Section 3 Overview of potential threats

Freshwater systems require special consideration in regards to threats, as it is not only local and obvious changes to habitat and species introductions that can cause impacts. The fluid nature of water means that freshwater habitats are often connected within broader networks (e.g. streams) and with terrestrial habitat. As a result threats from one area can be transmitted elsewhere, especially downstream, such that the cumulative result of practices in or around waterways or catchments can impact aquatic habitats in an area (e.g. Figure 13).

A range of documents provide background on threats to freshwater fishes and habitats in different parts of Australia[12,22,31,74,87,236,237]. The intention of this section is to summarise and develop a list of potential threats relevant to South Australia (Table 3), reinforced with local examples and as a summation from individual species accounts. While a list of threat categories is provided, a particular process rarely acts on its own and will likely have consequences of species decline interlinked with other threats overlapping on different spatial and time scales. For example habitat degradation, introduced species and local pollution would become more severe with loss of flow and during warmer periods. Some threats may have obvious and immediate impacts, while others take time to become evident (i.e. lag time) or are masked until a particular threshold is reached. The list of threats is not necessarily reflective of an order of severity. However, hydrological alteration is considered the primary or underlying threat to fish habitat and communities across South Australia.

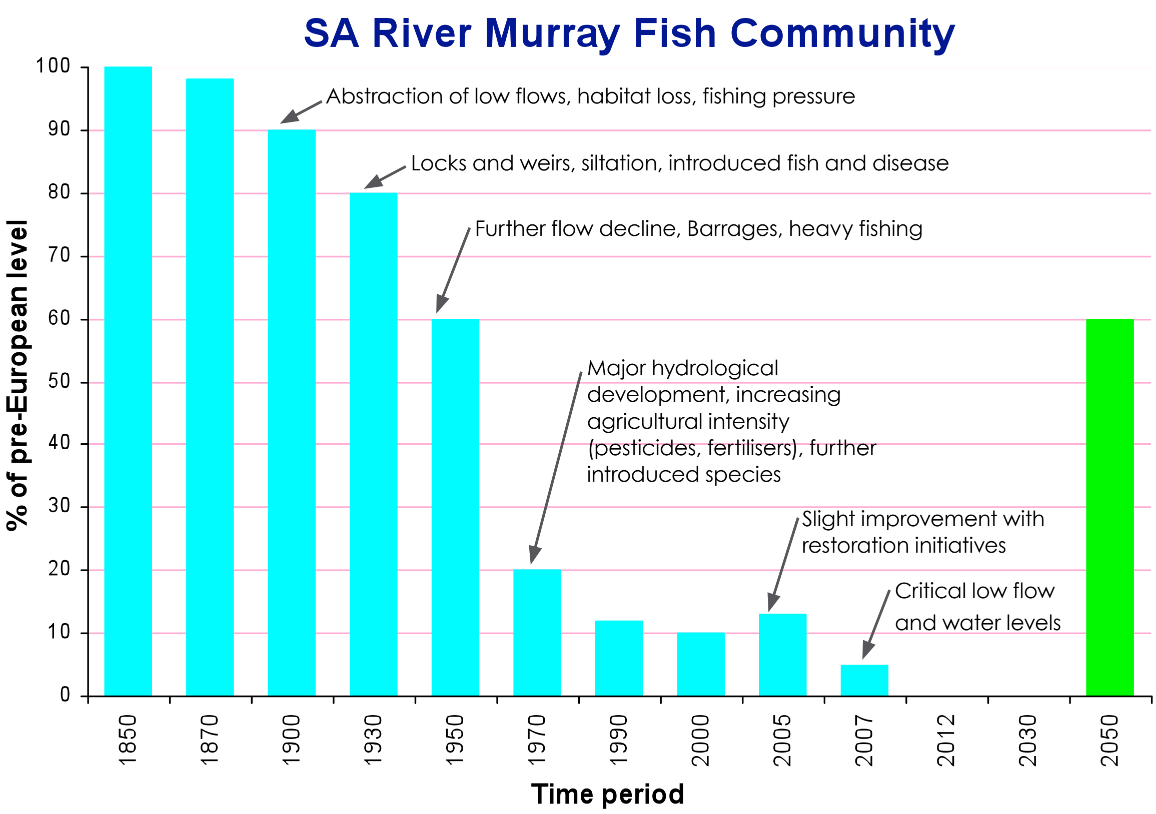


Figure 13. Decline of the SA River Murray fish community since European settlement. The model is developed after the MDBA Native Fish Strategy which considered decline in species diversity and abundance of native fish to have reached 10% of pre-European levels for the MDB by 2003. The green bar represents the target for restoration under the same strategy[236].

Table 3. Potential threats to freshwater fishes in South Australia.

Threat category	Examples causes (processes)
1. Hydrological (flow) alteration	
a) Loss of water from a system/habitat Reservoirs,	Farm dams, pumping surface and groundwater, drainage, climate change, plantations
b) Altered flow seasonality and variability	Provision for irrigation (i.e. seasonal reversal), dams (e.g. delay the onset of flow periods), land clearance, climate change
2. Habitat loss and degradation	
a) Removal and alteration of habitat (broad)	Reduced flow, drainage, damming, channelisation, river engineering, levees (floodplain loss), urbanisation
b) Removal and damage of riparian vegetation	Land clearance, stock access, urban/rural development
c) Loss of instream cover	Desnagging, dredging, siltation & overgrazing, altered hydrology, removal of aquatic vegetation, exotic plants, algal growth (nutrients)
d) Artificial barriers to fish movement and gene flow	Physical structures (e.g. weirs, dam walls, road culverts), biological barriers (e.g. loss of intervening habitat, predators, water quality, high velocity)
3. Lowered water quality	
a) Fish kills	Toxic substances (e.g. chemicals & pollutants), reduced flow, eutrophication, suspended sediments, temperature
b) Sub-lethal responses (e.g. reduced spawning or feeding ability)	Salinity, reduced dissolved oxygen, altered temperature (e.g. thermal pollution, loss of flow and shade, climate change)
c) Reduced habitat quality	Sedimentation, nutrient input (algal growth)
4. Alien species & stocking (biological pollution)	
a) Biological impacts (competition, predation, aggression, habitat modification)	Introduction and/or establishment of exotic and translocated native species
b) Transfer of disease and parasites	Introduction of exotic and translocated native species, discarded aquarium fishes and plants, inter-basin transfer and movement of materials, equipment and vegetation
c) Genetic impacts	Inappropriate translocation and stockings (e.g. mass releases, hybridisation)
5. Exploitation or use	
a) Reduced abundance and reproductive potential	Past and present fishing pressure and aquarium trade (recreational, commercial and illegal)
b) Trophic cascades and altered states	Selective removal of a keystone or prey species.
6. Population decline	
a) Loss of genetic diversity & reduced ability to adapt to change	Previous unnatural range contractions, ongoing population bottlenecks (e.g. exotic predatory species), fragmentation
b) Restricted range and/or small populations	Restricted range and/or small populations Vulnerable to lag effects, new threats, change and stochastic events, genetic problems (e.g. inbreeding)
c) Failure to include fishes in management and planning	Lack of: knowledge, monitoring/research, awareness (government & community) and appropriate legislation
7. Climate change	
a) Change in habitat and flow	Temperature increases, decreased and altered rainfall

3.1. **HYDROLOGICAL (FLOW) ALTERATION**

Hydrology (processes involving water) is the main driver to the presence, nature and dynamics of aquatic habitats. The hydrology of different habitat types or systems can vary considerably, depending on the source of water, position in a landscape and local climate and geology. Sources of water include (a) local rainfall and runoff, (b) linear or longitudinal flows (e.g. stream flow from headwaters to the sea), (c) lateral (outward) linkages such as the inundation of edge, wetland or floodplain habitat, and (d) vertical interactions with groundwater. All of these linkages can vary in their frequency, magnitude, duration, timing and rate of change to be temporally variable. Aquatic biota may also rely on particular aspects like flow for breeding, movement and survival, or have innate responses to components of natural water regimes such as flooding and disturbance[238,239].

Given the generally warm climate combined with low to moderate or variable rainfall in South Australia, the presence and dynamics of water is considered of primary importance in maintaining habitats for fishes. Many important fish habitats or critical summer refuges would simply not exist if not for river flow from higher rainfall areas or expression from groundwater sources (e.g. springs). Hydrological alterations relate to two main problems: loss of water and altered flow patterns.

(A) LOSS OF WATER Loss of water can result from any practice which removes water directly or impacts a source of water and thus eliminates or alters habitat at large and/or micro scales (e.g. the drying of a stream reach and loss of pools). A significant problem occurs with drying of habitat for small populations, and is most critical when water is already scarce during dry seasons or extended periods where human use tends to exacerbate already low levels. For example recent (last 10 years) widespread drying of once permanent fish habitat in streams and springs has been witnessed in areas of the Eastern Mount Lofty Ranges[25,51]. The recent prolonged period of low rainfall has also highlighted critical deficiencies in water management to maintain fish habitat in the Lower Murray[114,129] and South East[94].

In addition to drying of habitat, reduced flow volume can lead to reduced flushing of salts, altered geomorphology (e.g. reduction in channel depth, encroachment of reeds), reduced aquifer recharge and direct ecological implications. Loss of water can also reduce the magnitude of particular flow events limiting the size of floods and the amount of wetted habitat. For example, floods on the River Murray are now much fewer in frequency and smaller than which occurred naturally[185].

Direct removal can include:

- Drainage and conversion to alternative uses is a special problem for wetlands and floodplains either altering hydrology by limiting or removing wetting (see examples in Habitat loss).
- Deliberate drying of wetlands for management or during works along or in streams aquatic habitat (fish need water).
- Direct pumping from aquatic habitat impacts overall water availability and can increase the risks of habitat drying eliminating local flows and habitat components (i.e. lower water levels) or lead to total habitat loss. Again this can be an especial problem in dry periods and for localised populations.

Loss of water sources (linkages) can be caused by:

- Large dams and reservoirs capture water and limit the volume received by downstream environments (and alter the nature of flows and habitat downstream –see altered variability). Large dams impact most major river and stream systems in South Australia with the current exception being the unregulated Lake Eyre Basin. The River Murray now only receives one third of its natural flow volume into South Australia due to upstream dams and diversions (e.g. irrigation[186,241])and there is an extensive water supply network in the Western Mount Lofty Ranges involving numerous reservoirs including Myponga, Millbrook, Warren, South Para, Mt Bold, Kangaroo Creek and Little Para.
- Farm dams can have local and cumulative impacts within catchments contributing to overall loss of water from a system through capturing (abstracting) surface water. For example there are moderate to very high levels of farm dams in most areas of the Mount Lofty Ranges, with this form of water resource development escalating rapidly (e.g. doubling of storage volume in some catchments) in the last 10-15 years. In the Marne River Catchment for example, more than 640 dams capture on average

20% of water destined for stream flow, with this percentage of capture much higher in drier years and at certain times of year like summer when important small flows are virtually eliminated[149]. Similarly farm dams have been calculated to reduce the median summer flows, important for maintaining habitat presence and condition (e.g. cool oxygenated pools in Mediterranean type climates), by up to 72% in some years[150] (see also flow seasonality).

- Groundwater extraction is an underestimated and latent problem because groundwater sources (aquifers) are not directly obvious and in many cases not well known. Consumptive use of groundwater may lead to one or a combination of rapid extermination of small reserves, interception of flows destined for other areas or broader lowering of water tables, all of which may lead to reduction or loss of groundwater expression to the surface (e.g. flow discharging from springs) or lowered surface water levels where the two are interconnected. Because groundwater processes are often complex interactions between historic influences and surface water recharge, such processes may operate over long timelines. There is a particular danger of lag effects where impacts may not be evident for some time, nor be readily reversible once problems are evident. Groundwater is often relied on by aquatic biota during dry periods or in dry regions (e.g. desert mound springs, core refuges in the Mount Lofty Ranges and unique spring fed habitats in the South East) and there is thus a high potential for conflict with human consumptive use.
- Plantations are an emerging issue of water use due to the high density of trees (pine or Tasmanian Bluegum) and high water demands by mature trees especially in small catchments/waterways and areas of groundwater recharge. Water loss occurs through two processes: (1) plantations can act as an umbrella capturing rainfall and reducing aquifer recharge or runoff into streams and wetlands depending on the scale of the plantation relative to catchment area, and (2) plantations can be water pumps that use groundwater with subsequent lowering of groundwater levels (e.g. by as much as 9-10m depending on rainfall, plantation location and soil type). There is also potential habitat and water quality issues from plantation processes including erosion, runoff and chemical use. Leaf litter from plantations may have detrimental effects on water quality and in-stream processes when it enters waterways.
- Climate change will result in altered patterns of rainfall, runoff and drought (see later).

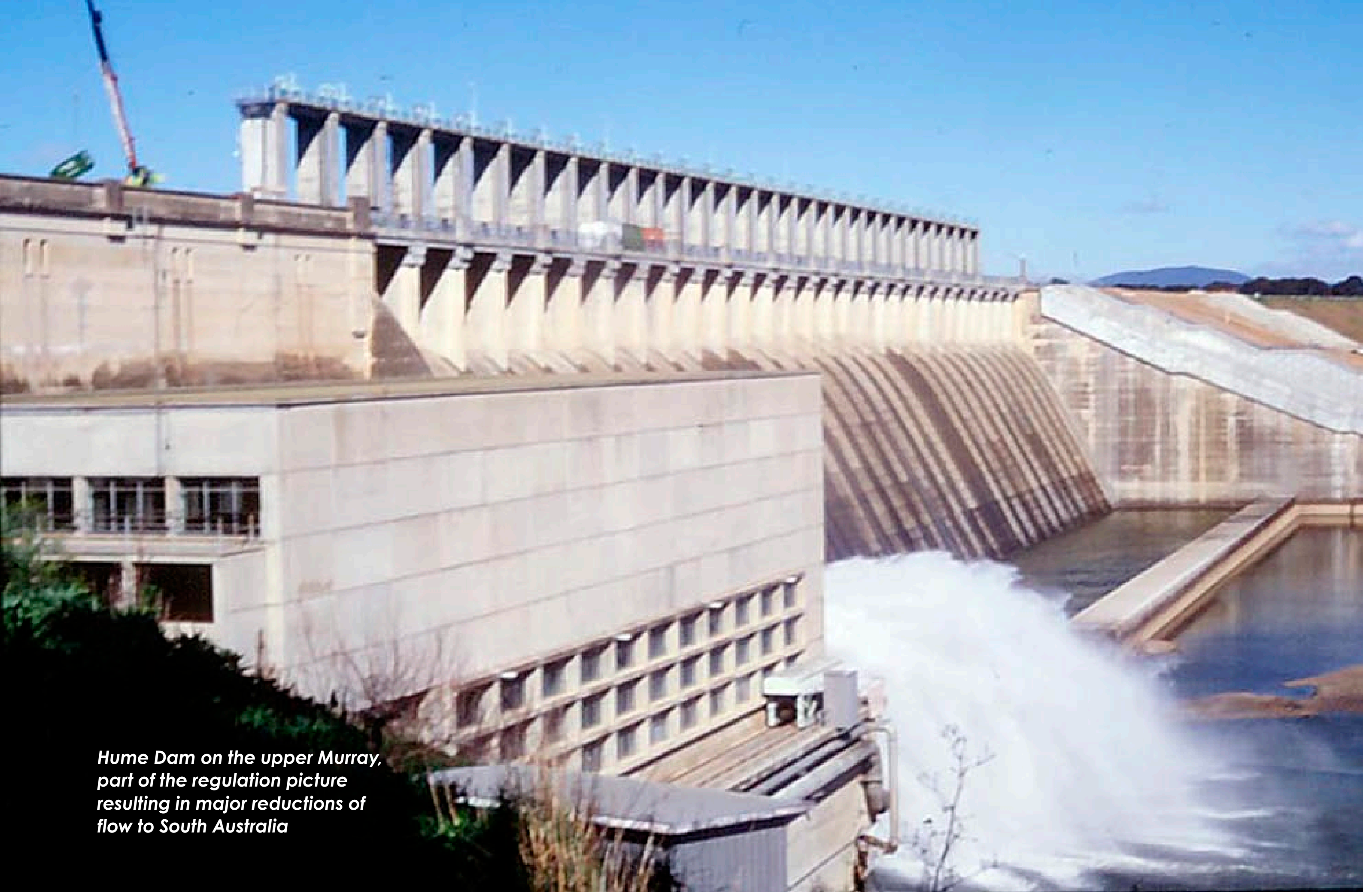
(B) ALTERED FLOW PATTERNS Altered flow patterns are interlinked with water loss, but involve more subtle hydrological alterations which change the nature of flow. Alterations of flow patterns can affect flow seasonality or timing and variability. This in turn can affect habitat suitability and directly interfere with species lifecycles.

Flow seasonality refers to the time of year flows occur, and local animals and plants are often tuned to natural cycles by having seasonal cues for breeding and movement. Alterations in flow seasonality may mean that flows start much later and do not link with appropriate times for fish spawning and movement for example, and lead to longer periods of exposure to low water levels and reduced water quality (e.g. temperature, dissolved oxygen, salt, pollutants). Altered timing of flow events (e.g. a shift from winter dominated flow and floods may also be out of synchrony with natural cycles or biological response impacting fish breeding and survival.

Natural variability in flows and water levels over time forms a part of ecosystem function and is thought to promote higher native species diversity. Shifts away from natural rates of variation can thus be a threat. Flows and flooding generates physical disturbance or fluctuation in habitats which can be important for ecological function, and involve processes such as flushing sediment and cleaning underwater surfaces, preventing the encroachment of reeds and diluting salts. Most native species have adapted to natural variability (e.g. they move outward into riparian vegetation during floods, utilise different habitat at different times of the year) while some exotic species like Gambusia and Carp are discouraged by variability or alternately favoured by stable conditions. Rapid water level fluctuations could lead to stranding of eggs or larval stages and unreliable habitat or cover for adults. At the other extreme stable environments might encourage or favour habitat generalists and invasive species over rare species[240].

Major causes of altered flow patterns include:

- Regulation (weirs, barrages, large dams/reservoirs) provide the plethora of impacts relating to altered flow patterns. Flow releases or overflow from large storages is unpredictable, commonly occurs during unnatural times when irrigation demand is high (e.g. summer along the River Murray), and is often 'all or nothing' where large bursts of water suddenly occur as an extreme disturbance (e.g. reservoir overflow). The series of Locks and Weirs along the River Murray and Barrages maintain highly stable weir pools as opposed to river habitat.
- Farm dams can have a large impact on seasonality by holding back or capturing runoff at the break or end of seasons and thus delaying flows until dams can overflow.
- Instream works such as dredging, modifications of river banks, road crossing and other structures, can drop water levels rapidly[57] thus stranding eggs or juvenile stages and removing access to important types of habitat (e.g. for spawning).
- Climate change may lead to altered rainfall patterns and timing reducing the onset of flow and altering the timing and frequency of larger flow events for which biota might be unaccustomed to (see later).
- Direct pumping (bottom left of photo) during a dry period, combined with reduced environmental flows from abstraction in the catchment led to the drying for the first time of this pool on Dawson Creek (2004) in the Mount Lofty Ranges, previous habitat of threatened Southern Pygmy Perch and Mountain Galaxias.



Hume Dam on the upper Murray, part of the regulation picture resulting in major reductions of flow to South Australia

Direct pumping during a dry period, combined with reduced environmental flows from abstraction in the catchment led to the drying for the first time of this pool on Dawson Creek (2004) in the Mount Lofty Ranges, previous habitat of threatened Southern Pygmy Perch and Mountain Galaxias

3.2. **HABITAT LOSS AND DEGRADATION**

Fish habitat can range from broad scale suitability (e.g. stream, river, wetland) to local or microhabitat requirements. Different species require habitat for a variety of reasons including:

- Cover from predators and competitors.
- Shelter from environmental conditions such as high flow velocity.
- Spawning structure or sites (e.g. hollows, submerged vegetation, gravel benches).
- Shade to maintain cool temperatures over warm periods.
- Food sources (e.g. aquatic and terrestrial invertebrates).

Cover or habitat components include submerged structures such as rocks, snags (woody debris) and aquatic plants, fringing or emergent vegetation such as reeds and sedges, and overhanging terrestrial vegetation.

Some species have more specialised requirements or reliance on cover than others, with differences also within a species at different stages of their life cycle (juveniles and small species normally need higher densities of cover). Habitat requirements can vary through time depending on different water levels and types of flow, especially during floods when normally dry habitats are utilised to escape dislodgment and unfavourable conditions (e.g. cover on river banks, floodplains).

Considering the different uses and roles of habitat, then not surprisingly habitat loss and degradation can take many forms and vary greatly in impact severity. Impacts can be obvious from processes which visibly directly alter habitat, but other changes may have more subtle impacts on the structure and connectivity of habitats or alter conditions relied upon by fishes.

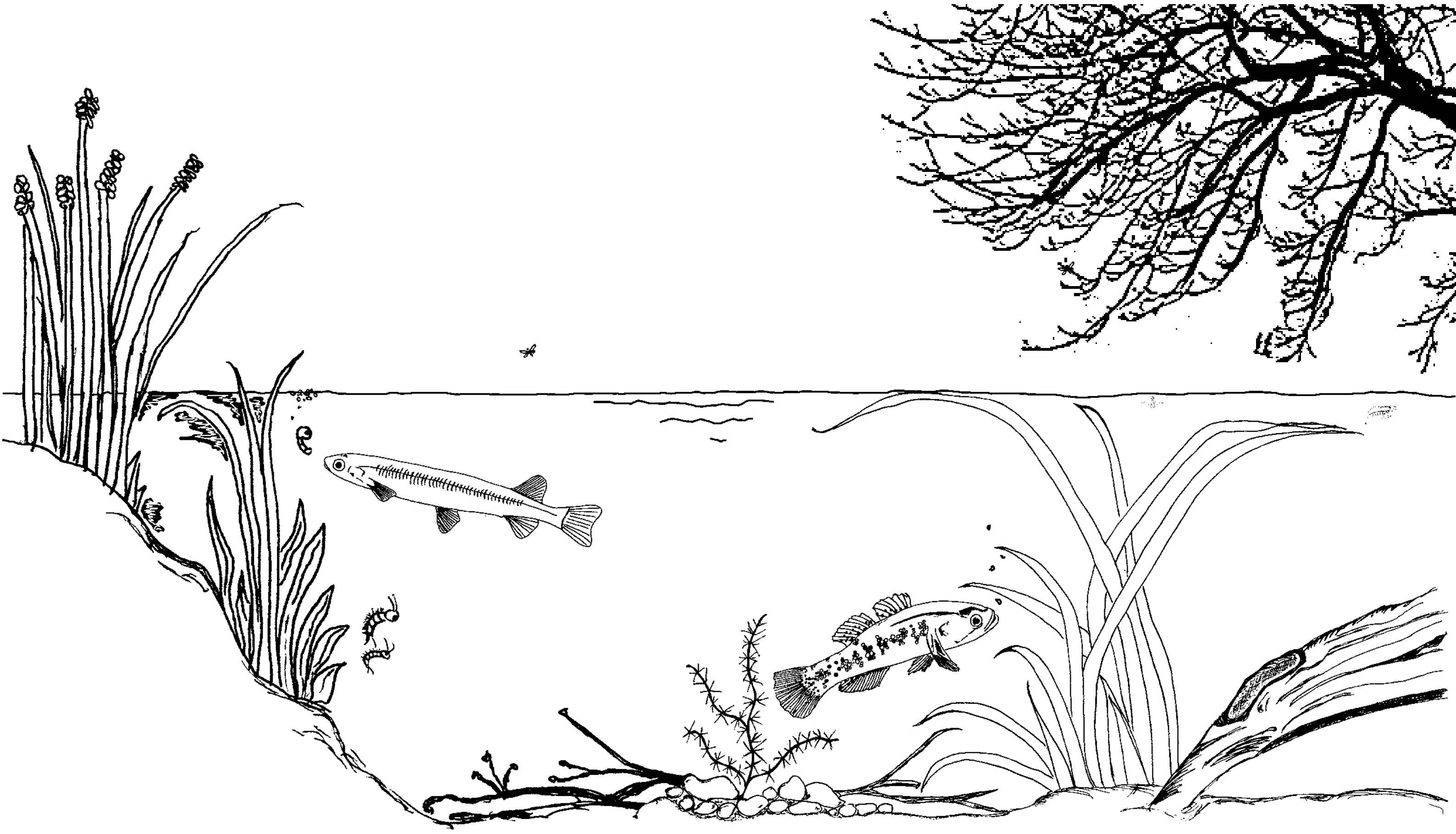


Diagram depicting different types of fish habitat: emergent and submerged aquatic vegetation, large and small woody debris (snags) and overhanging vegetation (shade, input of organic matter, future snags and source of terrestrial invertebrates) (B. McKenzie)

(A) REMOVAL AND ALTERATION OF HABITAT (BROAD) Much broad scale change to river systems has occurred since the advent of European settlement, whereby large areas of catchments have been progressively cleared. Subsequent changes to the nature of flow and sediment inputs have occurred with stream channel erosion, incision and siltation and are large scale issues transforming habitats in the Mount Lofty Ranges for example.

A change in landuse to urban and semi-urban environments transfers parts of catchments to artificial structure that changes the character and nature of waterways. Extensive changes have occurred in the Adelaide region (Figure 14), as well as other regional centres.

Other landscape level changes include drainage and river transformation.

Prime examples include:

- A comprehensive and still expanding network of drains in the South East which has resulted in the loss of over 90% of wetland habitats and alteration of most others[23,203,204].
- The loss (>40% total) or alteration (at least 50% or remaining) of a large percentage of swamps on the Fleurieu Peninsula (e.g. conversion to pasture)[242].
- Levees along the River Murray between Wellington and Mannum which have transformed (removed most swamp and wetland habitats.

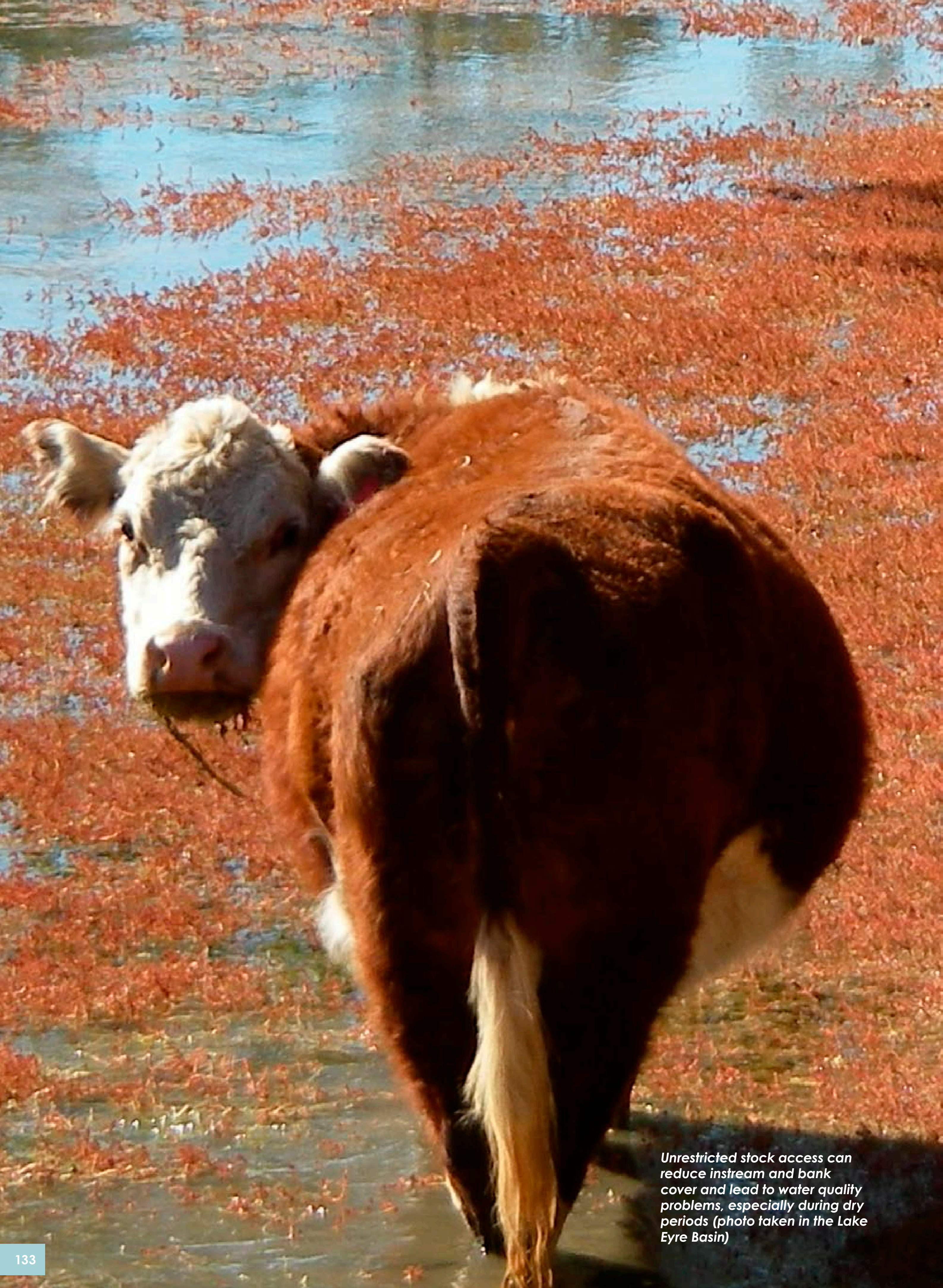
Many aspects of habitat change can be related to altered hydrology (see 3.1) such as stream drying, loss of flooding and access to fringing and wetland habitats.

(B) RIPARIAN VEGETATION Fringing terrestrial vegetation such as trees, shrubs and fringing water plants (e.g. sedges and rushes) can provide the base of habitat and food chains via the input of woody debris and living structure at both varying water levels. Hence buffers around streams and wetlands are important. Vegetation can also influence physical conditions such as water quality via shade (cooler temperatures in summer) and nutrient uptake or trapping silts.

Unrestricted stock access, land clearance and modifications for rural and urban development can significantly alter stream habitats[22,243]. During dry periods, stock can reduce cover and also affect water quality (especially oxygen levels) through wading and waste. In addition to the direct loss of cover, loss of riparian and terrestrial vegetation can also alter the structure or geomorphology of areas. For example trampled stream edges are unstable and more easily eroded leading to channelised environments with high velocity and little cover. Stock access to aquatic habitats is still common place in most areas of South Australia and heavy unregulated access is particularly likely to impact small sensitive habitats. Many urban habitats are stripped of riparian vegetation when they are transformed or channelised, especially in the Adelaide region (Torrens and Patawalonga catchments).

(C) LOSS OF INSTREAM COVER A decrease in the amount of instream cover available to fishes is often related to the level of land clearing and local riparian clearance (i.e. decreased input of woody debris). For example an extensive program was undertaken along the River Murray to remove large woody debris (snags) and thus improve navigation conditions. Siltation (build up of fine silts and sand) can smother underwater surfaces reducing physical cover such as rocks and suppressing plant growth. Similarly, leaf fall from exotic trees and high nutrient levels, encouraging growth of filamentous algae or dense floating plants (e.g. Duck Weed) which can also smother underwater surfaces.

Some physical activities are extremely disturbing to instream cover such as construction of road crossings, removal of aquatic vegetation undertaken for improved recreation or industry, instream dams or other works, dredging, and stream side development (e.g. infilling with dirt and rubbish). In the South East, the maintenance of natural streams as drains provides regular physical disturbance to stream beds, vegetation and banks[57]. Heavy stock access could also disturb instream cover, especially with large hoofed animals in small or fragile environments. The highest likelihood of impact from the loss of instream cover is in areas where sedentary and sensitive native fish occur, or for species that have particular requirements for cover such as hollows for spawning and guarding eggs.



Unrestricted stock access can reduce instream and bank cover and lead to water quality problems, especially during dry periods (photo taken in the Lake Eyre Basin)

(D) BARRIERS TO MOVEMENT AND MIGRATION Fish need to move between habitat sections for a variety of reasons and at a variety of scales. Large scale movements are undertaken by diadromous species, which require access between freshwater and estuarine/marine habitats at particular life stages (see Figure 15), and potamodromous species, which undertake large movements within freshwater. For example Murray-Darling Golden Perch tagged in South Australia around Renmark in the 1970s moved hundreds and even thousands of kilometres upstream and downstream during periods of river flow[162]. Other species may make smaller unidirectional or return movements for events such as spawning and feeding to particular habitats (e.g. floodplains, stream headwaters) or dispersal and recolonisation from refuges as part of regional populations. Even tiny species such as Carp Gudgeons and Dwarf Galaxias are known to move upstream and between wetlands[23,25,202].

Artificial barriers to fish movement are common in parts of South Australia and examples include:

- Reservoirs, dams and other major instream structures (e.g. barrages, locks and weirs).
- Instream farm dams or other structures.
- Smaller weirs including flow gauging stations.
- Levees (wetlands and floodplains).
- Elevated roads, culverts and crossings.
- Behavioural barriers such as darkened areas or inappropriate habitat (from habitat change).
- Physiological barrier such as high velocity flow or poor water quality areas.
- Biological pollution – presence of introduced predatory or aggressive fish.

In addition to direct blockage of upstream or lateral movement, fish concentrated below barriers are exposed to predators, stress and disease. Downstream passage can also be affected or result in high mortalities associated with falls over spillways or through highly turbulent areas.

While in the main artificial barriers to dispersal have a negative effect, it is worth noting that some fauna rely on barriers to escape other threats such as predatory introduced fish. Natural barriers provide long-term isolation for some species free from competition with both native and introduced species and introduction of fish into such areas can have impact on species biology, genetics and survival.

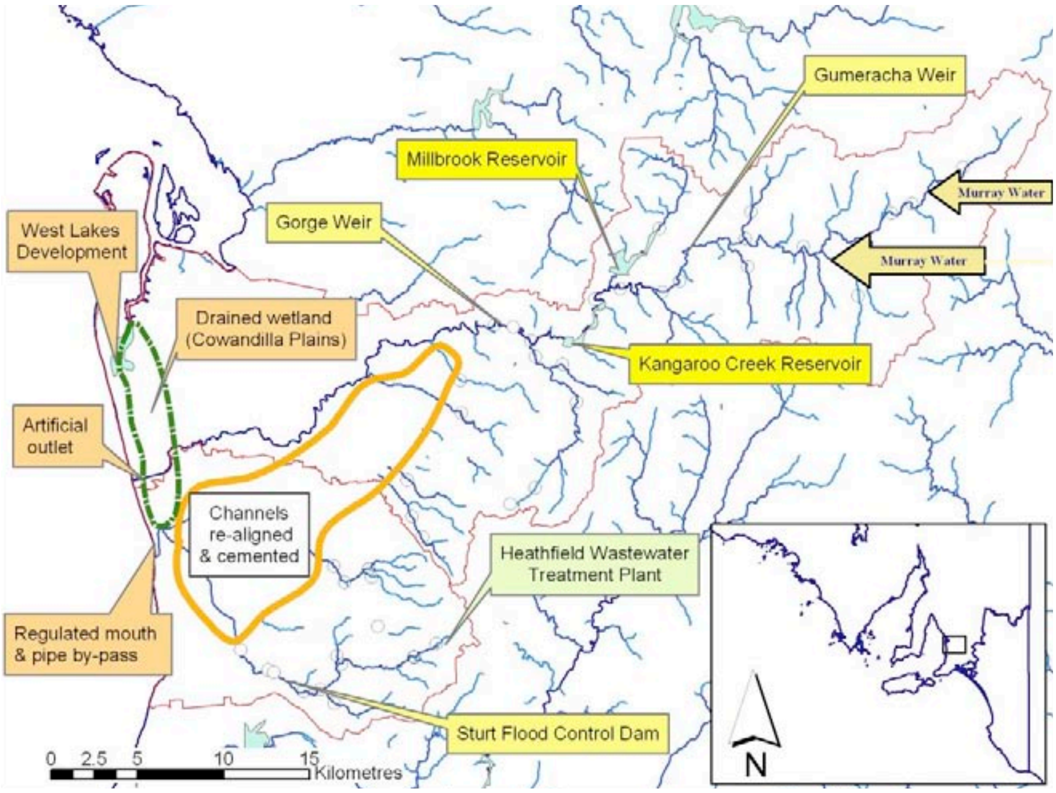


Figure 14. Example of major anthropogenic habitat changes to the Torrens and Patawalonga catchments[28].

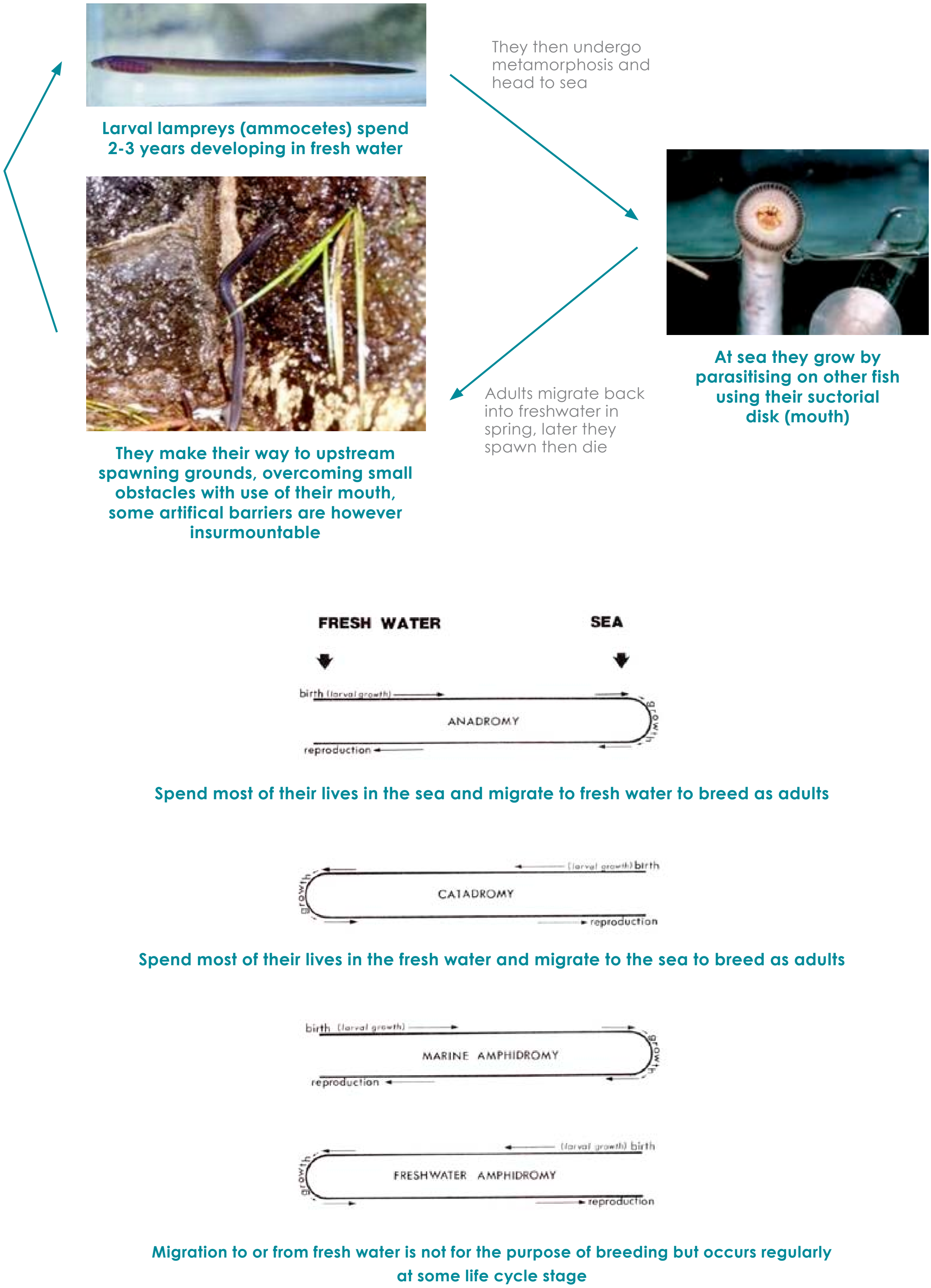


Figure 15. Schematic lifecycle diagram for diadromous species in South Australia, illustrated with the example of the anadromous Pouched Lamprey. Figure and text adapted from McDowall (1988)[244].

3.3. LOWERED WATER QUALITY

Water quality is a relatively complex combination of chemical and biological interactions in a local environment with broader influences. For example, levels of dissolved oxygen, one of the key water quality parameters, can be influenced by things like temperature, flow (aeration), suspended solids, concentration of organic carbon, and biological/chemical oxygen demand (fish, plants, algae, bacteria). Temperature in turn is governed by a variety of factors such as climate, water source, local radiation or shade and pool characteristics such as depth and surface area. Flow is further linked to water quality by diluting or distributing pollutants. Lowered water quality will have different implications or act as triggers for different processes such as fish mortality (fish kills), sub-lethal responses, and generate flow on effects to habitat quality. Negative effects will vary widely depending on fish condition, stress, species and age (size).

(A) FISH KILLS There are various potential causes of fish kills including natural events associated with habitat drying (e.g. temporary fish populations die as Lake Eyre recedes after flooding). Anthropogenic change can alter natural cycles of drying and water chemistry exacerbating natural events. In particular loss or reduction in base flow which might buffer oxygen or temperature levels, which can lead to suboptimal and ultimately lethal conditions[25].

Other inputs (pollutants) in isolation or combination are potential causes of fish kills:

- Pesticides such as Endosulfan (an organochlorine) are known to be toxic to fish[245]. Historically the pesticides Dieldrin and DDT were thought to harm fish populations in South Australia[176,202].
- Herbicides – in addition to impacting habitat (i.e. aimed to kill aquatic plants), these chemicals may be toxic, particularly the wetting agents used to help dispersal.
- Other toxic substance include heavy metals, acidic conditions[60,246], ammonia, hydrogen sulphide, winery waste and various industrial chemicals.
- High salinity and or temperatures can be above the tolerance of certain fishes.
- Turbidity (suspended solids) from runoff, instream or near stream works, can clog fishes gills and reduce oxygen availability.
- High nutrient levels from urban or agricultural runoff combined with warm still conditions promote blooms of algae and cyanobacteria (blue-greens) which can have a high demand for oxygen resulting in eutrophication.
- In urban environments toxic substances, organic load and large bacterial loads (high oxygen demand) occur with stormwater after rainfall, especially following dry warm periods. Both aforementioned problems could be linked to irregular fish kills observed in the Torrens Lake in the centre of Adelaide and Patawalonga Lake at Glenelg.

Disease may also cause mass mortality in fishes (see later).

Fish kills should be reported to the 24 hour FISHWATCH hotline on 1800 065 522.

(B) SUB-LETHAL RESPONSES The same factors involved in fish kills, but at sub-lethal levels, can impact on the condition of fish and the ultimate survival or successful breeding of individuals or populations in a chronic or cumulative way. Fish may be stressed, use extra energy or be unable to feed or breathe normally when exposed to certain substances. The potential consequences include poor fish condition and health (e.g. susceptible to disease and predators), increased abnormalities, poor growth and shorter lifespan, reduced or failed spawning, and low survival of eggs and larvae.

(C) REDUCED HABITAT QUALITY Other aspects of water quality may influence the structure or nature of aquatic habitats, linking together various other threat categories. For example un-naturally high turbidity limiting light penetration may inhibit plant growth, fish feeding, fish behaviour and water quality. Filamentous algae and suspended solids that settle may smother surfaces including food sources and breeding substrates. High salinity may affect other ecosystems components such as plant or macroinvertebrate composition and abundance having indirect impacts to fish feeding and habitat.

Fish kill of Flathead Gudgeon after pollutants entered a creek from a winery along the North Para River at Tanunda in April 2000[247]

Silt laden runoff from a roadway entering the Onkaparinga River Gorge

3.4. ALIEN SPECIES & STOCKING (BIOLOGICAL POLLUTION)

Alien species is used here to describe species exotic to Australia (SA *Fisheries Management Act 2007*) and Australian native species translocated outside their natural range. The introduction of organisms (biological pollution) outside their natural range is a worldwide problem in aquatic systems with serious impacts to ecosystems and biodiversity in numerous cases, particularly in small isolated habitats[248]. Fish translocated into one area have the potential to disperse more widely through connected waterways. The problem then escalates when these established species are more frequently encountered and further dispersed by humans. This is well illustrated by the rapid range expansion of Common Carp in Australia which included dispersal along river systems but has also many new isolated river basins and catchments including isolated wetlands around Adelaide.

Fish translocations can occur from a variety of mechanisms including deliberate releases (legal or illegal) or accidental movements (list adapted from a recent Australian review[249] with local examples provided where available):

- Deliberate legal stocking (recreation or conservation): permits for trout stocking in the Mount Lofty Ranges; attempts to form refuge populations of threatened native fishes.
- Contaminants of fish stocking (i.e. generally smaller fish that colonise aquaculture ponds and are then transported with juveniles of angling species): species such as Carp Gudgeon and Gambusia are potential candidates.
- Bait bucket introductions (i.e. live animals discarded after use at a different place to where they were captured): Goldfish were suspected to be introduced via this method in the Lake Eyre Basin[250].
- Transfers via water diversions (e.g. pipelines between river systems): several species which occur in the River Murray may have been introduced to the Torrens and Onkaparinga catchments via this linkage.
- Discarding of aquarium fish (and plants): Goldfish commonly occur in urban and rural centres[23,27,53].
- Escape from aquaculture facilities: marron on Kangaroo Island.
- Deliberate introductions for (a) pest control (e.g. Gambusia was distributed widely after WWII under the perception that it was a good mosquito control agent) and (b) biodiversity enhancement (e.g. wetland stockings[251]).
- Deliberate illegal stocking: many larger Australian native species including Murray Cod and Golden Perch have been stocked into waterways outside their natural range[1].
- Escape from outside ponds and farm dams close to waterways or that overflow during winter or storms.
- Transfer on commercial fishing gear.
- Deliberate release for cultural reasons.
- Contaminants of ballast water (shipping): estuarine/marine species that can colonise freshwater[141].

A variety of fishes, invertebrates and plants have been introduced into aquatic habitats of South Australia. This includes at least 27 alien fish species, fourteen of which have established populations and/or are regularly stocked (Table 4). The majority of such species have been introduced in and around Adelaide and in the Murray system. Problems with introduced organisms can be categorised as including (a) biological interactions, (b) transfer of disease and parasites, and (c) genetic implications. It is important to recognise that any species, exotic or native, introduced to areas where they do not naturally occur could cause one or more of these problems.

Table 4. Alien species recorded in South Australia by Drainage Division[1,252]. Alien fishes in natural waterways are regarded as established species (x) if their populations are self-sustaining or if they are continually stocked, and as introduced species if records are few and isolated (I) or confined to artificial (A) waterbodies (and potentially could become established); (*) recorded in marine habitat; (?) unverified record.

Family	Taxon	Common name	SEC	MD	SAG	LE	WP
Exotic species							
Cyprinidae	*Carassius auratus*	Goldfish	x	x	x	x	A
	Cyprinus carpio	Common Carp	I	x	x	A	
	Tinca tinca	Tench	x	x	x		
Cobitidae	*Misgurnus anguillicaudatus*	Oriental Weatherloach		I			
Salmonidae	*Oncorhynchus mykiss*	Rainbow Trout	I	x	x	I?	
	Salmo salar	Atlantic Salmon		I			I*
	Salmo trutta	Brown Trout	I	x	x		
	Salvelinus fontinalis	Brook Trout		I	I		
Poeciliidae	*Gambusia holbrooki*	Eastern Gambusia	x	x	x	x	I
	Phalloceros caudimaculatus	Speckled livebearer			x		
Percidae	*Perca fluviatilis*	Redfin Perch	x	x	x	I	A
Translocated Australian native species							
Plotosidae	*Tandanus tandanus*	Freshwater Catfish	I	A	x		
Galaxiidae	*Galaxiella pusilla*	Dwarf Galaxias			I?		
Melanotaeniidae	*Melanotaenia fluviatilis*	Murray Rainbowfish	I?	I	x		
Centropomidae	*Lates calcarifer*	Barramundi			I		
Ambassidae	*Ambassis agassizii*	Agassiz's Glassfish		A			
Percichthyidae	*Gadopsis marmoratus*	River Blackfish			A		
	Maccullochella peelii peelii	Murray Cod	I	A	x	I	
	Macquaria ambigua ambigua	Murray-Darling Golden Perch	I	A	x	A	
	Macquaria novemaculeata	Australian Bass		I	I?		
	Nannoperca australis	Southern Pygmy Perch		A	A		
Terapontidae	*Bidyanus bidyanus*	Silver Perch	I	A	A	A	
Eleotridae	*Hypseleotris* sp. 1	Midgley's Carp Gudgeon			x		
	Hypseleotris sp. 3	Murray Darling Carp Gudgeon	x				
	Mogurnda adspersa	Southern Purple-spotted Gudgeon		A	A		
	Philypnodon macrostomus	Dwarf Flathead Gudgeon			x?		
	Oxyeleotris lineolata	Sleepy Cod		I			
TOTALS		27	13	20	22	8	4
		known established	5	7	13	2	0

Drainage Divisions: SEC = South East Coast, MD = Murray-Darling, SAG = South Australian Gulf, LE = Lake Eyre, WP = Western Plateau

(A) BIOLOGICAL INTERACTIONS Direct and indirect problems associated with the biology of introduced organisms include those listed below, and are especially problematic during periods when habitats contract and native fish are confined. Impacts may be directed to sensitive groups or be manifested as ecosystem level impacts following the removal of certain species or resources (trophic cascades):

- **Predation:** many native fishes in South Australia are small species that have evolved in stream, spring, wetland and waterhole environments without exposure to large active predators. The introduction of large predatory fish into such areas poses a high risk to native fish, tadpoles and frogs, and macroinvertebrates especially decapod crustaceans (e.g. Spiny Crayfish and Yabbies). Smaller introduced species could also prey on the eggs or larvae of native fishes.
- **Competition:** juveniles of larger species or smaller growing species can compete for the same resources as native species including food but also available habitat (e.g. forcing a greater exposure to predators).
- **Aggression:** territorial or aggressive behaviour can impact native species through competition for space/habitat (above) and physical damage to individuals such as damage mucosal coat and fins (and hence increased risk of disease or reduced condition for spawning or growth).
- **Behavioural changes:** the presence of introduced species may alter the behaviour of native species feeding or foraging periods or force the use of suboptimal or non-preferred habitat.
- **Habitat alteration:** the feeding ecology or behaviour of introduced species may disturb environmental conditions required by some species or ecosystems (e.g. Carp disturb sediments and increase turbidity, remove of aquatic plants)

(B) TRANSFER OF DISEASE AND PARASITES Australia's long evolutionary isolation (tens of thousands to millions of years) has limited exposure to diseases (i.e. viruses, bacteria and fungi) and parasites. Therefore local native species may have a low immunity to new forms or strains introduced from oversees or interstate. Pathogens or disease causing agents can be primary or secondary in nature, causing disease in healthy or minimally stressed fish and fish with compromised health respectively. In the later case, poor environmental conditions or stress increases the susceptibility of populations to new or existing disease which may compromise survival of remnant or refuge populations[129].

Potential pathways for the introduction of diseases and parasites include:

- **Fish stocking:** the movement or introduction of fishes to regions, catchments or stream sections where they do not naturally occur, especially fish that have been apart from the natural environment, poses significant risks. This is especially true for exotic species that could carry disease or parasites which native fish have no acquired immunity for.
- **Discarded aquarium species:** a multitude of tropical and temperate freshwater species are utilised within the aquarium trade, and desired fishes are selected from around the world, facilitated through international exchange (importation). In the order of 8-10 million fishes are imported into Australia each year and with this comes an associated risk of importation of other micro-organisms (disease and parasites) including 'hidden' infections which may avoid detection[253,254]. The intentional or accidental release of fish, water or materials from aquariums and ponds into natural waterways thus provides an avenue for introducing disease and parasites to native fish (and is illegal).
- **Inter-basin transfers:** movement of water and organisms between areas provides another mechanism for dispersal of disease or disease carrying organisms. Pipelines such as those between the River Murray and catchments on the western Mount Lofty Ranges are an example.

Movement of materials such as unsterilised or not thoroughly cleaned fish sampling equipment, construction and maintenance machinery, and aquatic vegetation are all potential avenues for transportation of disease (plus potential introductions of fish and plants).

Current and potential diseases and parasites of native fishes in South Australia are poorly studied with little routine monitoring for new outbreaks. Potential problems include viruses such as EHNV and Gourami Iridovirus[253,255], fungal infection (e.g. *Saprolegnia, Aphanomyces*), bacterial infections such as Goldfish Ulcer Disease (linked to *Aeromonas salmonicida*)[256] and Fish Tuberculosis (*Mycobacteria*), and parasites such as tapeworm (*Bothriocephalus acheilognathi*) and Anchor worm (*Learnea* spp.).

(C) GENETIC IMPACTS

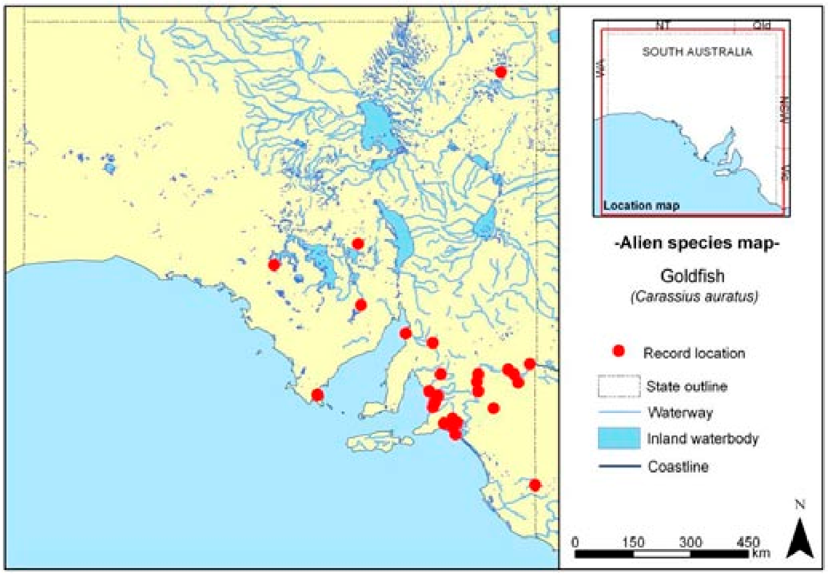
Two main categories of genetic impact can be considered in relation to fish introductions:

- Decline and fragmentation due to the direct impacts of introduced species. Biological interactions may lead to reduced population size (e.g. continual predation, exclusion from habitat, disease), population bottlenecks during critical periods, altered natural selection, and poor connectivity and gene flow within populations – all serving to reduce genetic diversity and uniqueness within a population.
- Reproductive interaction of local and stocked fishes. Mostly an issue with the translocation of Australian native species where mixing (reproduction) of different genetic strains or closely related species could lead to: (a) hybridisation and introgression (contamination with foreign genes) interrupting natural evolutionary trajectories and having other issues such as infertility and outbreeding depression, (b) the loss of distinct local genetic types (diversity) through swamping with new foreign genes[257,] and (c) reduced genetic diversity through swamping with genetically similar hatchery reared fish. Some relevant local examples include the risk of mixing fish from isolated regions such as distinct species of Golden Perch occurring in the Murray-Darling system and Cooper Creek, swamping the local genetic diversity of Murray Cod in the SA River Murray due to stocking fingerlings, or small distance translocations across catchment boundaries eliminating distinct genetic strains of smaller native fishes like Southern Pygmy Perch and Mountain Galaxias.

(D) SPECIES PROFILES Brief synopsis on the range, status, history of introduction and potential problems for introduced species in South Australia are detailed in family order (see Table 4). More detailed information on these species can be found in broader texts or reports[89,258,259,260,261,262].

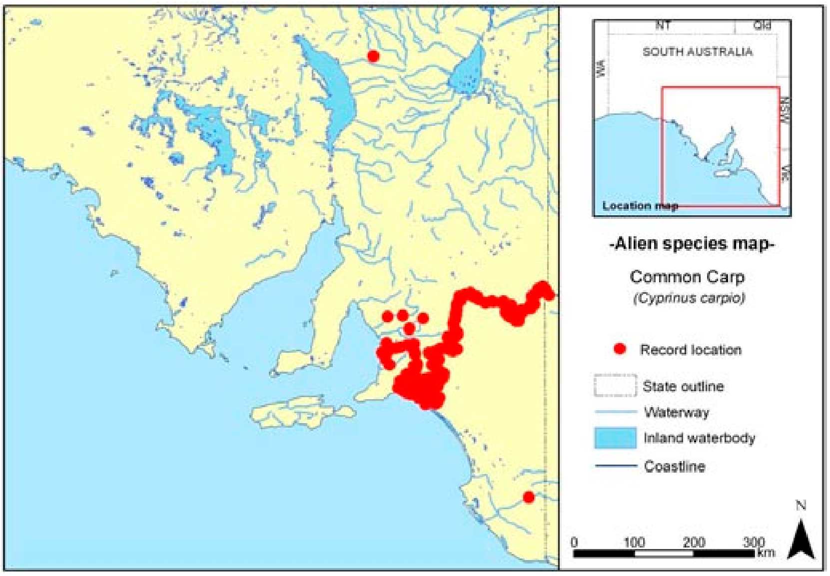
Goldfish

The species has been established in South Australian waterways for some time (at least early 1900s) with evidence of continuing introductions due to a close association with humans through culture (e.g. aquariums and ponds). Goldfish are common in the Murray and urban Adelaide but are also spread patchily throughout all major SA Drainage Divisions. While goldfish appear harmless, there is a potential to compete with native species for food (zooplankton, invertebrates), to modify habitats (e.g. suspend sediments in confined habitats; feed on and remove aquatic vegetation), and most importantly for the introduction of disease and parasites carried with their importation into Australia. The illegal use of Goldfish as live bait poses a high risk of introducing disease to native fish stocks, potentially ruining fishing opportunities and impacting biodiversity.



Common Carp

A species well known and much maligned by the general public, commonly referred to as European Carp. Carp became established in the Murray system in the late 1960s where it is now abundant and has since become established in other streams of the Western Mount Lofty Ranges (e.g. Onkaparinga, Torrens and Light rivers) as well as numerous local wetlands in the Adelaide region. Only isolated reports have been made from the South East and Lake Eyre Basin. The impacts of this species appear to be interlinked with broader environmental change, as they have a high tolerance for stable, stagnant habitats. Nevertheless, potential impacts are thought to include their high densities providing competition with small native species for food (zooplankton) and space, increased turbidity and loss of submerged aquatic vegetation due to their large adult size and feeding mode, and as vectors for disease and parasites. Any impacts are most noticeable in confined areas such as wetlands or stream pools.



Weatherloach and other potential exotic invaders

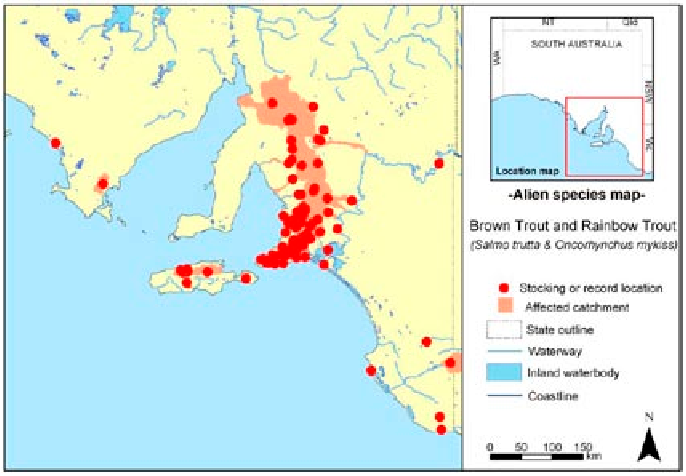
Only a few unverified records of Weatherloach have so far been made in South Australia, however the species (a small eel like fish reaching ~20cm) has become established in the eastern states and has undergone a rapid proliferation in the last 20 years. It is now advancing down the Murray River in Victoria towards the South Australian border. Potential impacts from species which is highly tolerant of environmental extremes include competition and potential predation on eggs and larvae of native fish[263], posing particular danger to species in the Mount Lofty Ranges and Lake Alexandrina. Other potential pest species that are established in other parts of Australia that could be a threat to local native species and ecosystems include Tilapia, Rosy Barb, and numerous aquarium species.

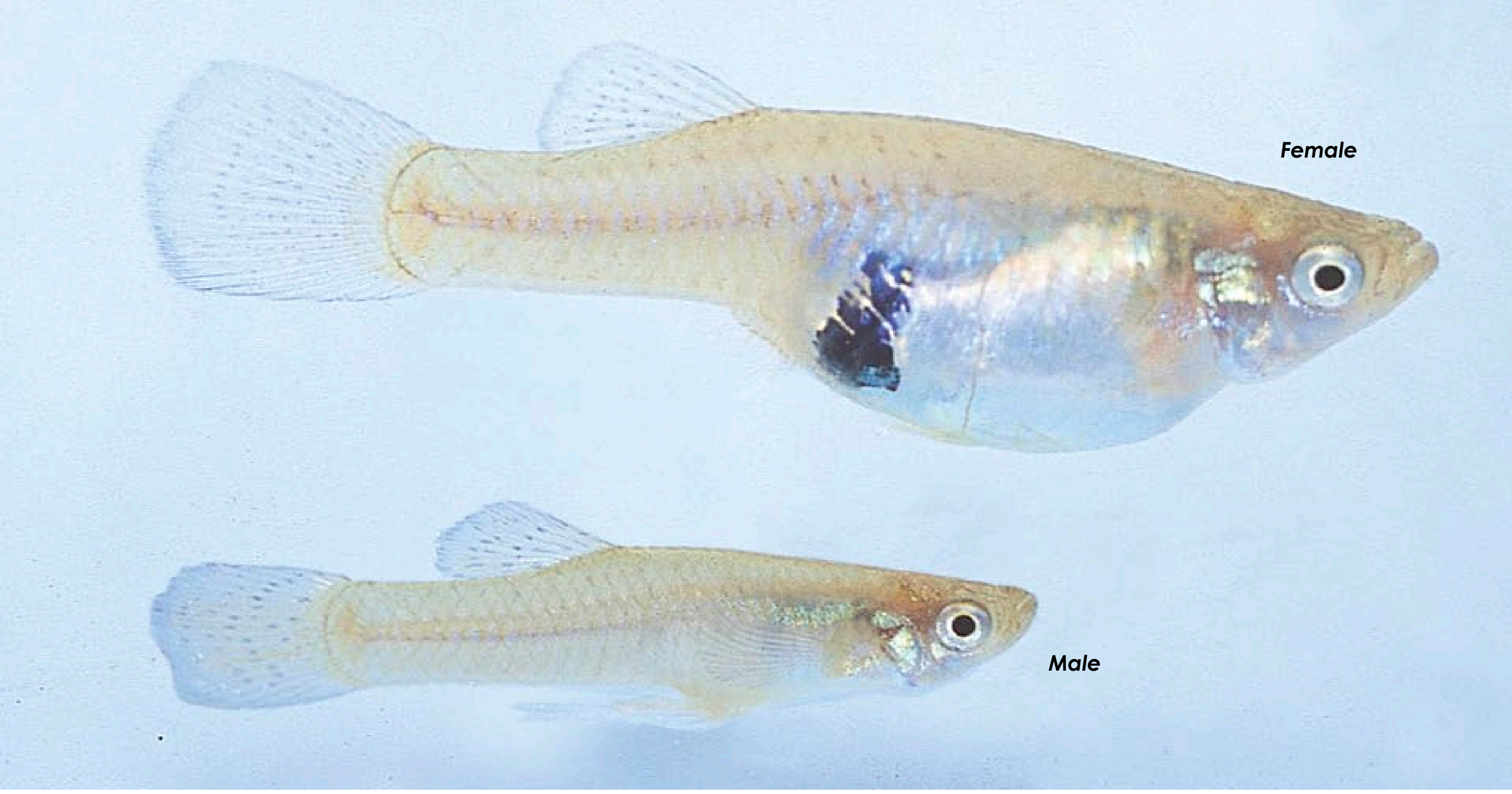
Stomach contents of a Brown Trout in the Finniss River catchment which includes 15 fish (Flathead Gudgeon and Mountain Galaxias) and numerous Glass Shrimp

Brown and Rainbow Trout

Trout have been systematically stocked into the South Australia's waterways since the late 1800s, especially after the 1950s. Given documented stocking locations, plus the likelihood of considerable other releases, it is fair to say that essentially any waterbody in temperate regions of the State (and some warmer regions) has probably received trout fingerlings at some stage. Several systems like the Broughton, Light, Torrens, Onkaparinga, Finniss, Hindmarsh and Currency catchments (Mount Lofty Ranges) and Mosquito Creek (SE) have each received hundreds of thousands of fingerlings over time[264]. Some populations appear to recruit in the wild but many are topped up with stockings under a PIRSA Fisheries permit system. The number of catchments stocked in recent times has been reduced mainly due to decline in environmental conditions to the point that areas are no longer suitable to carry trout signalling broader environmental problems, but tighter control is also being implemented.

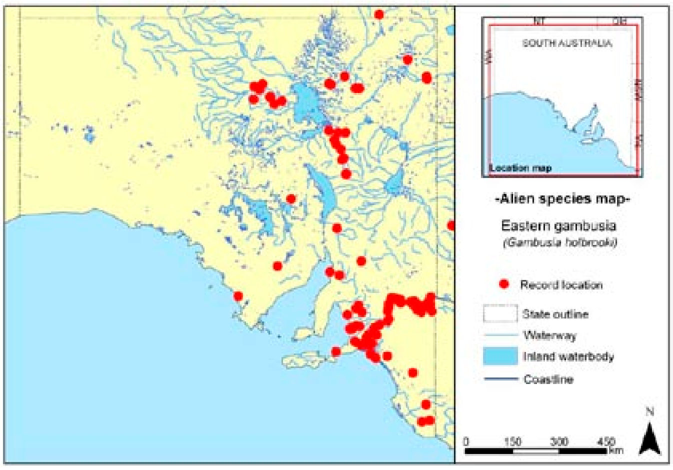
Both Brown and Rainbow Trout are active predators, often being much larger than species native to systems where they are stocked. Many of the impacts of trout probably occur upon initial stocking (e.g. loss of native fish populations in the Torrens[265]), however there is evidence of ongoing impacts to native species such as Mountain Galaxias, Climbing Galaxias and Southern Pygmy Perch. These native species have restricted fragmented distributions at some sites in the Mount Lofty Ranges likely attributable to the presence of trout[25,27,28,51]. Trout tend to occupy stream regions or pools with better water quality and flow and thus are in direct conflict with optimal habitat and refuge areas of native species. Trophic cascades are also possible due to heavy feeding on invertebrate fauna and possibly tadpoles.





Eastern Gambusia

The Eastern Gambusia (Gambusia for short) is a small fish that attains a length of less than 5cm. It is able to rapidly expand populations, giving birth to live young. It was originally introduced for mosquito control (especially around World War II), but is now known to be no better at controlling mosquito larvae than the native fish and macroinvertebrates which naturally fulfil this role. The species can negatively impact on these natural mosquito predators (hence use of the name Mosquitofish is discouraged). It occurs widely in South Australia and is considered a threat to many native fishes because it is aggressive, nipping at fins and the body of other fish, can predate on eggs and young fish, and can compete for food and space (e.g. aggressively defends shallow pool margins[39]). The largest impacts are likely to occur in confined habitats such as mound springs or isolated stream pools, or areas with sensitive small species such as Dwarf Galaxias and Pygmy Perches. The species has high tolerance of environmental extremes and hence can be favoured by declining environmental flows and habitat degradation.



Speckled livebearer

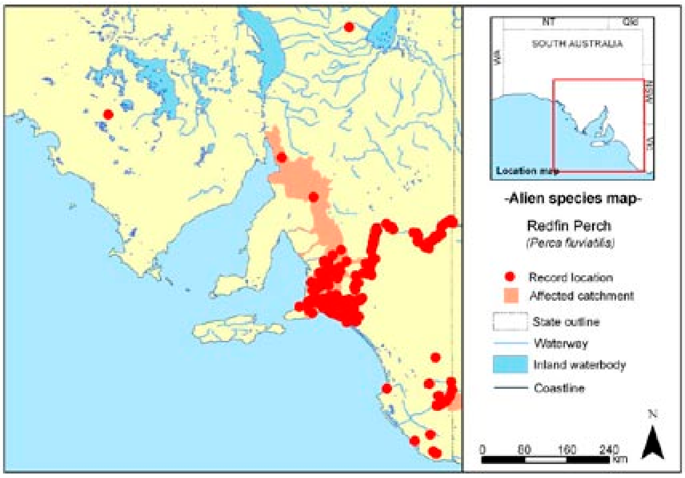
This species, a relative of the Gambusia, represents a newly documented invasion in South Australia (southern Adelaide)[252]. Like its cousin it is known to be aggressive and compete with native species. It has likely become established through escape or release from captive fish, and highlights the need for vigilance with regard to alien species introductions.

Redfin are an introduced predatory species which threaten populations of small fish such as Pygmy Perch and Galaxias

Redfin

Redfin have been spread widely in South Australia, particularly in the Adelaide region and South East of the State. Introductions occurred soon after settlement with records of the species becoming established in major areas such as the River Torrens and River Murray by the 1920s. They are most common in streams of the western Mount Lofty Ranges such as the Torrens, Onkaparinga rivers, Lake Alexandrina and some tributaries (Finniss and Angas rivers), and waterholes and streams of the South East including Bool Lagoon (when wet). Interestingly, harsh environmental conditions in recent years appear to have resulted in a decline in distribution and abundance in Mosquito Creek suggesting certain vulnerabilities or intolerances[118].

Compared to most small native fish, Redfin are large growing and are highly predatory (with a large mouth). The species can breed and grow rapidly with impacts likely to include competition for space and food (as juveniles), predation or behavioural shift forcing loss or exclusion of native fish from important habitat. A Western Australian study found diet of Redfin between 50-200mm comprised mostly small aquatic invertebrates, and Redfin >200mm preyed almost entirely on decapod crustaceans and fish. The study concluded that Redfin were believed to have played a significant role in the local extinction of three native fish species[266]. This matches local observations of potential impacts to species such as Southern Pygmy Perch, River Blackfish, Mountain Galaxias, Yarra Pygmy Perch and Murray Hardyhead in their respective distributions in the Mount Lofty Ranges, Lower Lakes and Mosquito Creek[13,23,25,113,260]. Impacts are likely to extend to Yabbies, Spiny Crayfish and tadpoles.

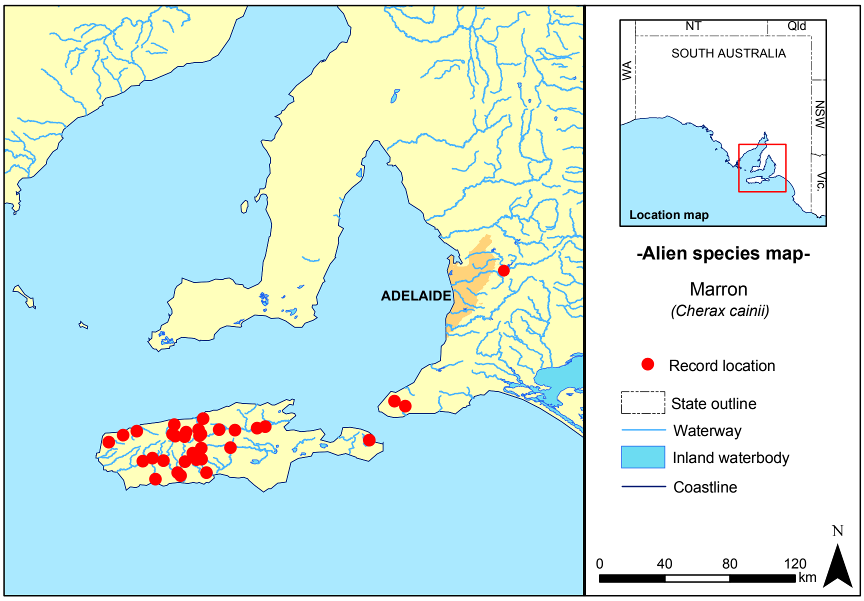


Native fish species

Large predatory species such as Murray Cod, Golden Perch and Freshwater Catfish are increasing used for stockings (angling purposes) with some records of translocated fish from South Australian waterways[1]. However, just because such species are native to Australia, does not mean that they will not pose a threat to areas where they do not naturally occur. Their potentially large adult size and predatory nature threaten small native species and invertebrates (especially Spiny Crayfish) in areas where they are stocked or escape to (e.g. from farm dams that overflow into natural waterways). Further, stocked fish may also carry disease from hatcheries or other areas, and there are potential genetic implications such as hybridisation or genetic swamping of native populations. Similarly, small native species stocked outside their natural range could compete for food and habitat with local species, transfer disease or parasites and have implications for mixing of different genetic strains. Stocking is seen as a way of improving declining fish populations, however it is often a band-aid solution which fails to address the underlying threats to species such as loss of habitat. Further, if undertaken incorrectly, stocking can cause its own problems through genetic impacts, disease introduction, impacts to other ecosystem components and increased competition pressures for natural populations.

Marron

Marron, native to Western Australia, is now widely established on Kangaroo Island and some sections of the Fleurieu Peninsula. In these areas they reach a very high biomass during concentrated conditions, and are likely to be impacting fish directly as a large aggressive animal (e.g. predation) or alter the food-chain (e.g. competition or replacement of natural invertebrates). The species has established over the last 20-30 years with mechanisms such as escape from ponds or dams and illegal movements and stocking probable. There has to date been little research or management undertaken on control of prevention of spread.



Willows

Willows comprise a number of species of deciduous water loving trees which can spread to line and choke small waterways and exclude native plants. Willows also have a heavy rapid leaf drop with fast decomposition which can lead to deoxygenation and poor water quality and smothering of underwater surfaces and vegetation. However, in some cases Willows now represent the only shade and sources of cover at some degraded sites and actually provide important habitat for species with requirements for cool conditions such as River Blackfish, Southern Pygmy Perch, Mountain Galaxias and Climbing Galaxias in the Mount Lofty Ranges. The sometimes crude methods used to control Willows involving heavy physical disturbance to stream edges and a subsequent transition from full to no shade can be a threat to native fish populations and a more gradual transition to native riparian vegetation is recommended.

3.5. **EXPLOITATION (USE)**

Catch and use of fishes occurs for a variety of purposes including recreational, commercial and cultural reasons (e.g. food, angling), for research, biodiversity enhancement projects (e.g. collecting fish for stocking wetlands) and for personal enjoyment or observation such as keeping native fish in aquariums. These uses can provide an appreciation of the intrinsic value of native species and a greater awareness and knowledge of their natural history and biology. However, the inappropriate or excessive use of native fish populations could provide an additional stress to threatened species and those with temporarily restricted distributions.

(A) REDUCED ABUNDANCE Use can ultimately reduce the abundance of species at a point in time or progressively. This has the potential to impact on the number of fish or critical mass required to sustain a population or basic levels of genetic diversity (e.g. appropriate number of spawning fish). Species vulnerable to exploitation include those with highly restricted ranges (e.g. desert fish[32], Pygmy Perches), which spawn infrequently or are slow growing, and species which occur in concentrated refuges during dry periods (e.g. larger fish of the Lake Eyre Basin in systems like Coopers Creek and the Neales River). Other species are susceptible to over harvest during spawning aggregations or migration.

(B) TROPHIC CASCADES Fish play a variety of roles in ecosystems such as being an important part or link in food chains. Nearly all small native species and juveniles of larger native species are carnivorous and hence consume aquatic and terrestrial macroinvertebrates and crustaceans. A particular aspect of this predation includes a role in mosquito control (by predation on wrigglers or adult mosquitoes). Small fish are in turn consumed by predators such as birds, water rats and larger fish. Larger predators potentially control the dynamics of other species (keystone species). Such food chains exist in a fine balance with environmental conditions, and hence the selective removal of certain species, especially larger predatory species like Murray Cod, may indirectly alter the composition of a local fauna by allowing the proliferation of certain smaller species ('top-down' ecosystem effects). Alternately the introduction of larger predators could eliminate small species but leave the food they previously were feeding on (for example leaving no natural predators of mosquito wrigglers in pools as has been observed with trout in the Mount Lofty Ranges[25]. The selective removal of a species through legal or illegal fishing effort could mean that another species takes its role in a system, so that efforts to recover the exploited species later on are less successful as it has been functionally replaced. This is an example of an altered ecosystem state.

Preparing a large catch of Murray Cod, a top order predator, caught at Renmark 1898. Photo courtesy of the State Library of South Australia (SLSA: B45136)

3.6. **POPULATION DECLINE**

A grouping of other potential threats relate to the current characteristics of populations and social and political factors. These are very much cumulative or interlinked with problems such as hydrological alteration or habitat loss but warrant specific inclusion and highlight.

(A) LOSS OF GENETIC DIVERSITY Genetic diversity is the backbone to biodiversity or the number of unique animals and plants that have evolved and occupy habitats in South Australia. Genetic diversity can be expressed on a number of levels including phylogenetic (deeper relationships such as Families and Genera), species boundaries, and within species variation. Within species variation can provide an ability to adapt to changing environmental conditions, and can relate to variability both between and within different populations of a species. For example, the Southern Pygmy Perch has distinct genetic lineages in the South East and Murray regions of the State, and individual catchments in the Mount Lofty Ranges harbour unique genes and frequencies of different genes (heterogeneity). These distinguish each pygmy perch lineage and form the basis of potential adaptation or evolution in their isolated habitats[13,22]. Processes that can erode genetic distinctness or within population/species variation include local extinctions or range contractions (e.g. from habitat loss), bottlenecks from low numbers of fish at a point in time (e.g. over harvest during drought), fragmentation (e.g. artificial barriers), and swamping with hatchery reared fish.

(B) RESTRICTED RANGE Many species or populations of threatened species have a limited area of occurrence. This can be due to natural isolation such as desert fish restricted to a particular stream (Flinders Ranges Purple-spotted Gudgeon) or group of artesian springs (e.g. Dalhousie endemics), or alternately species which were formally more widely spread but have contracted due to human related impacts like hydrological alteration. Good examples include River Blackfish in the River Murray drainage, a once widespread species that now occurs as four small populations, including one which is restricted to two refuge pools[25,267]. Spatially restricted species and populations face a variety of challenges for long-term survival. Any change in their habitat could be devastating, and changes to small areas could happen quite easily and quickly through both chance natural conditions (e.g. floods and drought) and threatening processes such as habitat change, species introduction, pollution events and water quality issues[247], and loss of flow. Any new small change cumulative to existing threats may push a population past sustainable limits.

(C) MANAGEMENT AND PLANNING Being hidden below the waters' surface, most native fish do not have a high profile in the community or among planners, land and resource managers, and developers. This is particularly the case for small, rare fish with no recreational fishing value. A general lack of awareness of species or regional faunas is a threat to South Australia's freshwater fishes because:

- **Lack of action:** a failure to address the specific conservation requirements or actions for threatened species or communities could lead to species loss.
- **New threats:** the requirements and conservation of native fish may not be considered during new developments or changes in landuse, and in restoration programs.
- **Limited funding:** fish may not receive the same levels of attention or priority in restoration and management, leading to few dedicated actions and a greater risk of species loss from the State.
- **Limited research:** there may be a tendency for limited research and monitoring leaving knowledge gaps on the presence or condition of ecological assets as targets for conservation and management and biological information available for management.
- **Legislative protection:** the importance of protecting fish populations, their habitat and flow processes has been (and is currently) poorly represented in State laws and regulations. This has particularly been the case for small species that tend to fall between the gaps of terrestrial species conservation and fisheries management.

3.7. **CLIMATE CHANGE**

The projections of climate change as a result of current and increasing world-wide green house gas emissions have considerable relevance for South Australia. Exact predictions are difficult given large temporal variations in climatic conditions, and with variations for different parts of the State, but the overall trend based on average seasonal and annual conditions suggests South Australia will become hotter and drier, with a change in the nature of rainfall events[268].

Notably in time, the prevailing low pressure systems from the south west which produce rainfall in the southern areas of the State, are projected to decrease in number but increase in intensity with an overall effect of less rain in more concentrated events, particularly in spring. The northern half of the State is predicted to become warmer (e.g. between 1 to 6°C) with an increasing frequency and magnitude in summer rainfall events (e.g. more floods). A summary of predicted changes in rainfall and temperature are contained in Figure 16. Broader changes are also likely to affect South Australia especially in the Murray-Darling Basin where with less rain, flow to South Australia could be further reduced.

Climate change has the potential for direct impacts along with an overarching role in exacerbating many existing threats. A change in climate could mean aquatic habitats are increasingly influenced by disturbance events of large floods and longer periods of drought, and overall warmer water temperatures and lower average flows (the latter could also result in increased concentrations of salt, nutrients and pollutants). This pattern is likely to be further intensified in developed regions as humans react to secure water supply with cumulative additions to existing abstractions (e.g. dams, groundwater pumping). All fishes will be susceptible to changes in their habitat extent and conditions (e.g. habitat loss, water quality tolerances), but those living in currently cooler and more predictable seasonal environments will be hardest hit (e.g. cool water species from the Mount Lofty Ranges and South East).

Sights like this concentrated refuge pool could become more common with reduced rainfall and higher temperatures, combined with existing water use

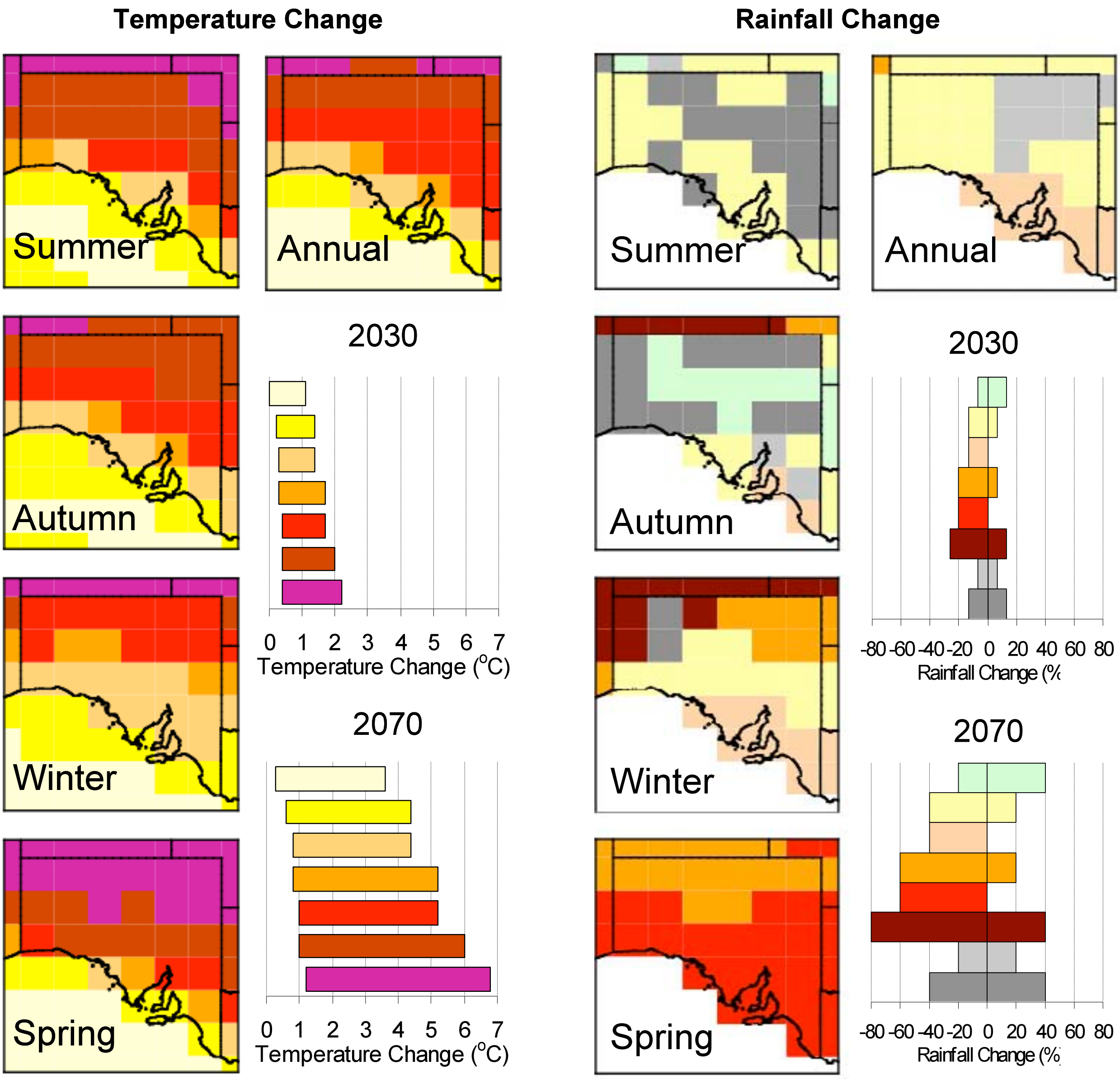


Figure 16. CSIRO climate change projections for South Australia covering (a) average seasonal and annual warming ranges (oC) for around 2030 and 2070 relative to 1990 and (b) average seasonal and annual rainfall change (%) for 2030 and 2070 relative to 1990. The coloured bars show ranges of change for areas with corresponding colours in the maps (reproduced with permission from McInnes et al. 2003[268]).