low velocity and moderate depth. Often associated with macrophytes and filamentous algae.	Small planktonic organisms and macroinvertebrates.	Recorded between 11° and 33.6°C.	6 cm	This species has declined across the Basin. Spawning habitat could be vulnerable to tilapia.
Silver perch *Bidyanus bidyanus*	Pelagic spawners, often migrate upstream to spawn.	Spring and summer when temperature exceeds 23°C.	Slow pools often near woody debris or reeds.	Omnivorous. Juveniles feed on filamentous algae and plankton. Adults feed primarily on macroinvertebrates and algae.	Recorded between 2°and 36°C.	At least 50 cm	This species has declined across the Basin. Could compete with tilapia for food resources.

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Species	Spawning habitat	Spawning season	General habitat preferences	Diet	Temperature range	Maximum size	Comments
Spangled perch *Leiopotherapon unicolor*	Soft substrates in shallows.	Late spring onwards when temperatures reach 20–26°C.	Wide range of habitats, rivers, lakes, billabongs, bore drains, preferring slow flowing areas and pools. Often associated with woody debris.	Primarily carnivorous feeding on aquatic insects, macro-crustaceans, micro-crustaceans and small fish. Also some herbivory.	4.1–40°C but lower survival below 7.2°C.	33 cm commonly to 15 cm	Known to prey on juvenile tilapia in north Queensland (Russell et al. 2010).
Golden perch *Macquaria ambigua*	Broadcast spawners of semi- buoyant eggs on flow events.	Spring and summer when temperatures exceed 20°C.	Lowland slow flowing rivers, waterholes and some lagoons. Preference for deep pools. Often associated with large woody debris and other cover.	Opportunistic carnivore. Adults consume macro-crustaceans, aquatic insects and fish. Juveniles consume aquatic insect larvae and micro-crustaceans.	No data	76 cm, commonly to 40 cm	Potential predator of small tilapia but David Roberts of Seqwater has found no evidence of tilapia predation by golden perch in stocked south-east Queensland impoundments.
Murray cod *Maccullochella peelii*	Adhesive eggs laid on hard surfaces like rocks, logs and clay banks. Males are egg guarders.	Spring and early summer when temperatures exceed 15°C.	Deep holes in rivers with plenty of cover like undercut banks, rock overhangs and large woody debris.	Ambush predator. Consumes macro-crustaceans, fish, frogs and ducklings.	No data	180 cm	Potential predator of small and large tilapia.
Trout cod *Maccullochella macquariensis*	Adhesive eggs laid on hard substrates.	Late spring.	Deeper pools with in-stream cover like rocks and boulders.	Macro-crustaceans, fish, aquatic insects.	No data	85 cm	Potential predator of tilapia, but distribution not likely to overlap much with projected range of tilapia.

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Species	Spawning habitat	Spawning season	General habitat preferences	Diet	Temperature range	Maximum size	Comments
Macquarie perch *Macquaria australasica*	Spawns at foot of pools. Eggs lodge in amongst cobble and gravel in riffles.	October to December.	Cool upper reaches of rivers and some reservoirs.	Macro-crustaceans, benthic aquatic insect larvae, micro-crustaceans.	No data but likely to tolerate low temperatures based on distribution in cool upper reaches.	46 cm	Not likely to overlap with tilapia projected distribution.
Two-spined blackfish *Gadopsis bispinosus*	Adhesive eggs laid on rock in gaps between cobbles and boulders.	November to December.	Cool headwater streams in forested catchments with boulders and cobble.	Aquatic insect larvae, terrestrial insects, occasional fish and macro-crustaceans. Juveniles eat more mayfly and midge larvae.	No data but is restricted to cool streams.	35 cm	Occupies habitat unsuitable for tilapia.
River blackfish *Gadopsis marmoratus*	Adhesive eggs laid inside hollow logs and possibly also on rocks and undercut banks. Males are egg guarders.	October to January when temperature exceeds 16°C.	Prefers habitats with good in-stream cover, including woody debris, boulders and aquatic vegetation. Restricted to upland sites in the north of its range.	Aquatic insects, terrestrial insects, crustaceans and occasional fish.	No data, but based on its limited northern Basin distribution it is unlikely to tolerate very high temperatures.	35 cm	Upland populations will be safe from tilapia invasion but SA populations could be vulnerable.
Bony bream *Nematalosa erebi*	Still waters. Scatter buoyant eggs.	October to February.	Lowland and foothill rivers, larger streams and floodplain wetlands. Often in open water.	Detritivore, consuming detritus, algae, microalgae, micro-crustaceans, and small amounts of aquatic insects, terrestrial insects, molluscs and macrophytes.	9–38°C. Low temperatures are thought to depress the immune response.	47 cm commonly to 200 mm	Diet may overlap with that of tilapia leading to competition. Tilapia may predate on juvenile bony bream. However bony bream remain common in impoundments with tilapia. Could be greater impacts in ephemeral waterholes.

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Species	Spawning habitat	Spawning season	General habitat preferences	Diet	Temperature range	Maximum size	Comments
Unspecked hardyhead *Craterocephalus stercusmuscarum fulvus*	Adhesive eggs are scattered in the vicinity of cover (aquatic vegetation).	October to February when temperature exceeds 24°C.	Rivers, streams, and floodplain wetlands. Most common in pools of the foothill zone in the northern Basin. Prefers slow-flowing or still habitats with aquatic vegetation.	Aquatic insects, micro-crustaceans.	The coastal subspecies has been recorded between 12.4 and 30.9°C. No data for Basin subspecies.	7.8 cm	Lower Murray populations could be impacted by tilapia, through disruption of macrophyte habitats, predation of fry and some competition for food.
Murray hardyhead *Craterocephalus fluviatilis*	Possibly similar to unspecked hardyhead.	September to April.	Margins of lakes, billabongs, and wetlands. Some deeper areas with aquatic vegetation. Does well in ephemeral deflation basin lakes and tolerates saline environments.	Micro-crustaceans, aquatic insects and algae.	No data	7.6 cm	This is a threatened species. Lower Murray populations could be impacted by tilapia through disruption of macrophytes and competition for food resources. Tilapia prefer similar habitats and also tolerate saline environments, where this hardyhead may currently have few competitors.
Darling river hardyhead *Craterocephalus amniculus*	No data	September–February.	Upper tributaries of the Darling River 250,900 m ASL in slow-flowing clear waters and amongst aquatic vegetation on stream edges. Edges of faster flowing habitats.	No data	No data	5.5 cm	The distribution of this species is unlikely to have much overlap with the potential distribution of tilapia in the Basin.

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Species	Spawning habitat	Spawning season	General habitat preferences	Diet	Temperature range	Maximum size	Comments
Eel-tailed catfish *Tandanus tandanus*	Substrate spawner, constructing nests of pebbles and gravel. Eggs laid in nest among gravel. Male guards and tends eggs in the nest.	Spring and summer when water temperatures are 20–24°C.	Slow-flowing streams, lakes and billabongs. Favours cover including snags, undercut banks and aquatic vegetation.	Aquatic macroinvertebrates including aquatic insects, macro-crustaceans and molluscs. Some fish are also consumed.	8.4–33.6°C (based on field records for SEQ populations).	90 cm, usually less than 50 cm.	Tilapia may compete for nesting sites or disrupt catfish spawning sites.
Hyrtl's tandan *Neosilurus hyrtlii*	Eggs scattered over sand and gravel substrates (Ross River). Non adhesive eggs sink into spaces between rocks and gravel.	Summer	Benthic species occurring in floodplain lagoons, waterholes, river pools and flowing areas.	Benthic carnivore. Small macroinvertebrates, molluscs, detritus.	Lower limits 812°C. Recorded in waters up to 36°C.	40 cm, usually under 28 cm.	May compete for food. Tilapia may disrupt spawning substrate.
Rendahl's tandan *Porochilus rendahli*	Alligator River populations migrate to lagoons to spawn.	Summer	Recorded in the Basin from lagoons, impoundments, river pools, anabranches, tributary streams in forested catchments. In Alligator rivers region prefers areas with dense aquatic vegetation.	Benthic feeder. Micro-crustaceans, aquatic insects, molluscs, detritus.	Lower temperature unknown; up to 38°C.	24 cm	Tilapia may compete for food species. This species is restricted and not very abundant in the Basin. Tilapia could be a threat.

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Species	Spawning habitat	Spawning season	General habitat preferences	Diet	Temperature range	Maximum size	Comments
Carp gudgeons *Hypseleotris* spp.	Adhesive eggs deposited on aquatic vegetation and twigs. Males guard eggs.	Spring and summer when temperatures exceed 22.5°C.	Slow flowing and still waters. Often associated with aquatic vegetation although can be common over bare silty substrates.	Benthic and mid-water carnivore. Micro-crustaceans, aquatic insects, including chironomid larvae.	Unknown, but broad distribution suggests wide range of temperatures tolerated.	7 cm	Potential prey of tilapia. Tilapia could interfere with macrophytes spawning sites. Still common in areas with tilapia in SEQ.
Purple spotted gudgeon *Mogurnda adspersa*	Rocks logs and aquatic plants are used as spawning substrates. Males guard and care for eggs.	Summer, when water temperatures are over 20°C.	Benthic species preferring cover such as rocks, cobble and aquatic vegetation. Found in slow moving and still waters of creeks, rivers and wetlands.	Small fish, tadpoles, macroinvertebrates.	In south-east Queensland recorded between 11.9 and 31.7°C	15 cm	Invasion by tilapia could threaten reintroduction of purple spotted gudgeon in SA, through predation of juveniles and disruption of aquatic macrophyte habitat. Upper catchment populations unlikely to overlap with tilapia.
Flathead gudgeon *Philypnodon grandiceps*	Eggs laid on wood and rocks and guarded by male.	Spring and summer when temperatures are between 18 and 27°C.	Slow-flowing areas of lowland streams and lakes.	Ambush predator of small fish, molluscs, tadpoles, macroinvertebrates.	Likely to tolerate broad range of temperatures based on distribution. 11–31°C in SEQ	11.5 cm	Juveniles could be prey for tilapia. Potential range of tilapia only overlaps with this species in Darling and lower Murray catchments.
Dwarf flathead gudgeon *Philypnodon macrostomus*	Unknown	Recorded breeding between 19 and 22°C in aquaria.	Still waters over muddy substrates, also over rocky substrates and near weedy areas.	Benthic carnivore, feeding mainly on aquatic insects.	8.4–31.7°C in south-east Queensland.	6.5 cm, usually under 4 cm.	Potential overlap of range with Tilapia in Condamine and lower Murray catchments. Predation by tilapia could reduce abundance of this already restricted (in the Basin) and not very abundant species.

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Species	Spawning habitat	Spawning season	General habitat preferences	Diet	Temperature range	Maximum size	Comments
Western blue-spot goby *Pseudogobius olorum*	Aquatic vegetation in brackish and freshwater. Male guards and fans eggs.	Spring	Estuaries, lower reaches of freshwater streams and lakes. Benthic over mud or rocky bottoms and in weedy areas.	Benthic crustaceans, algae.	No data	6 cm	Tilapia could impact on this species if it colonises the Lower Lakes. Tilapia have adversely impacted gobies in Fiji.
Lagoon goby *Tasmanogobius lasti*	Estuarine and freshwater habitats.	No data	Still and slow-flowing habitats over sand, silt and mud substrates.	No data	No data	5 cm	Tilapia have adversely impacted gobies in Fiji.
Flat-headed galaxias *Galaxias rostratus*	Benthic spawner.	August–September when temperatures exceed 10.5°C.	Slow-flowing waters, billabongs, lakes, swamps and rivers.	Aquatic insects and micro-crustaceans.	No data	14.6 cm	Range of this species and Tilapia only likely to have limited overlap. Tilapia could potentially impact lower Murray populations where this species is already rare.
Mountain galaxias *Galaxias olidus*	Underside of stones at the head of pools and riffles.	Spring, early summer and autumn.	Pools, slow flowing habitats, riffles.	Aquatic insect larvae, terrestrial insects.	No data but likely to be cold tolerant as it occurs above snowline.	14 cm	Range is unlikely to overlap much if at all with tilapia.
Common galaxias *Galaxias maculatus*	Brackish areas. Landlocked populations spawn in tributary streams on rising flows, laying eggs on terrestrial vegetation.	Autumn	Slow-flowing streams, margins of lagoons and lakes. Juveniles occupy shoreline vegetation.	Microcrustaceans, insect larvae, terrestrial insects.	No data but has temperate distribution.	19 cm	Tilapia could interact with Lower Lakes populations. May compete for juvenile habitat or could be potential predator of fry.

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Species	Spawning habitat	Spawning season	General habitat preferences	Diet	Temperature range	Maximum size	Comments
Desert rainbowfish *Melanotaenia splendida taetei*	Aquatic vegetation or roots of riparian vegetation.	When temperatures exceed 20ºC.	Slow-flowing and still habitats, including waterholes and ephemeral rivers.	Omnivorous. Small aquatic invertebrates and filamentous algae.	Likely to tolerate high temperatures.	9 cm	Tilapia could dominate and compete for food in drought refugia. Tilapia may prey on juvenile rainbowfish.
Murray–Darling rainbowfish *Melanotaenia fluviatilis*	Spawn amongst aquatic plants.	Spring and summer when temperatures exceed 20ºC.	Slow-flowing rivers, wetlands and billabongs.	Aquatic and terrestrial invertebrates and some filamentous algae.	Fairly wide range of temperatures tolerated, but tends to be absent from colder areas.	9 cm	Tilapia could dominate and compete for food in drought refugia in northern Basin. Tilapia may prey on juvenile rainbowfish or graze on spawning habitat.
Australian smelt *Retropinna semoni*	Demersal adhesive eggs scattered on aquatic vegetation, sediment or debris.	Spring, early summer, up to 9 months of the year, when temperatures reach 11–15ºC	Pelagic. Lakes and pools, also in riffle habitats in northern Basin.	Microcrustaceans, terrestrial and aquatic insects.	No data, but probably broad temperature tolerances given wide range.	10 cm, usually under 6 cm	Some impacts possible, but there are broad areas where range will not overlap. Coexists with tilapia in east coast streams.
Southern pygmy perch *Nannoperca australis*	Non-adhesive eggs scattered over the bottom substrate or among aquatic vegetation.	September–January when temperatures exceed 16ºC.	Slow or still waters with dense aquatic vegetation and cover.	Micro-crustaceans, small insect larvae and aquatic insects.	No data.	8.5 cm	Tilapia could threaten reintroduction and management efforts of this species in SA Lower Lakes. Impacts could include predation and disturbance of preferred habitat type.

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Species	Spawning habitat	Spawning season	General habitat preferences	Diet	Temperature range	Maximum size	Comments
Yarra pygmy perch *Nannoperca obscura*	No data	Spring, when temperatures are between 16 and 24°C.	Slow-flowing or still waters with abundant cover and aquatic vegetation.	Insect larvae and micro-crustaceans	No data	7.5 cm	This species is already rare in the Lower Lakes. Tilapia could be a further threat through predation of fry, destruction of habitat and competition for food.
Congolli *Pseudaphritis urvilli*	Marine spawner	May–August	Wetlands, lowland streams, estuaries, associated with cover such as logs, undercut banks and rocks.	Benthic carnivore, macro-crustaceans, aquatic insects, fish, snails and worms.	No data	30 cm	Congolli could be potential predator of Tilapia fry.

Conclusions

It seems that the environmental conditions and hydrology of the Murray–Darling Basin may be suitable for successful colonisation by Mozambique tilapia (*O. mossambicus*). These fish have evolved under riverine conditions (Fryer and Iles, 1972; Greenwood, 1974) and are capable of surviving fluctuating water levels and flooding (James and Bruton, 1992). They are also capable of successfully colonising lacustrine (lake, pond and billabong) habitats if the water levels in these habitats fluctuate in a cyclical pattern (James and Bruton, 1992).

Mozambique tilapia have the potential to colonise most of the larger rivers and water bodies in the lowlands of the northern Basin and some water bodies on the northern Basin slopes. Tilapia could also spread south to colonise the lower Murray and Lower Lakes in South Australia. Salinisation increases the potential for tilapia to overwinter in some southern areas. Upland areas, smaller water bodies and most of the southern Basin (other than the lower Murray) are at low risk of invasion, as tilapia would not be able to survive winter temperatures in those areas. In the northern Basin, smaller water bodies could be recolonised from winter refugia each summer. If minimum water temperatures rise by 2°C, as postulated with climate change, then tilapia could potentially colonise the entire lowland region of the Basin, including most of the southern region.

Native fish communities of the Basin are likely to be subjected to negative impacts if a tilapia invasion eventuated. The capacity of tilapia to mature early and stunt during adverse conditions, coupled with their reported ability to aestivate during droughts, suggests that tilapia are likely to dominate some ephemeral river systems in the northern Basin. This is likely to have negative consequences for most native fish species. Evidence from tilapia invasions of water bodies in Central America shows major decreases in fisheries productivity. Similarly, tilapia have also been linked to the extinction of native fish species in Venezuela, and localised elimination of species in Fiji and Papua New Guinea. Some fish communities are already under stress in the Basin, and tilapia could have severe impacts on these species through predation, competition, aggressive exclusion and alteration of habitats. It would be more difficult to exclude breeding tilapia from wetlands than European carp as tilapia are able to mature at much smaller sizes than carp and have a narrower body profile. Attempts to re-establish threatened fish communities in the lower Murray would be made more difficult if tilapia were to establish there. There is also the potential risk that tilapia could spread parasites and diseases endemic to east coastal Australian catchments (and to a lesser extent, exotic African parasites and diseases) into the Basin.

Tilapia may also have negative impacts on Basin water quality, especially potable sources, due to their dietary habit of feeding on detritus and other primary production. This could lead to an increase in total phosphorus, chlorophyll *a*, and cyanobacteria (blue-green algae) concentrations. Also, regular kills of tilapia in winter could create an environmental hazard, nutrient spikes and secondary kills of Australian native fish.

From an ecological perspective, we recommend that programs promoting early detection of tilapia and prevention of infestation of the Basin by tilapia be made a high priority. The best way of protecting aquatic ecosystems and native fish populations from the possible impact of tilapia is to make sure they do not enter the Murray–Darling Basin. A key facet of any prevention program for tilapia must be education and awareness, as people are a primary factor in the spread of this species in Australia.

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APPENDIX I:

Water temperatures in the Victorian part of the Murray–Darling Basin

Temperature parameters of selected sites in Victoria. All Victorian data are sourced from the Victorian Water Resources Data Warehouse: http://www.vicwaterdata.net/vicwaterdata/home.aspx

Site	Min	Med	Max	Comments
Goulburn River catchment				
Acheron River	3.6	11.7	26.0	
Goulburn River at Murchison	4.0	14.5	26.5	
	4.0	14.9	26.5	
Goulburn River at Trawool	6.4	16.0	24.3	Limited data.
Goulburn River (middle) at Trawool-Seymour Road, Trawool	7.0	14.0	24.9	
Goulburn River at Eildon	7.5	12.0	22.5	
Goulburn River at Shepparton	5.5	16.5	30.0	
Murrindindi River at Murrindindi above Colwells	3.4	9.5	24	
Avoca River catchment				
Amphitheatre	4.7	14.0	27.5	Three separate sets of data were obtained for this location. It is not clear what the difference is between the sets (e.g. depth location).
	3.8	11.8	32.6	
	5.0	14.0	25.2	
Coonooer	6.0	15.0	27.2	Similar to Amphitheatre.
	5.0	15.0	27.0	
	5.4	16.2	41.1 (29.6)	The highest temperature of 41.10C was only recorded once in December 2002 and could be a data error. The second highest temperature 29.60C is a more common occurrence in the area.
Quambatook	6.0	16.0	31.5	
Sandhill Lake Road	0.7	18.8	37.5	
Glenlogie Creek at Amphitheatre	7.0	15.0	26.0	

...continued

Site	Min	Med	Max	Comments
Campaspe River catchment				
Axe Creek	2.0	14.0	29.0	
Campaspe River in Ashbourne	1.2	11.6	26.5	
Campaspe River at Eppalock	5.3	14.0	24.9	
Campaspe River at Redesdale	6.0	14.3	26.3	
	5.0	15.0	30.3	
Campaspe River at Rochester	7.0	15.0	28.0	
	6.5	16.1	28.3	
Coliban River at Llyal	4.0	13.5	29.6	
Jackson Creek at Sunbury (Melbourne Water)	8.5	15.0	26.5	Limited data.
Loddon River catchment				
Bamawn main drain	5.7	17.8	32.8	
	7.8	20.3	36.3	Limited data.
	12.1	19.7	30.0	Limited data.
Loddon River at Kerang	5.5	17.2	35.2	
	6.0	16.5	30.5	
Loddon River at Appin South	5.0	15.5	28.5	
	6.0	15.7	31.2	
Loddon River at Laanecoorie	6.5	16.4	28.7	
Broken River catchment				
Broken Creek at Katamatite	5.0	15.0	33.7	
Broken Creek at Rices Weir	5.0	16.8	32.0	
Broken River at Goorambat (Casey Weir)	6.5	16.5	28.5	
	8.0	18.0	27.4	
Broken River at Moorngag	3.5	15.0	26.4	
Holland Creek at Kelfeera	5.5	15.4	34.0	
Moonee Creek at Lima	3.0	14.5	25.3	
Ovens River catchment				
Buffalo Creek at Myrtleford	7.0	14.0	25.5	
Fifteen Mile Creek at Greta South	6.0	14.8	34.0	
Happy Valley Creek at Rosewhite	5.5	13.2	25.0	

...continued

Site	Min	Med	Max	Comments
Ovens River at Bright	3.4	12.8	24.1	
	4.0	12.9	24.0	
Ovens River at Myrtleford	5.5	14.3	31.1	
Reedy Creek at Wangaratta North	6.0	16.5	29.5	
Ovens River at Wangaratta	6.0	17.5	29.5	
Kiewa River catchment				
Kiewa River at Bandiana	4.5	14.0	30.0	
Kiewa River at Mongans Bridge	3.0	12.0	25.7	
Mountain Creek at Coopers	4.0	11.0	22.7	
Running Creek at Running Creek	4.0	12.8	26.0	
Yackandandah Creek at Osbornes Flat	4.0	13.6	27.7	
Upper Murray catchment				
Mitta Mitta River at Hinnomunjie	1.5	11.5	25.2	
Mitta Mitta River at Tallandoon	5.0	12.9	27.6	
Mitta Mitta River at Colemans	3.8	11.5	26.0	
Snowy Creek below Granite Flat	0.3	1.0	14.0	

Australian Government

MURRAY–DARLING
BASIN AUTHORITY