REDUCING THE IMPACT OF ROAD CROSSINGS ON AQUATIC HABITAT IN COASTAL WATERWAYS – SOUTHERN RIVERS, NSW

REPORT TO THE NEW SOUTH WALES ENVIRONMENTAL TRUST

NSW DEPARTMENT OF PRIMARY INDUSTRIES

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Cover photo: Causeway with excessive headloss over Wadbilliga River on Wadbilliga Road (Tuross Catchment).

EXECUTIVE SUMMARY

Stream connectivity and habitat diversity are critical components of healthy rivers. Many fish have evolved to be reliant on a variety of different habitat types throughout their life cycle. The free passage of fish within rivers and streams and between estuarine and freshwater environments is a critical aspect of aquatic ecology in coastal NSW.

Waterway crossings can affect the health of aquatic habitat and fish populations in several ways. Structures such as causeways, pipes and culverts, can prevent fish passage by creating a physical blockage, a hydrological barrier, or by forming artificial conditions that act as behavioural barriers to fish. Road crossings have also been linked to increases in sediment and other inputs from adjacent floodplains and slopes. Furthermore, some structures can adversely affect fish by altering natural flow patterns, disrupting localised erosion and sedimentation processes, and affecting instream habitat condition.

Although current policy within NSW legislates the incorporation of fish passage into the design of all new instream structures, a legacy of poorly designed structures exists that detrimentally affects fish migration. As a result, the NSW Department of Primary Industries (NSW DPI) initiated a comprehensive investigation funded by the NSW Environmental Trust to specifically address the impact of road crossings upon fish passage and stream connectivity in coastal catchments. Detailed field assessments were conducted for over 6,800 waterway crossings in NSW coastal catchments, with over 1,400 identified barriers prioritised in terms of their impact on aquatic biodiversity, benefits should the structure be remediated, and the ease of structure remediation.

Fieldwork in the Southern Rivers region included assessment of 1,673 waterway crossings, with some of the primary findings including:

- 578 crossings identified as obstructions to fish passage throughout the Southern Rivers CMA region.
- 374 of these were recommended for remediation including:
    - 111 in the Shoalhaven-Wollongong subregion;
    - 77 in the Eurobodalla subregion;
    - 37 in the Bega-Eden subregion; and
    - 149 in the Snowy-Monaro subregion.
- The greatest number of obstructions were identified in the Bombala and Snowy River Shire Council areas (122 and 119 sites respectively).
- Pipe culverts and causeway crossings were the most common type of fish passage obstruction in the region (both being 34% of obstructions assessed).
- Box culvert crossings and ford crossings were also commonly found to prevent fish passage (16% and 12% respectively).
- Of structures recommended for remediation, nearly half were causeways (43%), followed by pipe culverts (29%), fords (13%), and box culverts (12%).

A ranking scheme for waterway crossing sites was developed to determine priorities for action in relation to fish passage. Crossings were ranked “high”, “medium” and “low” priority, with 55 high priority structures identified – the majority of which (72%) were found within the Shoalhaven-Wollongong and Eurobodalla subregions (18 and 22 sites respectively), with over half of these (46 sites) being causeways.

Shoalhaven City and Eurobodalla Shire LGAs possessed the greatest number of high priority sites (14 sites each), followed by Bombala (9 sites), Bega Valley Shire (7 sites), and Palerang Councils (6 sites). The greatest number of medium priority sites were located in Bega Valley Shire and Eurobodalla Shire LGAs (15 and 12 sites respectively).

Four structures were identified as being obsolete and could therefore be removed with minimal effort.

Five sites were identified as sediment input sites into a waterway, but were not fish passage obstructions. Several other sites were both sediment input sites and fish passage obstructions.

Overall recommendations for structure remediation include:

- Basic management/maintenance of sites (e.g. removal of sediment and debris blocking inlets);
- Modification of structures (e.g. retrofitting low-flow channels, installing fishways, sealing road approaches);
- Complete replacement of structures (e.g. causeways replaced with bridges or culverts); and
- Permanent removal of redundant (disused) structures.

The results of this investigation, including management recommendations are discussed herein.

ACKNOWLEDGEMENTS

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The NSW DPI Fisheries (Conservation and Aquaculture) Aquatic Habitat Rehabilitation Program team managed the project including research, fieldwork and report preparation, with valuable assistance from regional NSW DPI Fisheries (Conservation and Aquaculture) Conservation staff. Personnel involved in data collection, data analysis and report writing were: Sarah McGirr, Scott Nichols, Shaun Morris, Dr Matthew Gordos, and Charlotte Grove. Maps were produced by Mark Case.

The Southern Rivers Catchment Management Authority, State Forests (Department of Primary Industries), Department of Environment and Conservation and local Councils provided extensive advice and assistance toward the project.

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1. INTRODUCTION

The following document outlines results of a project entitled *Reducing the impact of road crossings on environmental flows, water quality and fish passage in coastal NSW.* The project was carried out by the NSW Department of Primary Industries Fisheries (Conservation and Aquaculture), and funded by the NSW Environmental Trust Program (Contract No. ET-H08030). This particular document is a report to the Southern Rivers Catchment Management Authority (SRCMA), providing results of the study relevant to the Southern Rivers region. Results for the Sydney Metropolitan, Hawkesbury-Nepean, Hunter-Central Rivers and Northern Rivers CMA regions are available in separate reports.

1.1 Project aims and objectives

This project was developed to identify and prioritise waterway crossings for remediation action in all coastal-draining catchments of NSW. This document outlines the findings of the study relevant to the SRCMA region.

The primary objectives and outcomes of the project were to:

- Identify and assess the impacts of road crossings on aquatic habitat within the SRCMA;
- Complete a field inventory of road crossing obstructions and identify other environmental impacts on aquatic habitat associated with road crossings;
- Develop an aquatic habitat management database and establish environmental auditing protocols for assessing road crossings;
- Demonstrate options for remediation and improved management of road crossings;
- Encourage remediation of priority sites with structure owners, and promote “fish-friendly” principles for application in future instream works;
- Establishment of remediation demonstration sites at two key road crossing sites within the SRCMA region; and
- Increase awareness of the importance of fish passage and aquatic habitat management for road management authorities and the broader community.

1.2 Study area

This report outlines the project results for the SRCMA region. The region encompasses the now merged Southern and South-East CMB regions, and includes all coastal (eastern) draining waterways south of Stanwell Tops (north of Wollongong) to the Victorian border, and the waterways of the Snowy River catchment within NSW (Southern Catchment Management Board, 2003; South East Catchment Management Board, 2003).

For reporting purposes four geographic zones within the region have been identified to highlight catchment and sub-catchment issues and priorities. These zones include:

1) Shoalhaven-Wollongong subregion;
2) Eurobodalla subregion;
3) Bega-Eden subregion; and
4) Snowy-Monaro subregion.

The geographical setting of each zone and the aquatic habitat issues related to these areas are outlined in Section 2.4. Management outcomes and recommendations from this study will be presented on a CMA, subregion, and LGA basis.

2. BACKGROUND

2.1 Fish passage in NSW

Stream connectivity and habitat diversity are critical components of healthy rivers. Many fish have evolved to be reliant on a variety of different habitat types throughout their life cycle. The free passage of fish within rivers and streams and between estuarine and freshwater environments is a critical aspect of aquatic ecology in coastal NSW.

Approximately 70 percent of the coastal fish species in southeastern Australia migrate as part of their lifecycles (Fairfull and Witheridge, 2003). These include key species such as Australian bass, sea mullet, short-finned and long-finned eels, freshwater mullet and freshwater herring. Recent NSW DPI Fisheries research in the Murray Darling Basin has indicated that a much higher percentage of native fish undertake some migration than previously thought (Baumgartner, *in prep*.). In the coastal catchments of NSW, it is likely that this trend will be continued as our knowledge of coastal fish biology and behavior develops through ongoing research and monitoring.

Impeding fish passage through the construction of dams, weirs, floodgates and waterway crossings can negatively impact native fish by:

- interrupting spawning or seasonal migrations;
- restricting access to preferred habitat and available food resources;
- reducing genetic flow between populations;
- increasing susceptibility to predation and disease through accumulations below barriers;
- fragmenting previously continuous communities; and
- disrupting downstream movement of adults and impeding larval drift through the creation of still water (lentic) environments.

For fish that have large-scale migrations in their life cycles, particularly anadromous and catadromous species, preventing fish passage can cause local extinctions above barriers and reduce population numbers downstream (Thorncraft and Harris, 2000).

The importance of free fish passage for native fish is recognised under the *Fisheries Management Act 1994* (FM Act), which has provisions specifically dealing with the blocking of fish passage. In addition, the installation and operation of instream structures, and the alteration of natural flow regimes, have been recognised as *Key Threatening Processes* under the FM Act and the *Threatened Species Conservation Act 1995*.

These legislative tools, and associated NSW Government policies on fish passage[1], act to regulate the construction of structures that may be barriers to fish passage. In addition, reinstating connectivity between upstream and downstream habitats and adjacent riparian and floodplain habitats has become an essential part of aquatic habitat management and rehabilitation programs in NSW.

2.2 Waterway crossings as barriers to fish passage

There are many types of instream structures that can obstruct fish passage by creating a physical blockage, a hydrological barrier or by forming artificial conditions that act as a behavioural barrier to fish. Barrier types can include dams, weirs, levees, stream gauging stations, waterway crossings, erosion-control structures and floodgates.

This report specifically focuses on waterway crossings. ‘Waterway crossing’ is a collective term for bridges, roads, causeways, culverts and other similar structures that can cause both direct and indirect impacts on fish and aquatic habitats (refer Photos 1-11). During their construction, habitat can be physically damaged by the removal of riparian and in-stream vegetation and disturbance to the bed and bank of the waterway which can increase sedimentation. An indirect impact of waterway crossings includes the localised extinction of a species from a waterway as populations become isolated, recruitment limited, and the ability of a species to survive reduced.

[1] See Section 7 for References

The extent to which waterway crossings impact on the movement of fish in rivers can depend on a) the design of the road crossing structure; b) the nature of flow, debris and sediment movement in the waterway; and c) the swimming capabilities of resident fish.

Pethebridge *et al*. (1998) identified 256 fish passage obstructions in the Southern Rivers region, of which more than 60 percent were caused by road crossings (specifically culverts and causeways).

In general, ***bridges*** and ***arch structures*** have the least impact on fish passage as they normally involve limited disturbance to the stream flow (Fairfull and Witheridge, 2003), thus allowing fish to pass underneath the structure over a wide range of hydrological conditions. Bridges that are built too low however, or structures with piers and footings that constrict the channel, can affect aquatic habitat and flow conditions underneath the structure.

Culverts are waterway crossings with ***pipes*** or ***box-shaped*** cells designed to convey flow underneath the roadway. Significant modification to the channel bed and changes to flow conditions are often associated with culvert installation. Increased flow velocity and turbulence and reduced flow depth may prevent fish from swimming through the structure. Warren and Pardew (1998) found that fish movement was inversely related to flow velocity at crossings and that culvert crossings exhibited the highest velocities of crossing types assessed. Some culverts may also have a step at the downstream end of the structure that creates a *waterfall effect* preventing fish from moving upstream at low flows. This waterfall effect may be a result of poor installation (the pipe being set higher than the stream bed level), or through the erosion of the stream bed on the downstream side, and the formation of a scour pool directly adjacent the culvert. Culverts can also hinder fish movement through lack of lighting and debris build up across the opening (caused by sediment or organic debris).

Causeways are a type of low-level crossing generally constructed at or near bed-level and are designed to convey water across the road surface as sheet flow. Some causeways however are raised well above bed-level and essentially act as a weir, preventing fish movement upstream. Causeways with low-flow pipes may also prevent fish passage due to high flow velocity, lack of lighting and blocking of the pipe opening.

Fords are a type of waterway crossing that directly incorporate the channel bed (termed “wet crossings”). Some fords are formed naturally at shallow points along a river, whilst others may be constructed with concrete or gravel. Such crossings generally pass fish when the river is flowing, however at very low flows fish passage may be hindered due to inadequate flow depth over the channel/road surface.

In tidal reaches, waterway crossings (especially those over drains) commonly incorporate **floodgates** that restrict fish passage between flood events. Floodgates include hinge-flap, winch, sluice, and auto-tidal designs. Between flooding, floodgates are generally maintained in the closed position thus ensuring a complete blockage to fish migration between estuaries and tidal tributaries. Although recorded during the investigation, floodgates have been treated as a separate management issue and thus were not included in the road crossing audit or prioritisation.

Photo 1. Causeway with high invert (headloss) and shallow water depth
(Currowan Ck, Eurobodalla subregion)

Photo 2. Pipe culvert with high invert (headloss)
(Black Swamp Ck, Snowy subregion)

Photo 3. Piped causeway with inadequate sized pipes, high invert (headloss) and shallow water depth
(Bettowynd Ck, Eurobodalla subregion)

Photo 4. Scoured causeway creating a large headloss
(Sawyers Ck, Shoalhaven/Wollongong subregion)

Photo 5. Box culvert with high invert (headloss) and shallow water depth
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Photo 6. Earth levee with inadequate sized pipes creating velocity barrier
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Photo 7. Redundant causeway used as bridge base, high invert (headloss) and shallow water depth
(Frys Ck, Shoalhaven/Wollongong subregion)

Photo 8. Ford with high invert (headloss)
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Photo 9. Pipe culvert of inadequate size and large sediment inputs
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Photo 10. Ford crossing with increased sediment loading
(Bullock Gully Ck, Eurobodalla subregion)

Photo 11. Box culvert with woody debris
(Stony Ck, Eurobodalla subregion)

2.3 Other impacts of waterway crossings

In addition to preventing fish passage, road crossings can impact on aquatic habitat by affecting water quality; disrupting natural flows and channel processes; as well as impacting on terrestrial species.

Road networks within forested areas, in particular unsealed roads and tracks, have been identified as significant sources of runoff and sedimentation. The extent to which water quality is affected is a function of the degree of hydrologic connectivity between sediment sources and the stream network (Farabi *et al.*, 2004; Takken *et al.*, 2004). Waterway crossings are an important part of sediment delivery pathways and, in the absence of adequate erosion and sedimentation controls (e.g. diversion drainage, vegetated swales or sediment basins), runoff generated from road surfaces may be carried directly to streams at these points. Similarly, road maintenance procedures can affect the rate at which sediment is delivered to streams (e.g. sediment spoil from the grading of unsealed roads left by the side of the road in direct proximity to waterways). In the case of low-level crossings such as fords, sediments can be directly disturbed by vehicles within the stream channel itself.

Road crossings can also impact on waterways by altering natural flow patterns, disrupting localised erosion and sedimentation processes, and affecting instream habitat condition. These impacts are most evident with structures resembling weirs and dams (e.g. large raised causeways). Such crossings can produce a *weir-pool effect* upstream of the structure, thereby creating a lentic (still) stream environment that can impede larval drift. The prevalence of these structures has reduced the capacity of eggs and larvae to reach preferred nursery habitat. Still-water environments can in turn, promote sediment accumulation and increase the potential for algal blooms. Alien species such as carp (*Cyprinus carpio*), goldfish (*Carassius auratus*), gambusia (*Gambusia holbrooki*) and redfin perch (*Perca fluviatilis*), have generalist habitat requirements and thrive in these disturbed habitats. In contrast, many native fish species have specialist flow requirements. As a consequence, in flow-modified waterways native fish fauna diversity, abundance, breeding success and ratio to introduced species is lower than less flow-modified streams (Gehrke and Harris, 2001).

Even very localised changes to channel flow conditions caused by road crossings can impact on instream habitat condition. For instance, increased flow velocities through culverts and piped crossings can lead to erosion downstream. Such changes can destroy instream habitat features through the infilling of pools, scouring of riffles, and undermining and removal of instream vegetation.

Impacts on riparian vegetation are also evident where waterway crossings create stable upstream weir pools. The lack of variation in water level can reduce the diversity of riparian vegetation and disrupt wetting and drying patterns crucial to the life history of many riparian species. Stable pools (such as those resulting from road crossings and weirs) tend to favour exotic plant species such as willows, resulting in reduced bank stability, increased erosion and channel widening.

Road crossings can also adversely affect terrestrial species. As with fish, land-based animals need to move between habitats to feed, breed, and to avoid predation and competition. Riverine corridors are used as natural byways for the movement of many land-based animals. Road crossings that are designed without terrestrial passage components may effectively isolate upstream and downstream riparian habitats. Crossings with raised and barricaded approaches prevent terrestrial species from following streams *over* the road surface. Low bridges and culverts without accessible vegetated banks or *dry cells* prevent land-based animals from moving *under* road crossings. Lack of riparian connectivity, including cleared easements adjacent to roadways at road crossings, can also deter animals from venturing across roads to follow waterways.

The following study primarily focuses on the impacts of road crossings on stream connectivity in the Southern Rivers region (see Sections 3 and 4). Other impacts (as listed above) were considered as part of the assessment process.

2.4 Waterways of the Southern Rivers region

The Southern Rivers Catchment Management Authority (CMA) region covers an area of approximately 2.9 million hectares. It is bounded in the west by the Great Dividing Range and in the east seaward to three nautical miles. The CMA area supports a population of half a million people (SRCMA, 2005).

The region extends from Stanwell Park north of Wollongong to the Victorian border in the south, and includes waterways of the Snowy River catchment within NSW. For reporting purposes four geographic zones (or subregions) have been identified to highlight catchment and sub-catchment issues and priorities. These include:

- Shoalhaven-Wollongong Subregion;
- Eurobodalla Subregion;
- Bega-Eden Subregion; and
- Snowy-Monaro Subregion.

Shoalhaven-Wollongong Subregion

The Shoalhaven-Wollongong subregion extends along the east coast from Stanwell Park in the north to North Durras in the south and comprises the catchments of Lake Illawarra, Minnamurra River, Shoalhaven River, Jervis Bay, Lake Conjola and Burrill Lake, as well as small coastal streams that discharge directly to the sea. This subregion has a total area of approximately 7,425sqkm.

The Shoalhaven-Wollongong subregion falls within the Batemans Marine Bioregion, and includes the Jervis Bay Marine Park. Established to conserve marine biological diversity and marine habitats, the Park covers 22,000 hectares and spans over 100km of coastline from Kinghorn Point in the north to Sussex Inlet in the south.

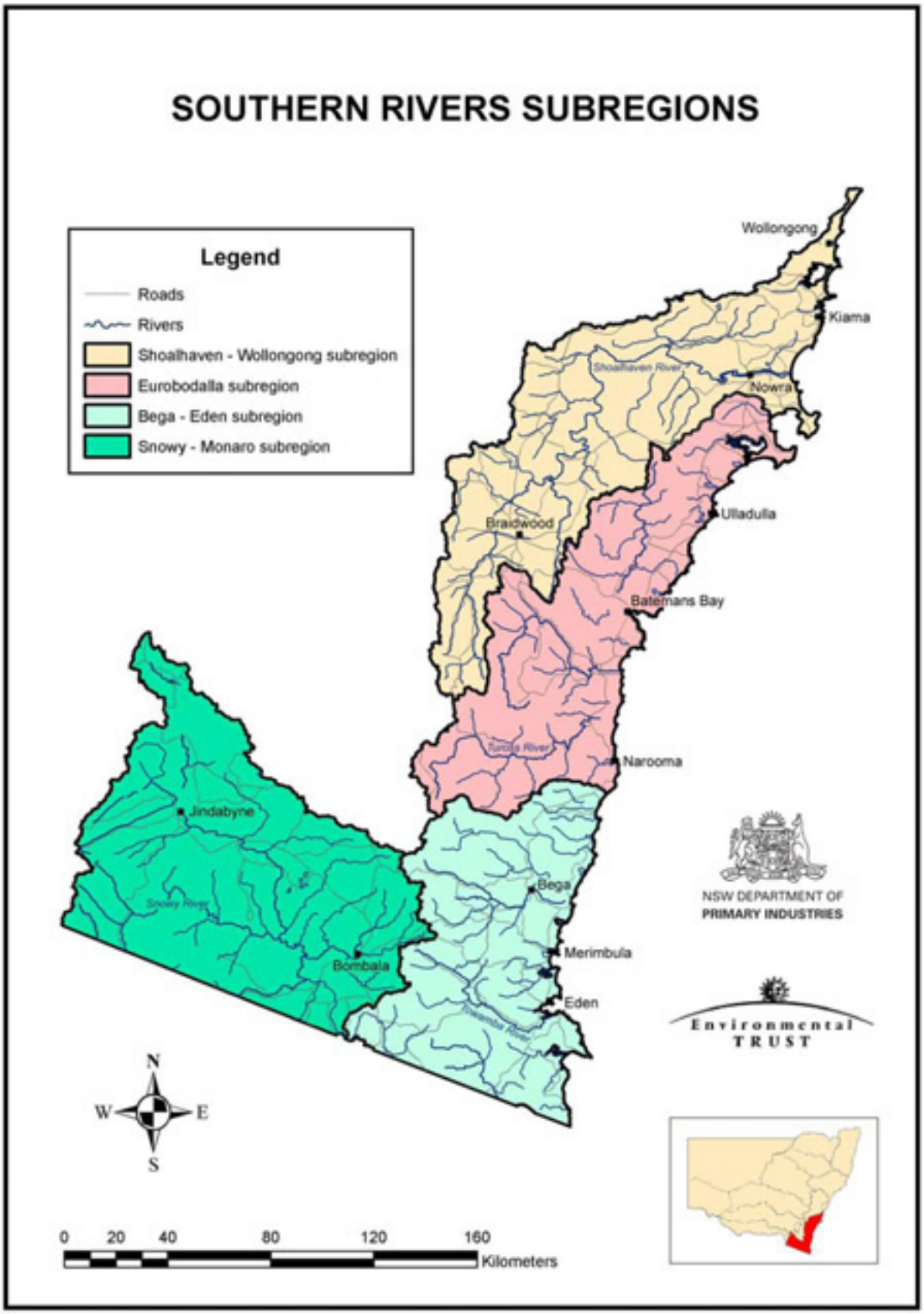
The subregion takes in seven local government areas (LGAs) including Wollongong City, Shellharbour City, Council of the Municipality of Kiama, Shoalhaven City, Wingecarribee Shire, Goulburn Mulwaree (formerly Greater Argyle) and Palerang (formerly Eastern Capital City).

The northern coastline is characterised by steep coastal waterways that drain the escarpment. Lake Illawarra catchment area is 270sqkm and is fed by Mullet Creek, Macquarie Rivulet and Duck Creek. The lake itself is shallow with extensive seagrass beds and supports a major commercial fish and prawn industry. The estuary is normally open but does close during prolonged drought. Minnamurra River to the south is a small coastal catchment entering the ocean just north of Kiama Harbour. The estuarine reaches support tidal wetlands with extensive mangrove stands.

The Shoalhaven River is the largest catchment in the SRCMA region covering an area of approximately 7,000sqkm. Major tributaries include the Kangaroo, Mongarlowe and Crookhaven Rivers. Tallowa Dam and reservoir located on the main stem of the Shoalhaven River is part of the Sydney Catchment Authority management area. Much of the upper reaches of the catchment fall within Morton National Park, whilst the lowland floodplain of the Shoalhaven supports a wide range of agricultural practices including a significant dairy industry.

Further south, the floodplain is characterised by coastal lakes fed by small freshwater streams. Many of these lakes are intermittently-closing and opening lakes and lagoons (ICOLLs) such as Lake Wollumboola, Swan Lake, Termeil Lake, Meroo Lake and Willinga Lake. Coastal lakes can support extensive seagrass meadows, diverse and abundant fish stocks and attract large numbers of migratory birds.

Previous reports have recorded up to approximately 150 weirs, dams or tidal barriers other than road crossings within this area (Thorncraft and Harris, 2000; NSW Fisheries, 2002b). This number is in all likelihood much larger however, due to the presence of other unlicensed structures on these waterways and road crossings that have not previously been identified. It is also likely that some of the tidal barriers will not form fish passage barriers, despite restricting tidal flow.



Map 1. Southern Rivers CMA subregions.

Eurobodalla Subregion

The Eurobodalla subregion extends from the southern shores of Jervis Bay in the north to Tilba Tilba in the south, and includes the waterways of the Clyde, Deua and Tuross Rivers, as well as many small coastal streams and lakes such as Durras Lake, Coila Lake and Wagonga Inlet. This subregion has a total area of approximately 7,060sqkm.

The Eurobodalla coast is also marked by many coastal lake systems, some of the larger catchments being Durras Lake, Lake Brou, Lake Mummuga, Corunna Lake and Coila Lake. Most of the lakes are fed by small freshwater floodplain streams, and have partially or intermittently open and closed entrances.

The subregion takes in the five Council areas of Shoalhaven City, Eurobodalla Shire, Palerang, Cooma-Monaro Shire and Bega Valley Shire LGAs. These include the major regional centres of Batemans Bay, Narooma and Moruya.

The Clyde River system is the largest catchment in the subregion covering an area of 2,900sqkm and includes the tributaries of the Buckenbowra River and Nelligen Creek. The headwaters and tributaries of the catchment are largely protected within National Parks and State Forests. Due to minimal catchment clearance and a lack of polluting industry or land practices, the catchment is considered one of the least-polluted large rivers in eastern Australia. The lower Clyde has important coastal wetlands and the estuary supports an extensive oyster industry.

The Deua-Moruya River to the south has a catchment area of 540sqkm, which is largely protected within the Deua National Park. The lower reaches are predominantly rural landuse with a small commercial fishing and oyster industry. To the south, Tuross Lake drains a catchment area of 2,150sqkm and includes the Tuross River, Yowrie River, Wadbilliga River and Wandella Creek tributaries.

Previous reports have recorded approximately 90 weirs, dams or tidal barriers other than road crossings within this area, although the number of instream barriers is likely to be much larger due to the presence of unlicensed structures and road crossings, which have not previously been identified (Thorncraft and Harris, 2000; NSW Fisheries, 2002b).

Bega-Eden Subregion

The Bega-Eden subregion extends from Wallaga Lake in the north to the Victorian border and is characterised by a steep escarpment with a narrow coastal plain. Landuse in the district includes dairy and beef cattle production, sheep grazing and forestry. The major river systems include the Murrah, Brogo, Bega, Towamba, Wallagaraugh and Genoa Rivers. This subregion has a total area of approximately 6,200sqkm.

As with the Eurobodalla subregion, the Bega-Eden coast has many coastal lake systems fed by small freshwater streams. These include intermittently opening lakes such as Wallaga Lake, Baragoot Lake, Cuttagee Lake, Wallagoot Lake and Curalo Lake.

The subregion incorporates the local government areas of Bega Valley Shire and Bombala LGAs. Major regional centres include Bega, Eden, Merimbula and Pambula townships.

The largest river system in the subregion is the Bega River catchment which covers an area of 2,800sqkm and includes the Bega River, Brogo River, Bemboka River and Tantawangalo Creek subcatchments. The Lower Bega is characterised by wide alluvial flats where dairy is the primary landuse. Several SEPP14 wetlands are located in the downstream reaches. The Bega estuary is closed to commercial fishing (recreational fishing haven) and provides nesting habitat for threatened shorebirds.

Further south, the major coastal embayment of Two-fold Bay is fed by the Towamba and Nullica River subcatchments. Other catchments in the area include the Pambula, Wonboyn, Merrica and Nadgee Rivers, which drain reasonably steep forest catchments within State Forest and National Park estate.

Nadgee River is largely protected in Nature Reserve lands. Nadgee Lake is considered to be one of the few remaining pristine lakes in NSW (DNR, 2005). To the west, the Genoa and

Wallagaraugh Rivers flow south through East Gippsland forests discharging into Mallacoota Inlet in Victoria.

Previous reports have recorded up to approximately 90 weirs, dams or tidal barriers other than road crossings within this area, although the number of instream barriers is in all likelihood much larger due to the presence of unlicensed structures and road crossings, which have not previously been identified (Thorncraft and Harris, 2000; NSW Fisheries, 2002b)

Snowy-Monaro Subregion

The Snowy-Monaro subregion is located in the south of the state and includes the NSW tributaries of the Snowy River catchment. The catchment headwaters flow from the Australian Capital Territory in the north, through the Australian Alps and from rivers running west off the South Coast Range. The Snowy River flows south to Victoria and discharges to Bass Strait south of Orbost. The major waterways in the catchment include the Bombala, Delegate, Maclaughlin, Eucumbene and Thredbo Rivers. This subregion has a total area of approximately 9,000sqkm.

The Snowy-Monaro is distinct from other areas in the Southern Rivers region in that the catchment includes extensive areas of alpine and sub-alpine environments. The catchment also incorporates the Snowy Mountains Hydro-electric Scheme. With a catchment area of 5,124sqkm, mostly within the Kosciuszko National Park, the Scheme diverts water from the Snowy River system into the Murray and Murrumbidgee River systems.

The other primary land use/industry types in the Snowy region include nature conservation (National Park estate), modified pasture grazing and plantation forestry along the eastern portion of the region.

The subregion incorporates the local government areas of Bombala, Snowy River Shire, and Cooma-Monaro Shire, and includes the townships of Bombala, Jindabyne and Thredbo.

Previous reports have recorded up to approximately 20 weirs, dams or tidal barriers other than road crossings within this area, although this number is in all likelihood much larger due to the presence of unlicensed structures and road crossings, which have not previously been identified (Thorncraft and Harris, 2000; NSW Fisheries, 2002b).

2.5 Aquatic biodiversity in the Southern Rivers region

The aquatic habitats of the Southern Rivers region comprise freshwater, estuarine and marine environments. From montane streams to lowland floodplain wetlands and coastal lagoons, the extensive range of aquatic habitats supports a diverse assemblage of aquatic species including approximately 47 finfish species that inhabit freshwater and/or estuarine systems for at least part of their lives (refer Appendix A). The region supports an array of aquatic invertebrates including insects, prawns, crayfish and freshwater mussels, with the southern distribution of the threatened Adams emerald dragonfly (*Archaeophya adamsi*) potentially occurring within coastal draining waterways south of Wollongong.

The aquatic threatened species Macquarie Perch[2] (*Macquaria australasica*) and Australian Grayling[3] (*Prototroctes maraena*) are found in the region. The Southern Rivers also includes key protected estuarine and marine species including the threatened Black cod (*Epinephelus daemelii*), Weedy seadragon (*Phyllopteryx taeniolatus*), and Estuary cod (*Epinephelus coioides*). It also potentially has remnant populations of the endangered estuary inhabiting Green sawfish (*Pristis zijsron*), although the most recent confirmed record for this species is in 1972.

Over 60 species of frogs are found in the region including several threatened species (i.e. Giant burrowing frog, Green and golden bell frog, Giant barred frog, Red-crowned toadlet, Corroboree frog and the Booroolong frog). Many reptiles are also found in wetlands within the region including skinks, snakes, water dragons and one freshwater turtle (the Eastern long-necked turtle - *Chelodina longicollis*). In addition, platypus (*Ornithorhynchus anatinus*) and water rats (*Hydromys chrysogaster*) - both mammals specialised for freshwater aquatic habitats - can be found in many creeks within the region.

[2] Listed as 'Vulnerable' under the NSW Fisheries Management Act, 1994 (FM Act)
[3] Listed as Endangered under the EPBC Act and protected under the FM Act

All these aquatic species are dependent on healthy streams and access to diverse habitats for their survival. Freshwater fish habitats in the Southern Rivers include swamps, floodplains, wetlands, streams and rivers. These broad habitat types provide niche habitats such as pools and riffles, gravel beds, boulders, snags, aquatic vegetation, riparian vegetation and riparian overhangs and undercuts. Birds and terrestrial-based animal species also rely on these habitats to support the food web within the broader ecosystem and also to provide fringe habitat.

Many freshwater and estuarine habitats are essential for conserving aquatic biodiversity and have been listed as Endangered Ecological Communities[4] (EECs) in recognition of their rarity, vulnerability and their importance as both aquatic and terrestrial habitat. These include river and floodplain communities in the Southern Rivers such as: Freshwater wetlands on coastal floodplains, Montane peatlands and swamps, Swamp oak floodplain forest, Swamp Sclerophyll forest on coastal floodplains and Coastal saltmarsh. In addition, Blue Lake in Kosciuszko National Park is listed as a Wetland of International Importance under the 1971 Ramsar Convention.

As with rivers and lakes, these wetland, saltmarsh and swamp communities are subject to pressures such as fragmentation, flood mitigation, draining and infilling and modification of freshwater and tidal flows due to artificial structures being erected. For example, the EEC freshwater wetlands on coastal floodplains have markedly reduced in size and distribution, with less than 2,700ha remaining from Sydney to Moruya (in the mid 1990s) and less than 1000ha in the Eden region in 1990 (DEC, 2005).

Aquatic habitat rehabilitation, in particular reinstating stream connectivity, is essential for maintaining aquatic biodiversity and protecting the integrity of rivers, lakes and wetlands in coastal NSW. This particular project was designed to identify locations where the greatest environmental gains could be made when undertaking such remediation works.

[4] Listed under the NSW *Threatened Species Conservation Act* 1995.

3. PROJECT METHODS

3.1 Previous investigations

The initial phase of the project involved the collection of data for inclusion in the *NSW Coastal Road Crossings Inventory* - a database of waterway crossing sites that have been identified as requiring remediation (from a fish passage and/or aquatic habitat perspective).

Fish passage and instream structure reviews have previously been undertaken in coastal NSW by Williams *et al.* (1996), Pethebridge *et al*. (1998), and Thorncraft and Harris (2000). The current project used the previous studies as baseline data and updated their findings within a road crossing perspective.

3.2 Desktop and field assessment

Fieldwork in this study included on-ground assessment of road crossings sites identified through the following desktop assessments:

a) Assessment of 1:25,000 topographic maps for the Southern Rivers region. Sites where roads traversed waterways of Stream Order 3 or greater were flagged for assessment;

b) LGA data provided additional sites for review. Councils were asked to provide information on known road crossing barriers and potential obstructions across the region, particularly sites identified for future maintenance/ remediation works; and

c) Road crossing obstructions and barriers identified in previous studies, including Williams *et al.* (1996), and Pethebridge *et al.* (1998) reports.

Over 1,700 sites were initially identified for assessment in the Southern Rivers region, although sites within marginal habitat (ephemeral streams, headwaters or upland swamps) were removed from this initial list.

Fieldwork in the Southern Rivers region was conducted from November 2004 to June 2005. An assessment sheet was developed prior to fieldwork commencing, ensuring consistency in data collection (Appendix B). This assessment sheet was converted into a digital format, allowing data to be collected and stored on a handheld PDA ("Personal Digital Assistant") device in the field. In the field road crossings were identified and mapped as data layers using GPS software. Information collected for each site was linked to the mapped point and stored in an underlying database. All information collected could then be retrieved or updated at a later date (in the field or office) by clicking on the mapped point, and accessing the underlying database. Locating sites was facilitated through the use of data layers indicating waterways, roads, and towns.

Data collected for each structure included: structure type and description, ancillary uses of the crossing (eg bed control); road type (sealed vs. unsealed); whether the structure was a barrier to fish passage, and if so what type; aquatic and riparian habitat condition; channel morphology (eg width and depth); and surrounding land use. Location information (eg section of the catchment), structural details (eg ownership, number of barriers downstream, available upstream habitat), and further environmental considerations (ranges of threatened and protected species and wildlife reserves – Marine Parks, SEPP wetlands) were also determined.

Location details (GPS readings or map grid references) were also recorded and digital photographs taken for each site. All data recorded in the road crossing audit was downloaded into the NSW Department of Primary Industries Fisheries (Conservation and Aquaculture) Fish Habitat Database prior to comparative analysis to determine regional remediation priorities.

3.3 Prioritising fish passage obstructions

A prioritisation scheme was developed to assist in ranking road crossing structures requiring remediation (Appendix C). The scheme was developed to determine regional priorities based on the following categories: a) habitat value, b) structure impact, c) environmental value, and d) modification criteria.

All data within the four criteria listed above (data listed in Appendix C) were weighted according to their relative value (e.g. sites with a Habitat Class 1 received a greater weighting than other sites where the Habitat Class was less; sites within protected areas such as Water Reserves or National Parks and State Forests, were seen to have a greater value than other land uses such as local reserves or farm land; and sites where the structure was obsolete received a greater weighting than sites where the structure is still in use).

Data within the Habitat Value Criteria and Structure Impact Criteria determine the quality and amount of habitat available to fish, how impacted the catchment is as a result of man made structures, and the actual impact the structure is having on fish movement. These criteria therefore directly indicate the effect the structure has on fish movement and the likelihood of the site being a site where fish passage is required. Environmental Value Criteria and Modification Criteria describe the local environment.

The overall prioritisation process therefore placed a greater emphasis on data within the Habitat Value and Structure Impact Criteria, with all data from these two criteria being weighted more than those from the Environmental Value and Modification criteria.

Final scores for each site were determined by summing all four criteria. The prioritisation process was applied to all road crossings within the Southern Rivers CMA region that were identified as fish passage obstructions and possessed a recommended remedial action.

Results are presented in Section 4 illustrating overall CMA results, and trends and priorities for subregions and LGAs.

Recommendations were made on how the structures could be modified to allow for effective fish passage, and are discussed in Sections 4.5 - 4.7. It is expected that data collected from this project, and the recommendations made within it, will guide local and state government agency expenditure and allow remediation works to be incorporated into future work programs.

LIMITATIONS TO RAPID ASSESSMENT TECHNIQUES

In this study, rapid assessment of road crossings provides a ‘snap shot’ view of environmental conditions at a site. Due to the sheer number of road crossings in the Southern Rivers region, detailed assessments of each structure could not feasibly be conducted.

For the purposes of informing future planning, the application of a rapid assessment technique (the fieldwork methodology and desktop prioritisation outlined above) was a simple and effective way of highlighting the extent of the problem and determining broad regional priorities.

It is understood however, that many environmental, social, cultural and economic considerations would need to be reviewed before undertaking any on-ground works recommended within this report. In particular, detailed environmental assessments and cost-benefit analyses would need to be conducted before on-ground works were pursued.

4. ASSESSMENT RESULTS

4.1 Overall project assessment results

Statewide, over 6,800 structures were visited in coastal draining waterways of NSW, with over 1,400 structures identified as barriers to fish passage. The most common type of road crossing barriers that were identified in this study in coastal draining waterways of NSW were causeways and pipe culverts, with box culverts and fords also commonly acting as barriers to fish passage.

4.2 Types of road crossing obstructions in the Southern Rivers region

A complete data set from this study is available in a separate file (*Road Crossings Inventory – Southern Rivers - CD database*) and includes data on road crossing location information, environmental data and recommended remediation action. The discussion below focuses on trends within the data and the top priority sites for remediation.

Approximately 1,673 sites were visited in the Southern Rivers region. Of these, a total of 578 road crossings were identified as obstructions to fish passage, with 374 structures recommended for remediation (refer Appendix F – Map 2).

Several types of road crossings were assessed in the study including fords, causeways, pipe culverts, box culverts and bridges. Several sites identified had combination designs – for example, box culverts placed on top of causeways. Within the Southern Rivers region, the most common road crossing barriers identified were causeways and pipe culverts (both 34% of all structures identified), with box culverts and fords being the next most common barrier types (16% and 12% of all barriers respectively) – refer Figure 1.

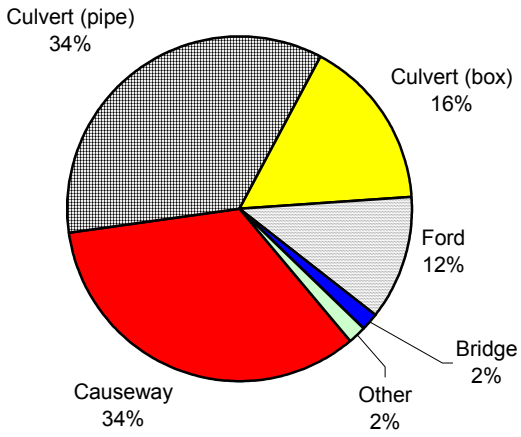


Figure 1. Structure types identified as fish passage barriers in the Southern Rivers region.

Of the structures with recommended remediation actions, 43% of sites were causeways (164 sites), 29% were pipe culverts (107 sites), 13% were fords (47 sites), and 12% were box culverts (45 sites). These figures reflect the severity of each of the structure types on fish passage, and the frequency of use of these structures within the Southern Rivers region.

Causeways, pipe culverts, and fords are all cheaper alternatives to other structures such as box culverts and bridges, and are therefore more likely to be employed as road crossings – especially on smaller waterways. Causeways and pipe culverts are also more likely to act as fish passage barriers than other structure types due to the formation of sheet flow across causeways (lack of flow depth); the presence of high, linear, water velocities through pipes; and the creation of a waterfall effect on the downstream side of a causeway and a pipe culvert if the pipe is set incorrectly (above bed level). It is for these reasons that a greater number of causeways and pipe culverts were identified as fish passage barriers than other structures within the Southern Rivers.

4.3 Summary of road crossing results by subregion

In this study, many road crossings were identified as an obstruction to fish passage but not recommended for remediation due to reasons such as the site being located in *minimal fish habitat* (naturally marginal habitat rarely utilised by fish such as ephemeral waterways – Class 4 fish habitat), or that the site was located in a heavily degraded or highly modified waterway where other factors play a larger role in dictating river health (e.g. concrete stormwater channels and piped waterways with little or no habitat value).

Table 1 outlines the number of road crossing obstructions identified and recommended for remediation in each of the four subregions.

Table 1. Action summary – waterway crossing obstructions & remediation recommendations

	Shoalhaven - Wollongong subregion		*Eurobodalla subregion*		*Bega-Eden subregion*		*Snowy-Monaro subregion*		*TOTAL*	
Fish Passage Obstructions	Tot+	RR*	Tot+	RR*	Tot+	RR*	Tot+	RR*	Tot	RR*
Causeway	88	71	47	39	21	18	40	36	195	164
Ford	5	2	17	10	8	5	38	30	68	47
Culvert (box)	36	18	18	7	5	4	34	16	93	45
Culvert (pipe)	27	14	36	21	16	8	123	64	202	107
Bridge	6	4	0	0	2	2	1	0	9	6
Combination structure/other	0	0	0	0	1	0	9	3	10	3
TOTAL	**162**	**109**	**118**	**77**	**53**	**37**	**245**	**149**	**578**	**372**

+ Total number of road crossings identified as a potential fish passage obstruction.
* Number of structures recommended for future remediation.

As can be seen in Table 1 and Figure 2, the number of barriers identified and recommended for remediation closely reflected the size of the subregion. The Snowy-Monaro subregion is the largest of the four subregions within the Southern Rivers and possessed the greatest number of obstructions identified and recommended for remedial action. This was followed by the other subregions in the following order: Shoalhaven-Wollongong, Eurobodalla, and Bega-Eden.

Within the Snowy-Monaro subregion, the greatest number of obstructions recommended for remedial action were causeways and pipe culverts (100 sites), following a similar trend to the LGA breakdown in Section 4.4 (the Snowy-Monaro subregion comprises the Snowy River Shire, Bombala, and Cooma-Monaro Shire LGAs, with Bombala LGA driving the number of structures within this subregion). This subregion is in the upper catchment of the Snowy River system, and is also characterised by a greater number of smaller waterways and rivers, leading to a greater likelihood of road crossings.

The Shoalhaven-Wollongong subregion is the second largest in the Southern Rivers and, due to its proximity to the major regional centres of Wollongong, Shellharbour and Nowra, is also the most populated. The greater population within this subregion determines that a greater amount of road infrastructure is required for access throughout the region, leading to a greater number of road crossings across waterways. Within this subregion, causeways were the most common form of fish passage barrier recommended for remedial action (71 sites), followed by box and pipe culverts (18 and 14 sites respectively).

In the Snowy-Monaro subregion and the Shoalhaven-Wollongong subregion, only approximately one third and one quarter of their area respectively is devoted to National Parks, State Forests, and Sydney Catchment Authority Water Reserve. This is in contrast to both the Eurobodalla and Bega-Eden subregions, where National Park and State Forest Reserves cover the majority of their area. As a result, the latter two subregions had the lowest number of crossings that formed fish passage barriers recommended for remediation, due to the lesser number of access tracks within these reserves, and the use of timber bridges or fords where crossings are required (particularly the case within State Forest Reserves).

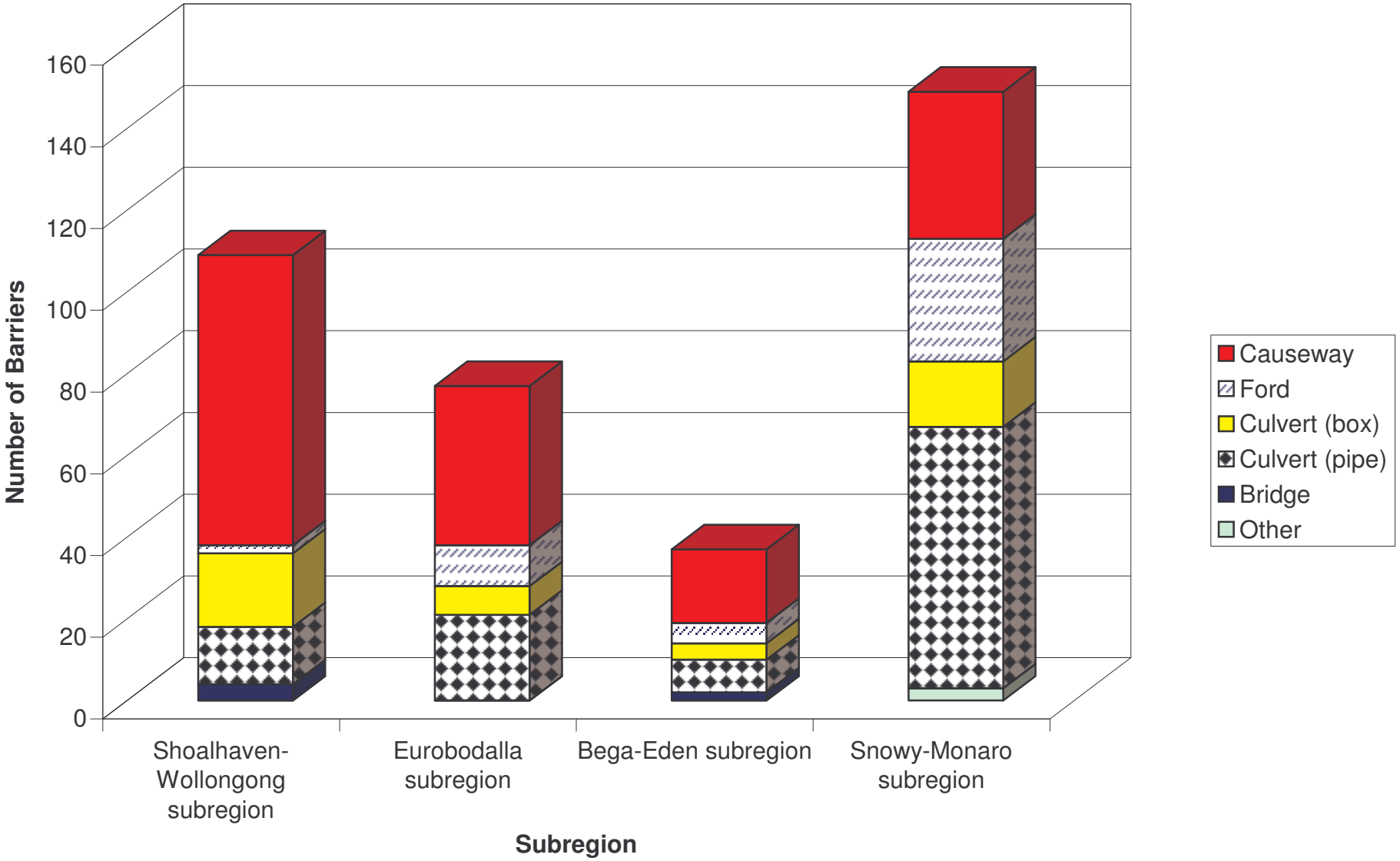


Figure 2. Fish passage obstructions with recommended remedial actions in the Southern Rivers subregions.

A greater number of crossings were identified as fish passage barriers within the Eurobodalla subregion compared to the Bega-Eden subregion, most likely as a direct result of the greater population of this region, and the greater length of coastline and number of coastal draining waterways. Approximately half the coastline within the Bega-Eden subregion is under reserve, with only a small amount of road infrastructure associated with them, resulting in extremely low levels of access. In the Eurobodalla subregion, a large majority of the reserves are higher in the catchment, with a number of small towns being dotted along the coast where public access is generally present throughout.

With the exception of the Snowy-Monaro subregion, causeways were the most numerous crossing type recommended for remediation in all subregions (causeways were the second most common crossing type within the Snowy-Monaro subregion, behind pipe culverts). Pipe culverts, box culverts and fords were the next most common fish passage obstructions identified and recommended for remedial action in all other subregions.

4.4 Summary of road crossing results by LGA

This project assessed approximately 1,673 road crossings sites across the 12 LGAs that comprise the Southern Rivers CMA region (nearly 30,000sqkm), with 578 identified as obstructions to fish passage. Many of these structures (204 sites) were deemed to have a negligible impact on fish movement, leaving 374 structures identified as requiring some form of remedial action.

Table 2 outlines the percentage area of each LGA within the Southern Rivers CMA region, the number of sites identified as obstructions in each, and the number of sites recommended for remediation.

Table 2. Waterway crossing assessments by local government area, Southern Rivers CMA

Local Government Authority (LGA)	LGA area within CMA (sqkm)	LGA area as % of Study Area	Total # of sites identified as fish passage obstructions	Total # recommended for remediation
Bega Valley Shire	6,277	21.11	62	41
Bombala	3,958	13.31	122	99
Cooma-Monaro Shire	779	2.62	8	5
Eurobodalla Shire	3,428	11.53	80	50
Goulburn Mulwaree Shire (formerly Greater Argyle)	1,418	4.77	12	8
Council of the Municipality of Kiama	257	0.86	16	10
Palerang (formerly Eastern Capital City)	3,318	11.16	62	46
Shellharbour City	154	0.52	6	6
Shoalhaven City	4,559	15.33	68	50
Snowy River Shire	4,850	16.31	119	48
Wingecarribee Shire	442	1.49	2	1
Wollongong City	296	0.99	21	8
TOTAL	29,736	100	578	372

The greatest number of obstructions to fish passage were identified within the Bombala (122 sites) and Snowy River Shire (119 sites) local government areas. Snowy River Shire LGA is the second largest local government area within the Southern Rivers CMA region (4,850sqkm – 16.31%), whilst Bombala LGA is the fourth largest (3,958sqkm – 13.31% of the total area). The number of barriers identified within these LGAs therefore partly reflects the size of each LGA, but is also likely to reflect the nature of the catchments within these LGAs. Both Bombala and Snowy River Shire LGAs form part of the Snowy-Monaro subregion (upper reaches of the Snowy River catchment), where a large number of small waterways (stream order of 3 or less) are present. In these smaller waterways, causeways and pipe culverts are cheaper to construct, therefore being more commonplace, and (as discussed earlier) are more likely to form fish passage barriers than other structure types, resulting in a greater number of problem sites being identified.

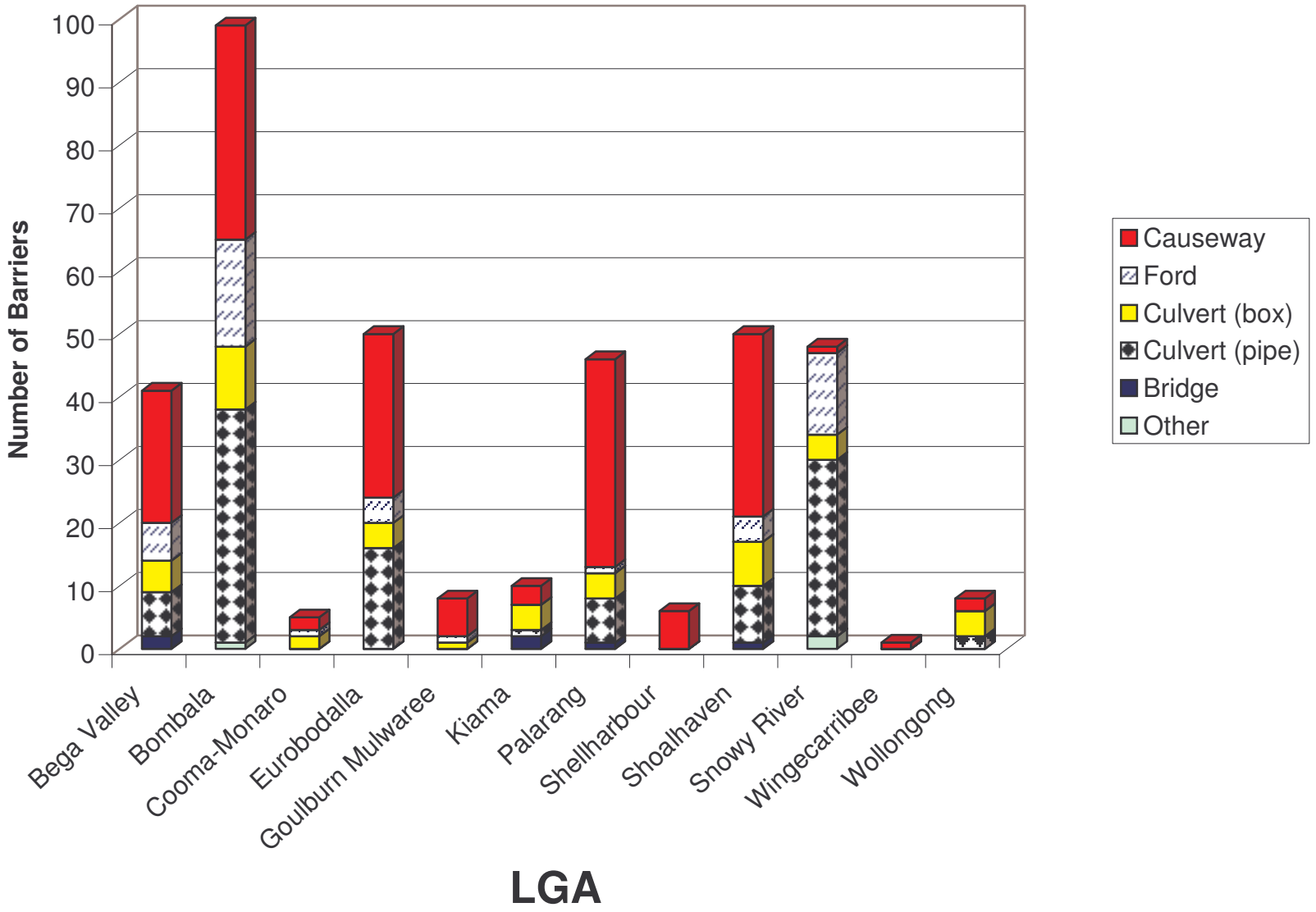


Figure 3. Actioned structure types identified as fish passage barriers in the Southern Rivers region by Local Government Authority.

As shown in Figure 3, the greatest number of sites recommended for remedial action were also within the Bombala LGA (99 sites), with the second and third greatest number of fish passage obstructions recommended for remedial action being within the Shoalhaven City and Eurobodalla Shires (50 sites each) LGAs. The latter LGAs are the third and fifth largest by area within the Southern Rivers CMA region (4,559sqkm – 15.33% for Shoalhaven City, and 3,428sqkm - 11.53% for Eurobodalla Shire), thus partly accounting for the larger number of sites. The Snowy River Shire LGA possessed the fourth largest number of sites recommended for action (48 sites), despite having the second largest number of sites identified as fish passage barriers. This is possibly due to many of the barriers within this LGA being high in the catchment, and therefore less likely to benefit greatly from remediation compared to sites further downstream in the catchment.

The lowest number of sites identified as fish passage barriers (2) and recommended for remediation action (1) were within the Wingecarribee Shire LGA, which comprises only 442sqkm (1.49%) of the Southern Rivers CMA area. However in the smallest LGA in the Southern Rivers CMA (Shellharbour City: 154sqkm or 0.52% of the CMA), 6 sites were identified as fish passage obstructions, all of which were recommended for remedial action. This is likely to be due to this LGA being located on the coast within a reasonably heavily populated area (combined with greater road infrastructure).

A range of remediation options have been suggested for fish passage barrier sites including:

- Basic management/maintenance of sites (e.g. removal of sediment and debris blocking inlets);
- Modification of structures (e.g. retrofitting low-flow channels, installing fishways);
- Complete replacement of structures (e.g. causeways replaced with bridges or culverts);
- Permanent removal of redundant (disused) structures.

4.5 Southern Rivers road crossing remediation priorities by subregion

Setting goals and targets for aquatic habitat rehabilitation in the Southern Rivers CMA region requires a clear understanding of the extent of aquatic habitat degradation and where we can achieve the best outcomes. The method of prioritising roads crossings (outlined in Appendix C) is an adapted model to cater for specific aquatic habitat and biodiversity features found in the rivers and creeks of the Southern Rivers.

This section of the report presents the major findings of this study on a subregion and local government basis, highlighting regional priorities for fish passage remediation.

All 367 instream structures that were recommended for remediation were determined as either ‘high’, ‘medium’ or ‘low’ priority sites according to an objective prioritisation process (refer to Appendix F: Maps 3-6). This process resulted in 55 sites being determined as high priority and 49 sites as medium priority: all other sites were regarded as having lesser importance with regard to fish passage in the Southern Rivers region. Sites that were regarded as a lesser priority should still be considered for remediation, although the urgency for remediation is not as great. These sites should be included on the owner’s maintenance schedules and remediated when possible.

Table 3. High and medium priority sites – Southern Rivers subregions

Subregion	High Priority	Medium Priority
Shoalhaven-Wollongong	18	18
Eurobodalla	22	13
Bega-Eden	6	14
Snowy-Monaro	9	5
TOTAL	**55**	**49**

As shown in Table 3, the majority of high priority sites were found in the Eurobodalla and Shoalhaven-Wollongong subregions, followed by the Snowy-Monaro and Bega-Eden subregions. Medium priority sites were generally spread throughout all subregions, with the exception of the Snowy-Monaro subregion, which contained only 5 medium priority sites.

Of the high priority sites, nearly half (46%) were located in the lower part of the catchment, close to (or within) the vicinity of tidal influence. Remaining sites were divided nearly equally between the middle and upper catchments.

A general aquatic habitat management principle is to initially address obstructions to fish passage lower in a catchment before addressing those higher in a catchment. The premise behind this principle is two-fold: barriers in the lower catchment are likely to affect catadromous and anadromous[5] species more than those higher in the catchment, and that waterways are larger closer to their estuary, allowing a greater amount of critical habitat to be made available following remediation of a structure in this section.

Nearly half (44%) of the high priority sites identified in this study were located where rare or threatened species are known to occur, or were within their range. For the Southern Rivers, these species comprise Macquarie Perch (*Macquaria australasica*), and Australian grayling (*Prototroctes maraena*), both of which migrate as part of their life cycle – grayling is amphidromous (juveniles return upstream to freshwater habitats after being swept downstream as larvae); Macquarie perch is potamodromous[6]. One reason for the decline of the Australian grayling is thought to be the presence of instream barriers which can effectively stop upstream movement of juveniles - hence the greater need to remediate instream barriers such as roads and weirs that occur within its range.

The known distribution for both Australian grayling and Macquarie perch occurs in habitat with an intact riparian and aquatic zone, and natural flow regime. Both the Eurobodalla subregion and the Shoalhaven catchment have large areas of protected habitat, either as a Water Reserve (Shoalhaven), National Park or State Forest (Eurobodalla subregion) providing good – excellent aquatic and riparian habitat and leading to a greater likelihood of occurrence of these species.

In addition, within the Shoalhaven catchment below Tallowa Dam, the current water regime is relatively natural due to the “transparent” method of water collection in this catchment. The current natural water regime, both within the Shoalhaven catchment and within most waterways of the Eurobodalla subregion, encourages good growth of riparian and aquatic vegetation, creating good fish habitat. This is reflected in the findings of this study, with all but five high priority sites possessing good – excellent aquatic and riparian zones (aquatic and riparian zone condition was fair for all other sites).

Throughout the Southern Rivers region, most high priority structures (62%) were found outside of protected areas and on rural land or other landuse. Of the remaining high priority sites, 25% were within State Forest, National Park, or Water Reserve, whilst 12.5% were located in a regional reserve or some form of local bushland. This indicates that the vast majority of high priority structures are present on property managed by local Council or private landholders, whilst one quarter of all high priority fish passage obstructions are located in State owned land.

4.6 Southern Rivers road crossing remediation priorities by LGA

When viewing the spread of high and medium priority sites by LGA (Table 4), it can be seen that the greatest number of high priority sites were located in the Shoalhaven City, and Eurobodalla Shire LGAs (15 and 14 sites respectively), followed by Bombala (8 sites), Bega Valley Shire (7 sites) and Palerang Councils (6 sites).

Shoalhaven City LGA encompasses the lower end of the Shoalhaven River system, whilst Eurobodalla Shire LGA completely encompasses the Clyde, Deua, and Tuross River systems. As mentioned above, higher priority sites were generally located in the lower end of river systems where barriers are likely to have a greater impact on migratory fish.

[5] *Catadromous* - fish that spend most of their life in fresh water and migrate to more saline waters to breed (estuaries/ocean); *Anadromous* – fish that spend most of their life in the sea and migrate to fresh water to breed. Juveniles of catadromous species are more likely to be affected by fish passage obstructions lower in the catchment as they are poorer swimmers, and must negotiate barriers whilst migrating against the direction of flow.

[6] *Amphidromous* - fish that migrate between the sea and fresh water, but not for the purpose of breeding. *Potamodromous* - fish that migrate wholly within fresh water.

Within the Southern Rivers region, the greatest number of medium priority sites were located in Bega Valley Shire and Shoalhaven City LGAs (18 sites and 10 sites respectively). As with Eurobodalla Shire LGA, Bega Valley Shire LGA has a large number of waterways, although unlike Eurobodalla Shire, where sites were spread over a number of waterways, 8 of the 18 medium priority sites were located in the mid reaches of the Towamba River.

Table 4. High and medium priority sites – Southern Rivers region local government areas

Local Government Authority (LGA)	High Priority	Medium Priority
Bega Valley Shire	7	15
Bombala	9	3
Cooma-Monaro Shire	2	0
Eurobodalla Shire	14	12
Council of the Municipality of Kiama	2	0
Goulburn Mulwaree Shire	0	1
Palerang	6	4
Shellharbour City	1	2
Shoalhaven City	14	10
Snowy River Shire	0	1
Wingecarribee Shire	0	1
TOTAL	**55**	**49**

No high or medium sites were recorded for Wollongong City Council LGA, although a major barrier to fish passage visited as part of this project was removed through a collaborative project between WWF Australia, NSW DPI Fisheries (Conservation and Aquaculture), and TXU Tallawarra (WWF Australia and NSW DPI, 2005) – see end Section 4.7.

Appendix D (Table 10) lists the all high priority sites for the Southern Rivers region.

4.7 Southern Rivers remediation options and top priority sites

Table 5 indicates the top 20 high priority sites within the Southern Rivers region, and associated recommended management actions.

Within the Southern Rivers region, the majority of high and medium priority structures were found to be causeways (46 high priority, 29 medium priority structures), whilst pipe culverts, fords and box culverts, and a single bridge structure comprised the remaining priority structure types.

Causeways and pipe culverts are more likely to cause fish passage obstructions due to the creation of headloss, flow depth, and velocity issues across the structure. Flow depth is likely only to be a problem for causeway structures where water moves across the surface of the structure. A headloss barrier can occur for both structure types due to the lack of low flow sections or cells within the structure, or the formation of scour pools on the downstream side of the structure. Velocity barriers can occur within pipe culverts where long distances of moderate-high velocity water passes through the structure, requiring fish to expend a large amount of energy when attempting to move against the stream flow.

Of the high priority sites identified within this study, four sites were determined to be obsolete structures, with two sites being fish passage obstructions due to the presence of debris (sediment build up, or plant material including large woody debris). These six sites could therefore be remediated relatively easily and cost effectively within a short time frame.

Obsolete structures are potentially remediated more easily than structures that are still required, as they can simply be removed – often for minimal cost. Prior to removal of a structure consultation with adjacent and upstream landholders is required to determine if the structure is serving an ancillary purpose, such as creating a freshwater environment upstream of the site in an area that would have previously been saline. It is possible that the freshwater pool is being used by adjacent landholders to provide water for irrigation, stock, or domestic purposes, and that removal of the structure will affect their ability to access a freshwater source. In this case, the provision of off-stream water storages, and watering points, in addition to riparian stock fencing may also be required, and will contribute to the overall project costs.

As part of the "demonstration site" component of this project, one obsolete structure has been removed (a redundant causeway on South Creek, Hawkesbury-Nepean CMA region), with a second (a redundant causeway on the Wallamba River, Hunter/Central Rivers CMA region) being investigated for removal. Further details on demonstration sites can be found in a companion report ("*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*").

The ease of remediating obsolete structures contrasts with eight high priority structures identified that require more major works (and thus a significant financial contribution) to provide for fish passage. Such recommendations include the installation of a fishway, construction of a bridge, installation of box culverts with low flow cells, and increasing the number of cells on structures of greater than 10m wide.

More than half of the high priority structures within the Southern Rivers require replacement of or complete removal of smaller structures (<10m wide). Generally works recommended for these structures include the installation of box culverts with low flow cells, increasing the number of cells, and lowering the invert of the existing structure.

Table 5. Top 20 priority sites – Southern Rivers region

Rank	*Crossing ID*	*Waterway/ Subcatchment*	*Structure Type*	*Road Name*	*Recommendation*
1	BEGA058	Tantawangalo Creek	Causeway	Kameruka Estate Road	Modify one cell to allow for majority of flow to pass through (left bank cell)
2	CLYD032	Nelligen Creek	Causeway	The River Road	Increase size, number & lower setting of cells to improve water flow
3	CLYD020	Clyde River	Causeway	The River Road	Bridge / raised section
4	GIPP015	Merrica River	Causeway	Merrica River fire trail	Partial removal or install a box culvert partway along the structure (3 sided culvert)
5	SHAO001	Broughton Creek	Causeway	Private drive off Princes Hwy	Box culvert with low flow cell / fishway / bridge
6	CLYD036	Currowan Creek	Causeway	The Western Distributor	Fishway / bridge / box culvert
7[#]	MORU019	Deua River	Causeway	Private drive off Araluen Road	Bridge / improve culvert size and remove levee
8	CLYD033	Currowan Creek	Causeway	The River Road	Large culvert / bridge / fishway
9	CLYD044	Buckenbowra River	Causeway	Hanns Road	Box culverts / fishway / bridge
10	SHOA097	Shoalhaven River	Causeway	Stewarts Crossing Road	Low flow channel / improve grade to top of causeway (downstream invert)
11	CLYD040	Buckenbowra River	Causeway	Quart Pot Road	Box culverts with low flow cells / bridge
12	SHOA008	Broughton Mill Creek	Causeway	Unused road on property 'Oakleigh'	Remove - clear debris
13	SNOW095	Corrawong Creek	Causeway	Settlers Road	Box culvert with low flow cells
14	CLYD029	Sheepstation Creek	Culvert – Pipe	Kings Highway	Lower invert
15	TURO050	Wadbilliga River	Causeway	Wadbilliga Road	Box culvert with low flow cells
16	CLYD010	Berrara Creek	Ford	Blackbutt Road	Box culvert
17	BEGA046	Pambula River	Causeway	Private unnamed road off Mount Darrugh Rd	Box culvert
18	CLYD043	Quart Pot Creek	Causeway	Hanns Road	Box culvert with low flow cell / bridge / fishway
19	GIPP014	Long Swamp Creek	Causeway	Scrubby Creek Road	Timber bridge
20	MORU025	Telowar Creek	Causeway	Neringla Road	Additional culverts / bridge

[#] This site has now been remediated.

It should be noted that the seventh highest priority site identified through this project in the Southern Rivers CMA region (MOR019) was noted to be an illegal structure, as a consequence the owner has been prosecuted for breaches to the *Fisheries Management Act 1994*, and the structure has now been removed.

A second site inspected as part of this project (a redundant road crossing on Duck Creek in the Shoalhaven/Wollongong subregion) was removed prior to the prioritisation process being undertaken (removal complete in January 2005). This structure was the most downstream barrier on Duck Creek, and its removal opened up an additional 5km of habitat to fish passage in the region.

Removal of structure occurred as a result of an Environmental Trust funded project jointly undertaken between World Wildlife Fund Australia and NSW DPI Fisheries (Conservation and Aquaculture), in collaboration with TXU Tallawarra (WWF Australia and NSW DPI, 2005).

Of the high priority sites listed above, several have a recommendation of "[multiple] box culvert[s] with low flow cell[s]". This remediation option aims to improve the cross-sectional area of a structure, so as to minimise high water velocities that occur when water is funnelled into cells that are too small. In addition, the provision of low flow cells enable fish to traverse the structure under low flow conditions. A low flow cell is set into the bed of the waterway, so that during low flow conditions this cell is the only one that is inundated. During low flow conditions, water is directed through this cell, with additional cells becoming operable as water levels rise. Surrounding substrate remains in the base of the cell, further minimising the impact of the structure on fish movement by minimising behavioural reluctance to traverse the structure.

In the Hunter/Central Rivers CMA region, "Dixons Crossing" on the Karuah River was remediated as part of the demonstration site component of this project in collaboration with the Roads and Transport Authority (RTA), and Great Lakes Council. Dixons Crossing was a low level causeway identified as a fish passage barrier due to excessive headloss and water velocity (through a single pipe culvert) – refer Figure 4a. The structure was remediated through the installation of multiple box culverts with three centrally located low flow cells (Figure 4b).

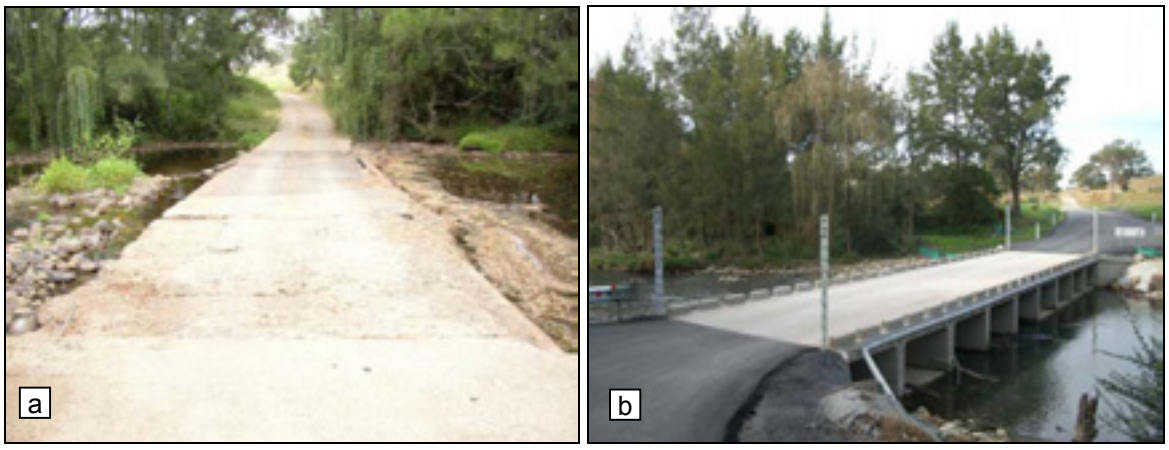


Figure 4. Dixons Crossing causeway (Karuah River) prior to (a), and following (b) remediation – note three central low flow cells.

In the Southern Rivers CMA region, the 11th highest priority site – Quart Pot Road causeway, Buckenbowra River – is also being remediated through the installation of box culverts and low flow cells as part of the demonstration site component of this project. Further information regarding remediation of demonstration sites can be found in a companion report ("*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*").

Figure 5. Faulkland Road Crossing modified partial width rock ramp fishway (a) during construction, (b) completed work.

Alternative technologies can also be employed to provide fish passage where traditional methods are unfeasible (e.g. due to funding restrictions). Several causeway crossings on the Gloucester River (Hunter/Central Rivers CMA region) have been remediated by Gloucester Shire Council through the construction of modified partial width rock ramp fishways adjacent the crossings (Figure 5 and Appendix E). These modified fishways run along the downstream edge of the causeway and have their upstream exit at a low flow point on the causeway structure itself (low flow depression in the causeway capping). This means that fish must still negotiate a shallower section of water across the top of the causeway.

A causeway on Bucketts Road, Gloucester River, is being remediated as part of the demonstration site component of this project, with further information on this project being found in a separate report ("*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*").

Other technologies that can provide fish passage at a potentially lesser cost include installation of "Doolan Decks" (prefabricated modular concrete and wood strut based bridges), and Super Cor® Box (high weight bearing wide corrugated iron cells) (Richmond Valley Council, 2006; Big R Manufacturing, 2004). Further information on these alternatives is available from NSW DPI Fisheries (Conservation and Aquaculture).

4.8 Southern Rivers sediment input sites

During this study, several sites were identified as both fish passage barriers, and as sediment input sites. In addition, five sites were identified as sites that were contributing to the sediment loading of a waterway, without forming a fish passage barrier. Of these, three were within protected areas such as National Park or State Forest, whilst the remaining two were in unprotected areas (such as farming land). It is recommended that these sediment input sites be investigated and remediated as part of regular maintenance works to minimise loss of fish habitat through the smothering of aquatic vegetation, riffles and deeper pools within a waterway. Sediment input sites can be remediated effectively through sealing of road approaches, installation of drainage diversion works, and construction of sediment control basins to limit or stop sediment input into a waterway.

As part of the demonstration site component of this project, part of Wapengo Lake Road (Wapengo Lake catchment) is being sealed, drainage diversion works installed, and sediment control basins constructed to limit sediment input into the adjacent waterway and Lake Wapengo. A second sediment input site in the Hawkesbury-Nepean CMA (Goodmans Ford, Wollondilly River) has also been remediated as part of the demonstration site component of the project. Further details on these projects can be found in a companion report: "*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*".

Prior to undertaking rehabilitation projects, including remediation of fish passage obstructions, there are several steps that should be followed to determine the viability of the project, including setting of objectives, feasibility of the project, formulation of designs, and methods of evaluation. These steps are discussed in Section 5.

5. STEPS IN STREAM REHABILITATION PROJECTS

This study provides baseline data for the rehabilitation of stream connectivity in the Southern Rivers NSW. The following summary illustrates how this report can inform and lead to on-ground stream rehabilitation works. For this purpose, a *12 Step Stream Rehabilitation Process*, taken from the Manual for Rehabilitating Australian Streams (Rutherfurd *et al.*, 2001), has been adopted here to outline the main stages of undertaking on-ground fish passage projects.

The Rutherfurd stream rehabilitation process includes the following steps:	
1. Visions and goals	7. Setting measurable objectives
2. Gain support	8. Feasibility
3. Assess stream condition	9. Detailed design
4. Identify problems and assets	10. Evaluation
5. Priorities	11. Implementation
6. Strategies	12. Maintenance and evaluation

Steps 1 – 5 Visions and goals, gaining support, assessing stream condition, identify problems and assets, priorities:

This report has provided information to successfully complete steps 1 to 5 in the process of rehabilitating fish passage barriers by achieving the following:

- Establishment of a vision for reinstating stream connectivity and improving fish passage in coastal waterways of NSW;
- Providing a source document for stakeholders outlining major findings and providing management recommendations for regional groups and local government; Promotion of the report findings will offer an opportunity to gain broad regional and local support for future initiatives;
- Identifying specific road crossings that are obstructions to fish passage across the Southern Rivers region;
- Establishing and implementing a method of prioritising fish passage obstructions at the regional and subregion/catchment scale.

Steps 6 to 12 in the stream rehabilitation process need to be undertaken by relevant stakeholders (private landholders, Councils, state government and the CMA) with the aim of achieving on-ground outcomes. The following is a summary of how those steps can be achieved for road crossing remediation in coastal NSW.

Step 6 – 8 Strategies, setting measurable objectives, and feasibility:

Strategies for rehabilitation, in this instance options for remediating road crossings, need to be set out within an overall rehabilitation plan that involves outlining specific project objectives. In this investigation, rapid assessments were conducted for waterway crossings to provide a 'snap shot' view of environmental conditions at a site. Due to the sheer number of structures in the Southern Rivers region, detailed assessments of each structure were not feasible. For the purposes of informing future planning, the application of a rapid assessment technique (the fieldwork methodology and desktop prioritisation outlined above) was a simple and effective way of highlighting the extent of the problem and determining broad regional priorities. It is understood however, that many environmental, social, cultural and economic considerations need to be reviewed before undertaking on-ground works recommended within this report. Additional pertinent considerations include:

- Location of other instream structures (e.g. weirs and dams) and natural barriers within the waterway that were overlooked during the initial assessment;
- Existence of sensitive habitats in the vicinity of proposed works;
- Impact of structure removal/modification on channel bed and bank stability;
- Presence of Acid Sulfate Soils;
- Impacts of mobilising sediment stored behind the crossing;

- Impacts on water quality (e.g. from contaminated sediments) and water chemistry (e.g. at tidal barriers) upon upstream and downstream habitats;
- Additional uses for the structure (e.g. pumping pool, bed-control structure, floodgate);
- Benefactors and stakeholders – identifying support and opposition; and
- Estimated costs of various remediation options.

The above factors must be considered well before detailed designs for remediating a fish passage barrier should be considered.

Step 9 – Detailed design:

Design guidelines in relation to undertaking 'fish friendly' road crossing projects can be found in:

- *Why do fish need to cross the road? Fish passage requirements for waterway crossings.* (Fairfull & Witheridge, 2003); and
- *Fish passage requirements for waterway crossings – Engineering Guidelines*. (Witheridge, 2002).

Fairfull and Witheridge (2003) provides a comprehensive overview of the best way to plan, design and construct waterway crossings to minimise impacts on fish passage and aquatic habitats. NSW DPI Fisheries requires that these national guidelines be followed by anyone intending to design and construct a waterway crossing in NSW. For engineers, Witheridge (2002) also provides a comprehensive and useful engineering guide to the design and construction of 'fish and fauna friendly' waterway crossings. Both documents were developed with the input of a national steering committee of experts in the field of road design, construction and fish passage.

Table 6 is adapted from Fairfull and Witheridge (2003) and provides a summary of preferred waterway crossing designs depending on waterway CLASS (see Appendix C - Table 8 for characteristics of different waterway classes).

Table 6. NSW DPI-preferred waterway crossing type in relation to waterway class

Waterway Classification	Minimum Recommended Crossing Type	Additional Design Information
CLASS 1 Major fish habitat	Bridge, arch structure or tunnel	Bridges are preferred to arch structures.
CLASS 2 Moderate fish habitat	Bridge, arch structure, culvert [1] or ford	Bridges are preferred to arch structures, culverts and fords (in that order). [1] High priority given to the 'High Flow Design' procedures presented for the design of these culverts—refer to Design Considerations section of Fairfull and Witheridge (2003).
CLASS 3 Minimal fish habitat	Culvert [2] or ford	[2] Minimum culvert design using the 'Low Flow Design' procedures; however, 'High Flow Design' and 'Medium Flow Design' should be given priority where affordable.
CLASS 4 Unlikely fish habitat	Culvert [3], causeway or ford	Culverts and fords are preferred to causeways (in that order). [3] Fish friendly waterway crossing designs possibly unwarranted. Fish passage requirements should be confirmed with NSW DPI Fisheries.

In contrast to road crossing designs, NSW DPI Fisheries does not use a generic classification system to stipulate remediation designs for highly-engineered structures such as fishways. Rather, decisions are based on the specifics of the biology and hydrology of the waterway and the conservation value of the site to determine the most appropriate course of action. Design advice is provided on a case-by-case basis.

Step 10 – 12: **Evaluation, implementation, monitoring and maintenance:**

Steps 10 to 12 are common steps in any project management process and include establishing an evaluation procedure, implementing the plan and assessing the success of the project. These stages include developing a timeline, allocating responsibilities, finalising funding, conducting on-ground works and organising an evaluation schedule.

For road crossing remediation works, establishing a working group (comprising representatives from relevant government agencies and other associated parties) to ratify a remediation works plan is an effective way of ensuring that the plan meets project objectives.

Permit and works approvals requirements in relation to road crossing construction, modification and maintenance in NSW can be found in:

- *Policy and Guidelines for Fish-Friendly Waterway Crossings* (NSW Fisheries, 2003); and
- *Policy and Guidelines for Aquatic Habitat Management and Fish Conservation* (NSW Fisheries, 1999).

The financing of on-ground rehabilitation works can be achieved through several avenues of cost-sharing between stakeholders and value-adding to existing programs/projects. Funding opportunities include State and Federal environmental grants for aquatic habitat rehabilitation projects. The NSW Department of Primary Industries Fisheries (Conservation and Aquaculture) can assist road managers, structure owners and community groups interested in applying for funding related to stream connectivity and fish passage projects in NSW.

6. RECOMMENDATIONS

This study contributes to the management of aquatic habitats in the Southern Rivers region of NSW by achieving the following outcomes:

- Development of a road crossing remediation inventory,
- On-ground application of a road crossing assessment method,
- Identification of remediation options for road crossing sites,
- Application of a prioritisation method to rank fish passage obstructions, and
- Promote and educate the findings of the report.

A complete data set from this study is available in a separate file (*Road Crossings Inventory – Southern Rivers - CD database*) and includes data on road crossing location information, environmental data and recommended remediation action. The recommendations in relation to remediation options for each site have been provided as a basic indication of the scale and extent of remediation required (e.g. complete structure removal, retrofitting, minor modification, maintenance, etc).

A separate report outlines the results of on-ground works ("demonstration sites") undertaken as part of this project ("*Reducing the impact of road crossings on aquatic habitat in coastal waterways – on-ground works component*").

Recommendations:

- The Southern Rivers CMA, local government, other structure owners, and NSW DPI Fisheries (Conservation and Aquaculture) should investigate the feasibility of remediating the high priority sites identified in this report. Detailed assessments of each individual site will be required prior to significant monetary investment at these locations;
- Sites that are obsolete, or where debris is creating a fish passage barrier, are able to be remediated with minimal financial outlay, and minimal stakeholder negotiation – these sites could therefore be remediated in the near future;
- Sites lower in the system, or those occurring on waterways with few other barriers, should be remediated in preference to sites where a large number of barriers are present downstream of the site;
- Sites where rare or threatened species are present within the catchment should be remediated in preference to sites outside the distribution of these species; and
- Sites identified as producing sediment input into a waterway should be investigated, as continual sediment input into the waterway can lead to the destruction of fish habitat.

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Appendix A – Freshwater and estuarine finfish of the Southern Rivers, NSW

8. APPENDICES

Table 7. Freshwater and estuarine finfish of the Southern Rivers region NSW

Scientific Name	Common Names	Status	Migration[7] and habitat
Acanthopagrus australis	Yellowfin bream Silver bream	Common	Amphidromous; coastal marine; estuaries & inshore reefs
Afurcagobius tamarensis	Tamar River goby	Common	Estuaries, coastal lakes & lower freshwater river reaches
Aldrichetta forsteri	Yellow-eye mullet	Common	Marine & estuarine; brackish coastal lakes & lower freshwater reaches
Ambassis marianus	Estuary perchlet Glass perchlet	Common	Local migration; brackish mangrove estuaries & tidal creeks
Amniataba percoides	Banded grunter	**EXOTIC**; **NSW NOXIOUS LISTING**	Freshwater habitats – in Clarence River, has potential to spread to the Southern Rivers region
Amoya bifrenatus	Bridled goby	Common	Estuarine & marine waters
Anguillia australis	Short-finned eel	Common	Catadromous; coastal rivers & wetlands
Anguilla reinhardtii	Long-finned eel	Common	Catadromous; coastal rivers
Arrhamphus sclerolepis	Snub-nosed garfish	Common	Coastal bays & brackish estuaries
Atherinosoma microstoma	Smallmouthed hardyhead	Common	Unknown migration pattern; coastal estuarine & fresh waters
Carassius auratus	Goldfish	**EXOTIC**	Widespread in lowland rivers
Carcharhinus leucas	Bull shark	Common (not abundant)	Estuaries, lower reaches of rivers; coastal waters
Chanos chanos	Milkfish	Common	Amphidromous; Warm water marine & estuarine species, will travel up rivers
Cyprinus carpio	Common carp	**EXOTIC**; **NSW NOXIOUS LISTING**	Still gentle flowing rivers in inland NSW & some catchments along the coast
Elops hawaiensis	Giant herring	Common	Sheltered embayments and estuaries
Epinephelus daemelii	Black cod	**NSW THREATENED SPECIES (*VULNERABLE*)**	Inshore marine caves & rocky reefs; larger juveniles around rocky shores in estuaries (natural distribution to south of Bega NSW)
Gadopsis marmoratus	River blackfish	Reduced range	Local migration; freshwater streams only
Galaxias brevipinnis	Climbing galaxias	Uncertain; Distribution contracted	Amphidromous; headwaters & forested streams
Galaxias maculatus	Common jollytail	Common	Catadromous; coastal streams, lakes & lagoons – salt & fresh water environs
Galaxias olidus	Mountain galaxias	Common	Local migration; moderate & high elevations in coastal & inland rivers
Gambusia holbrooki	Gambusia, Plague minnow	**EXOTIC**; **NOXIOUS LISTING**	Widespread in coastal & inland NSW
Gerres subfasciatus	Silver biddy	Common	Marine estuaries & bays, brackish coastal rivers & lakes
Gobiomorphus australis	Striped gudgeon	Common	Amphidromous; coastal streams generally at lower elevations
Gobiomorphus coxii	Cox's gudgeon	Common	Potamodromous; freshwater reaches of coastal rivers
Hypseleotris compressa	Empire gudgeon	Common throughout its range	Unknown migration; lower reaches of coastal rivers
Hypseleotris galii	Firetailed gudgeon	Common	Potamodromous; freshwater reaches of coastal streams
Liza argentea	Flat-tail mullet	Common	Estuaries & sea beaches

[7] Migration patterns of freshwater fish include: *Potamodromous* – fish that migrate wholly within fresh water; *Anadromous* – fish that spend most of their life in the sea and migrate to fresh water to breed; *Catadromous* - fish that spend most of their life in fresh water and migrate to the sea to breed; *Amphidromous* - fish that migrate between sea and fresh water, but not for the purpose of breeding.

Appendix A – Freshwater and estuarine finfish of the Southern Rivers, NSW

Lutjanus argentimaculatus	Mangrove Jack	Common	Estuaries & tidal river reaches
Macquaria australisica	Macquarie perch	**NSW THREATENED SPECIES (*VULNERABLE*)**	Potamodromous; freshwater; natural distribution Hawkesbury R, Shoalhaven River & inland NSW
Macquaria colonorum	Estuary perch	Uncertain	Amphidromous; estuarine areas in coastal rivers & lakes
Macquaria novemaculeata	Australian bass	Uncertain	Catadromous; Coastal rivers up to 600m altitude
Megalops cyprinoids	Oxeye herring	Common	Amphidromous; marine & estuarine, juveniles & small adults frequent freshwater reaches of rivers
Monodactylus argenteus	Diamondfish Silver batfish	Common	Bays, mangrove estuaries, tidal creeks & lower reaches of freshwater streams
Mordacia mordax	Shortheaded lamprey	Moderately abundant in some rivers	Anadromous; coastal rivers from Hawkesbury River to southern catchments
Mordacia praecox	Non-parasitic lamprey	Uncertain	Anadromous; has been found in Moruya & Tuross rivers in NSW
Mugil cephalus	Striped mullet Sea mullet	Common	Amphidromous; lower reaches & estuaries of coastal catchments
Mugilogobius platynotus	Flat backed goby	Common	Estuaries, can tolerate freshwater but mainly a marine species
Myxus elongatus	Sand mullet	Common	Amphidromous as juveniles; estuaries & brackish waters in lower river reaches
Notesthes robusta	Bullrout	Limited abundance but not threatened	Catadromous; tidal estuaries & fresh waters
Oncorhynchus mykiss	Rainbow trout	**EXOTIC**	Local migration; montane regions along the Great Dividing Range
Perca fluviatilis	Redfin perch	**EXOTIC**	Still and slow-flowing waters in inland rivers & southern coastal NSW
Philypnodon grandiceps	Flathead gudgeon	Common	Unknown migration; inland & coastal waters especially lakes & dams
Philypnodon sp.	Dwarf flathead gudgeon	Common	Unknown migration; coastal & inland streams
Platycephalus fuscus	Dusky flathead	Common	Amphidromous; marine & estuarine waters
Potamalosa richmondia	Freshwater herring	Not common but not considered under threat	Catadromous; estuaries & coastal fresh water rivers
Pristis zijsron	Green sawfish	**NSW THREATENED SPECIES (*ENDANGERED*)**	Inshore marine & estuaries; last confirmed sighting in 1972 from Clarence River (natural distribution to Jervis Bay NSW)
Prototroctes maraena	Australian grayling	**FEDERALLY THREATENED SPECIES**	Amphidromous; coastal waterways from Hawkesbury River south to Victoria
Pseudaphritis urvillii	Congolli Tupong	Abundant throughout its range	Catadromous; south coast NSW & the Snowy River catchment; freshwater & estuarine
Pseudogobius sp	Blue-spot goby	Common	Sheltered estuaries & coastal lakes
Pseudomugil signifer	Pacific blue-eye	Common	Amphidromous; eastern draining catchments
Redigobius macrostoma	Largemouth goby	Common	Amphidromous; estuaries, coastal rivers & some freshwater streams
Rhabdosargus sarba	Tarwhine	Common	Coastal waters, often entering estuaries
Retropinna semoni	Australian smelt	Common	Potamodromous; Inland & coastal freshwater
Salmo salar	Atlantic Salmon	**EXOTIC**	Restricted to cooler waters, including Lake Jindabyne, Snowy River catchment.
Salmo trutta	Brown trout	**EXOTIC**	Restricted to cooler waters; montane waterways above 600m elevation.

Sources: McDowall (1996), Thorncraft and Harris (2000), Yearsley *et al.* (2001), Allen *et al.* (2002), NSW Fisheries (2002c), and NSW DPI (2005a, 2005b).

Appendix B – Desktop and Field Assessment Form

COASTAL NSW WATERWAY CROSSINGS – DESK TOP ASSESSMENT FORM

ASSESSOR: _____ **DATE:** _____ **CROSSING ID:** _____
CATCHMENT: _____ **WATERWAY:** _____
STREAM ORDER: _____ **ELEVATION:** _____ **LGA:** _____

---

1. LOCATION INFORMATION

1a Location: Nearest Town: _____ Road Name: _____

1b Section of Catchment (please circle)**:** Upper Middle Lower

1c Upstream catchment area (sq. km) _____

---

2. STRUCTURE DETAILS

2a Structure ownership (please circle): Federal State Local Government Private Landholder

2b Distance to the next potential barrier: Upstream _____km Downstream _____km

2c Owner of the next potential obstruction (please circle):
Upstream: Federal State Local Government Private Landholder
Downstream: Federal State Local Government Private Landholder

2e If crossing blocks fish passage, how much habitat upstream would become available if crossing was modified to allow for fish passage _____km

---

3. ENVIRONMENTAL CONSIDERATIONS

3a Threatened and protected aquatic species present (please circle):
Olive perchlet Eastern freshwater cod Purple spotted gudgeon Oxleyan pygmy perch
Macquarie perch Black cod Australian grayling Estuary cod

3b Other key aquatic species present: _____
_____

NB. Use *Fishfiles* or *Freshwater Fish Research Database*. Include recreational and commercial fish species and key species such as platypus, turtles and waterbirds (if identifies in the field).

3c Environmental status: _____
_____

NB. Include terrestrial threatened species, critical habitat, conservation rating (HCV etc) and protected area status (eg. MPA's, SEPP, and significant wetlands, reserves, NP's and wilderness listings) if known.

ADDITIONAL COMMENTS IF REQUIRED:_____
_____
_____
_____
_____
_____
_____

Appendix B – Desktop and Field Assessment Form

COASTAL NSW WATERWAY CROSSINGS – FIELD ASSESSMENT FORM

ASSESSOR: _____DATE: _____CROSSING ID: _____
CLASS: _____GPS (or Grid ref and map number) _____
PHOTO NUMBERS: _____

---

1. LOCATION INFORMATION
1d Surrounding Land Uses (please circle)**:** Forested / Grazing / Cropping / Urban / Rural / Industrial
Description of land use:_____

---

2. STRUCTURE DETAILS
2a Road Type (please circle): Sealed / Unsealed

2b Structure Type (please circle):
Bridge - single or multiple span or arched structure raised above channel bed.
Culvert - pipe or box shaped cell to convey water underneath roadway.
Pipe - cylindrical-celled culvert.
Weir - instream structure designed to back water upstream.
Causeway - low-level crossing designed to convey water over road; may have low-flow pipe.
Ford – low level crossing formed directly on the channel bed in a shallow section of a watercourse.
Floodgate - gated levee to regulate flow between floodplain and stream channel.

2d Structure Description
No. of cells or pipes _____Height (from downstream bed level to structure crest)._____m
Width (bank to bank) _____m Width (upstream to downstream)_____m
Construction material (please circle): Concrete / Timber / Steel / Rock / Gravel / Sand/Fines

2e Ancillary purposes (eg bed-control structure, pumping pool) _____

---

3. ENVIRONMENTAL CONSIDERATIONS
FISH PASSAGE
3a Does the crossing potentially block fish passage (please circle): Yes / No
If yes what type of blockage (please circle one or more):
Vertical drop: est (mm) _____ **Slope** (est grade): _____
Velocity: High Moderate Low If known, Velocity (m/s) _____
Turbulence: High Moderate Low **Debris:** Present / Absent
Flow depth through structure (mm): _____ **Light:** None / Minimal / Adequate
Other: _____

3b Is there **flow over/through** the structure: Yes / No **3c** Does water pool upstream of the structure: Yes / No
If yes, what is the average length of pool _____m and depth of the pool _____m

3c Is there **terrestrial passage** under or over the structure: Yes / No

3d Location of next obstruction if different to desktop study (GPS or road name or Grid reference and map name and number): Upstream _____ Downstream _____

HABITAT
3e Bank Height _____m; **channel width** _____m; **low flow channel width** _____m & **depth** _____m

3f Habitat features (substrate type, pools, riffles, gravel bed, boulders, macrophytes, snags, undercuts, riparian overhangs etc): _____

3g Condition of aquatic habitat:	**excellent**	**good**	**fair**	**poor**	**very poor**
3h Condition of riparian zone:	**excellent**	**good**	**fair**	**poor**	**very poor**

---

4. COMMENTS (channelised, erosion, saltation, reduced water quality, riparian & aquatic pests etc):
_____
_____

---

5. RECOMMENDATIONS: _____
_____

Appendix C – Prioritisation Process

Throughout NSW, the Department of Primary Industries Fisheries (Conservation and Aquaculture) applies a basic 'CLASS' system to assign aquatic habitat values to waterways. Table 8 outlines the characteristics of each waterway class. This criterion was used in the prioritisation scheme as one of the main criteria to determine the habitat value of road crossing sites in the Southern Rivers CMA region.

Table 8. NSW DPI classification of fish habitat in NSW waterways

Classification	Characteristics of waterway class
CLASS 1 Major fish habitat	Major permanently or intermittently flowing waterway (eg river or major creek); habitat of a threatened fish species or 'critical habitat'.
CLASS 2 Moderate fish habitat	Named permanent or intermittent stream, creek or waterway with clearly defined bed and banks with semi-permanent to permanent waters in pools or in connected wetland areas. Marine or freshwater aquatic vegetation is present. Known fish habitat and/or fish observed inhabiting the area.
CLASS 3 Minimal fish habitat	Named or unnamed waterway with intermittent flow and potential refuge, breeding or feeding areas for some aquatic fauna (eg fish, yabbies). Semi-permanent pools form within the waterway or adjacent wetlands after a rain event. Otherwise, any minor waterway that interconnects with wetlands or recognised aquatic habitats.
CLASS 4 Unlikely fish habitat	Named or unnamed waterway with intermittent flow following rain events only, little or no defined drainage channel, little or no flow or free standing water or pools after rain events (eg dry gullies or shallow floodplain depressions with no permanent aquatic flora present).

Data utilised in each of the four criteria are shown in Table 9.

Habitat value data for a site also provided an indication of the quality of habitat for fish (including the size of the waterway, and location in the system), how impacted the site and catchment were from human activity (number of barriers downstream, and distance to next barrier downstream), and how the remediation of the structure would benefit fish (amount of habitat potentially made available upstream of the site).

The structure impact criteria indicated the physical impact of the structure on fish passage. True/false values were assigned to each of the data, in addition to an actual height value for headloss.

Table 9. Data employed to determine road crossing criteria

Habitat Value Criteria Waterway Class Section of Catchment Number of Road Barriers Downstream Distance to next Road Barrier Downstream Habitat Available Upstream	**Structure Impact Criteria** Headloss Slope Presence of Debris (Woody or Sediment) Velocity Flow Depth Light
Environmental Value Criteria Low Flow Channel Width Aquatic Habitat Condition Riparian Habitat Condition Sealed/Unsealed Road Presence of Rare or Threatened Species Environmental Status	**Modification Criteria** Is Structure Obsolete? Ease of Remediation Any Additional Uses?

Appendix C – Prioritisation Process

A headloss across the structure of greater than 100mm can affect the migration of native fish, as can a slope greater than 1:20 (in estuarine / lowland environments, where upstream movement of juvenile fish is most crucial, this figure can be as low as 1:30). Similarly, long distances where high linear velocities are encountered (such as in long pipe culverts) can inhibit fish movement. Physical limitations on the ability of a fish to pass a structure also occur where the crossing outlet itself is blocked by woody debris or sediment, or where the depth of water in the structure is minimal (n.b. depth requirements vary depending on the size of resident fish. Large bodied natives [such as Macquarie perch] may require depths greater than 200mm). A lack of light within a structure can potentially form a behavioral barrier to some native fish species, regardless of the flow conditions and water depth within the culvert.

Data employed in the environmental value criteria described the local habitat condition (channel width, aquatic vegetation and riparian vegetation condition), and thus the local habitat features available for fish. The surrounding land use (whether the site was within a National Park, Water Reserve, State Forest or was farming land), and whether rare or threatened species were actually or potentially present within the catchment also contributed to the environmental value of a site.

The likelihood of sediment contribution to the waterway as a result of road design (eg unsealed approaches, lack of sediment controls) also formed part of the environmental value criteria due to its potential impact on instream habitat. Sediment inputs into a waterway either from road crossings directly, or from drainage works associated with them, may impact on native fish habitat through the smothering of aquatic vegetation, riffles, or infilling of deep pools within a waterway.

The modification criteria took into account additional uses for the site that may decrease remediation options available (eg if the structure was acting as a bed control structure or providing a pumping pool for water extraction upstream of the site), the ease of remediation (the recommended action for the site and how costly this would be), and if the structure was required (an obsolete structure being more likely to be remediated through removal than a structure that was still in use).

The scoring system used to prioritise sites according to the above criteria is presented overleaf.

Appendix C – Prioritisation Process

INITIAL PRIORITISATION						
A) STREAM HABITAT VALUE CRITERIA						**SCORE**
Primary aquatic habitat rating						
Habitat Class		1	2	3	4	
Location in the system		Tidal	Lower	Middle	Upper	
Downstream obstructions		0	1-2	3 - 5	> 5	
Upstream habitat – stream length opened up (>/= 3rd order)		> 20 km	10 – 20 km	5 - 10 km	1 - 5 km	< 1 km
B) STRUCTURE IMPACT CRITERIA						
Environmental effect rating						
Physical barrier	Headloss	> 1000 mm	500 - 1000 mm	250 – 500 mm	100 - 250 mm	
	Slope	"True"				
	Debris	"True"				
	Blockage	"True"				
Hydrological barrier	Velocity	"True"				
	Flow depth	"True"				
Behavioural barrier	Light penetration	"True"				
					SUBTOTAL	

SECONDARY PRIORITISATION					
C) ENVIRONMENTAL CRITERIA					
Secondary aquatic habitat rating					
Low-flow channel width	> 15 m	10 – 15 m	5 - 10 m	< 5 m	
Instream habitat condition	Good		Fair		
Riparian condition	Good		Fair		
Point Sediment Impacts	Unsealed		Sealed		
Threatened species	"True" Class 1-2 (within range, likely habitat)		"True" Class 3 (within range, unlikely habitat)		
Landuse / Environmental Status	National Park = 1	State Forest = 2	Rural = 3		
D) MODIFICATION CRITERIA					
Structure use and remediation cost rating					
Obsolete Crossing	"True"				
Ease of Remediation	Maintenance	Box Culvert Low Flow Channel	Bridge		
Ancillary uses	Flood mitigation = 1	Bed Control = 2	Pump pool, Irrigation = 3		
				SUBTOTAL	
				TOTAL	

Appendix D – High Priority Sites in the Southern Rivers CMA

Table 10. Priority fish passage obstructions in Southern Rivers region

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
1	BEGA058	Bega/Eden, Bega Valley Shire	Tantawangalo Ck	Kameruka Estate Rd	-36.7329	149.7191	1	Causeway	HL,V	Modify one cell to allow for majority of flow to pass through (left bank cell)	27.0
2	CLYD032	Eurobodalla, Eurobodalla Shire	Nelligen Ck	The River Rd	-35.6413	150.1278	1	Causeway	HL	Increase size, number & lower setting of cells to improve water flow	11.0
3	CLYD020	Eurobodalla, Shoalhaven City	Clyde R	The River Rd	-35.5308	150.2000	1	Causeway	HL,V	Bridge / raised section	17.5
4	GIPP015	Bega/Eden, Bega Valley Shire	Merrica R	Merrica River Fire Trail	37.3048	149.9268	1	Causeway	V	Partial removal / install a box culvert partway along the structure (3 sided culvert)	11.0
5	SHOA001	Shoalhaven/ Wollongong, Shoalhaven City	Broughton Ck	Private Dve off Princes Hwy	-34.7593	150.7525	2	Causeway	HL,LF	Low flow channel / fishway / bridge	5.5
6	CLYD036	Eurobodalla, Eurobodalla Shire	Currowan Ck	The Western Distributor	-35.5754	150.0594	1	Causeway	D,V	Fishway / bridge / box culvert	9.0
7#	MORU019	Eurobodalla, Eurobodalla Shire	Deua R	Private Dve off Araluen Rd	-35.8468	149.9847	2	Causeway	HL,V	Bridge / improve culvert size and remove levee	21.0
8	CLYD033	Eurobodalla, Eurobodalla Shire	Currowan Ck	The River Rd	-35.5710	150.1585	2	Causeway	HL,LF	Large culvert / bridge / fishway	16.0
9	CLYD044	Eurobodalla, Eurobodalla Shire	Buckenbowra R	Hanns Rd	-35.6749	150.0005	2	Causeway	HL,D,LF	Box culverts / fishway / bridge	5.0
10	SHOA097	Shoalhaven/ Wollongong, Palerang	Shoalhaven R	Stewarts Crossing Rd	-35.2483	149.8925	2	Causeway	HL,LF	Low flow channel/improve grade to top of causeway (downstream invert)	47.0
11	CLYD040	Eurobodalla, Eurobodalla Shire	Buckenbowra R	Quart Pot Rd	-35.7281	150.0706	2	Causeway	HL,LF	Box culverts with low flow cells / bridge	1.0
12	SHOA008	Shoalhaven/ Wollongong, Shoalhaven City	Broughton Mill Ck	Unused Rd on property 'Oakleigh'	-34.7524	150.7128	2	Causeway	HL,D,V,L	Remove - clear debris	1.5
13	SNOW095	Snowy/Monaro, Bombala	Corrawong Ck	Settlers Rd	-36.8879	148.8107	2	Causeway	HL,LF	Box culvert with low flow cells	29.0
14	CLYD029	Eurobodalla, Eurobodalla Shire	Sheepstation Ck	Kings Hwy	-35.6661	150.1671	1	Culvert – Pipe	HL	Lower invert	1.5

* HL = Headloss; V = Velocity barrier; LF = Low flow depth; S = Slope >1:20; D = Woody or sediment debris; L = Light.
# This site has now been remediated (removed).

Appendix D – High Priority Sites in the Southern Rivers CMA

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
15	TURO050	Eurobodalla, Bega Valley Shire	Wadbilliga R	Wadbilliga Rd	-36.2756	149.6135	2	Causeway	HL	Box culverts with low flow cells	7.0
16	CLYD010	Eurobodalla, Shoalhaven City	Berrara Ck	Blackbutt Rd	-35.1915	150.5205	2	Ford	HL,D,LF	Box culvert	6.0
17	BEGA046	Bega/Eden, Bega Valley Shire	Pambula R	Private Unnamed Rd off Mount Darrugh Rd	-36.9151	149.7760	2	Causeway	HL,V,S	Box culvert	20.0
18	CLYD043	Eurobodalla, Eurobodalla Shire	Quart Pot Ck	Hanns Rd	-35.6993	150.0081	2	Causeway	HL,LF	Box culvert with low flow cell / bridge / fishway	4.0
19	GIPP014	Bega/Eden, Bega Valley Shire	Long Swamp Ck	Scrubby Creek Rd	-37.2328	149.8497	2	Causeway	HL	Timber bridge	12.0
20	MORU025	Eurobodalla, Eurobodalla Shire	Telowar Ck	Neringla Rd	-35.7298	149.7920	2	Causeway	HL,V,LF	Additional culverts / bridge	5.0
21	SHOA109	Shoalhaven/ Wollongong	Shoalhaven R	Farrington Rd	-35.5091	149.6719	2	Causeway	HL,V	Fishway	52.0
22	TURO002	Eurobodalla, Eurobodalla Shire	Coila Ck	Fox Gully Rd	-36.0111	150.0528	2	Ford	HL,LF	Culvert/bridge	4.0
23	SNOW212	Snowy/Monaro, Bombala	Jacksons Bog	Unnamed Rd	-36.9955	149.0966	2	Causeway	D,V,LF	Box culvert with low flow cell remove debris	30.0
24	SNOW177	Snowy/Monaro, Cooma-Monaro Shire	Maclaughlin R	Monaro Hwy	-36.5624	149.2918	2	Causeway	HL,V,LF	Box culvert or bridge	27.0
25	SHOA031	Shoalhaven/ Wollongong, Shoalhaven City	Brogers Ck	Watamolla Rd	-34.7289	150.6401	2	Causeway	HL,V,LF,L	Box culvert with low flow cells	2.0
26	SNOW181	Snowy/Monaro, Bombala	Bombala R	New Line Rd	-36.7067	149.3946	2	Causeway	V,LF	Box culvert / bridge	40.0
27	WOLL032	Shoalhaven/ Wollongong, Municipality of Kiama	Frys Ck	Minnamurra Falls Rd	-34.6398	150.7585	2	Bridge/ Causeway	HL,D,LF	Remove causeway - footings on bridge need to be reinstated	4.0
28	SNOW079	Snowy/Monaro, Bombala	Delegate R	Browns Camp Rd	-37.0282	148.8290	2	Causeway	V	Remove	14.0
29	SNOW192	Snowy/Monaro, Bombala	Dragon Swamp Ck	Dragon Swamp Creek Rd	-36.8091	149.3994	2	Causeway	HL,LF	Box culvert / bridge	20.0

* HL = Headloss; V = Velocity barrier; LF = Low flow depth; S = Slope >1:20; D = Woody or sediment debris; L = Light.

Appendix D – High Priority Sites in the Southern Rivers CMA

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
30	CLYD016	Eurobodalla, Shoalhaven City	Cockwhy Ck	South Arm Rd	-35.5377	150.3459	2	Culvert - Pipe	D,LF,L	Clear debris and remove sediment curtain	3.5
31	CLYD013	Eurobodalla, Shoalhaven City	Stony Ck	Private Rd to "Mount Airlie"	-35.3327	150.4185	2	Causeway	HL,D,LF	Lower invert of pipes / replace with box culverts if causeway still required	2.5
32	WOLL023	Shoalhaven/ Wollongong, Shellharbour City	Marshall Mount Ck	Calderwood Rd driveway off 'Calderwood Farm'	-34.5526	150.7460	2	Causeway	HL,D,V,LF	Lower culverts / fishway	2.0
33	TURO029	Eurobodalla, Eurobodalla Shire	Punkally Ck	Mount Dromedary Trail	-36.2670	150.0525	2	Causeway	HL,LF	Box culvert and low flow cell	1.5
34	CLYD022	Eurobodalla, Shoalhaven City	Cockwhy Ck	track off Princes Highway to "The Hapgood Rd"	-35.5448	150.2821	2	Causeway	D,L	Remove / box culvert	2.0
35	SHOA125	Shoalhaven/ Wollongong, Municipality of Kiama	Unnamed tributary to Crooked R	Princes Hwy	-34.7502	150.7883	2	Culvert - Pipe	HL,LF	Low flow channel and remove debris	1.2
36	SNOW191	Snowy/Monaro, Bombala	Coolumbooka R	Coolungunbra Rd	-36.8629	149.3914	2	Causeway	HL,V,LF	Box culvert with low flow cell	50.0
37	SNOW173	Snowy/Monaro, Cooma-Monaro Shire	Maclaughlin R	Warresal Rd	-36.4169	148.6244	2	Causeway	HL,V,LF	Box culvert	16.0
38	SHOA118	Shoalhaven/ Wollongong, Palarang	Jerrabuttgulla Ck	Private Dve off Hereford Hall Rd	-35.7788	149.5671	2	Causeway	HL,V,LF	Larger culverts - lower structure invert	8.0
39	SHOA050	Shoalhaven/ Wollongong, Palarang	Ningee Nimble Ck	Oallen Rd	-35.1664	149.9917	3	Culvert - Box	HL,D,LF	Clear debris - high invert only problem at very low flows-	3.5
40	TURO030	Eurobodalla, Eurobodalla Shire	Dromedary Ck	Dromedary Trail Rd	-36.2694	150.0516	2	Causeway	HL,D,LF	Box culvert with low flow cells	2.5
41	SHOA032	Shoalhaven/ Wollongong, Shoalhaven City	Ryders Ck	Watamolla Rd	-34.7396	150.6179	2	Causeway	HL,LF	Remove	3.5
42	CLYD002	Eurobodalla, Shoalhaven City	Unnamed trib to Currambene Ck	Woolamia Rd	-35.0139	150.6384	1	Culvert - Pipe	D,L	Lower upstream side of invert so that pipe is level, remove sleepers from downstream side / box culvert	2.5
43	BEGA041	Bega/Eden, Bega Valley Shire	Leos Ck	Nullica Short Cut Rd off Princes Hwy	-37.0998	149.8472	2	Ford	LF	Box culvert with low flow cell	17.0

* HL = Headloss; V = Velocity barrier; LF = Low flow depth; S = Slope >1:20; D = Woody or sediment debris; L = Light.

Appendix D – High Priority Sites in the Southern Rivers CMA

Rank	Crossing ID	Subregion, LGA	Waterway	Road Name	Latitude	Longitude	Stream Class	Structure Type	Barrier Type*	Recommendation	Available u/s Habitat (km^2)
44	SNOW200	Snowy/Monaro, Bombala	Native Dog Ck	Unnamed Rd	-36.6663	149.2935	2	Causeway	HL,V,LF	Box culvert with low flow cell	9.0
45	TURO040	Eurobodalla, Bega Valley Shire	Wandella Ck	Wandella Rd	-36.2821	149.8420	2	Causeway	V	Box culvert and low flow cell	5.0
46	GIPP012	Bega/Eden, Bombala	Genoa R	Unnamed Private Rd	-37.1597	149.3207	2	Causeway	D,V	Box culvert with low flow cell (barrier at medium flows)	4.5
47	MORU014	Eurobodalla, Eurobodalla Shire	Candoin Ck	Dwyers Creek Rd	-35.9468	150.0530	2	Causeway	HL,D,L	Increase culvert size, rocky ridges either side are natural barriers at low flow	3.5
48	SHOA012	Shoalhaven/ Wollongong, Shoalhaven City	Bundewallah Ck tributary	Bundewallah Rd	-34.7501	150.6563	2	Causeway	HL,LF	Lower invert – box culvert with low flow cell	0.5
49	SHOA038	Shoalhaven/ Wollongong, Shoalhaven City	Kangaroo R	Upper River Rd	-34.6751	150.5984	2	Causeway	HL,LF	Box culverts with low flow cells / bridge	4.6
50	SHOA026	Shoalhaven/ Wollongong, Shoalhaven City	Brogers Ck	Brogers Creek Rd	-34.7047	150.6882	2	Causeway	HL,LF	Box culvert with low flow cells	1.0
51	SHOA041	Shoalhaven/ Wollongong, Shoalhaven City	Sawyers Ck	Scone Rd	-34.7342	150.5691	2	Causeway	HL,S,LF	Box culvert with low flow cells	0.4
52	SHOA033	Shoalhaven/ Wollongong, Shoalhaven City	Sawyers Ck	Scone Rd	-34.7395	150.5656	2	Causeway	HL,S,D,LF	Box culvert with low flow cells	2.5
53	SHOA049	Shoalhaven/ Wollongong, Palarang	Nadgengutta Ck	Braidwood Rd	-35.1377	150.0674	2	Causeway	LF	Improve culverts / box culvert, clear vegetation close to culvert upstream side	2.5
54	TURO005	Eurobodalla, Eurobodalla Shire	Little Bumbo Ck	Bumbo Rd	-36.0391	150.0100	2	Causeway	LF	Remove and install bridge as planned	4.5
55	SHOA091	Shoalhaven/ Wollongong, Palarang	Wog Wog Ck	Scone Rd	-35.2473	150.0282	2	Causeway	V,LF	Additional box culverts with low flow cell	8.0

* HL = Headloss; V = Velocity barrier; LF = Low flow depth; S = Slope >1:20; D = Woody or sediment debris; L = Light.

Appendix E – Conceptual Diagrams of Fishways Employed in Australia

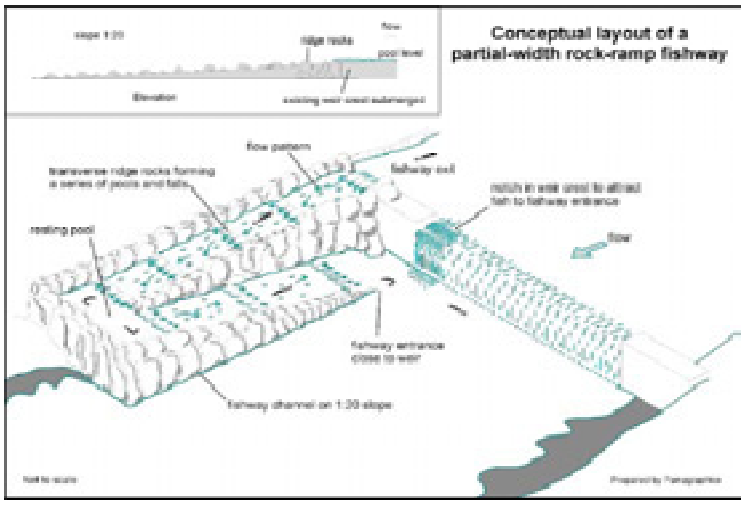
The following remediation options are primarily employed on structures not requiring vehicle access (e.g. weirs or infrastructure such as water delivery pipes). Information is presented here to provide a guide on alternative remediation options, and as a guide for native fish passage requirements (fish passage is optimal when there is a maximum slope of 1:20 – 1:30, an effective depth of water to allow adult fish to pass (>200mm), the absence of headloss >100mm, the absence of long distances of high, linear velocity water).

Rock ramp fishways
Rock ramp fishways were developed as a simple and relatively low-cost adjunct to more formally engineered fishway designs, particularly for overcoming low barriers and subsequently in association with stream erosion control works. This type of fishway is particularly valuable for providing fish passage at existing low weirs. They are generally built on slopes that attempt to match the surrounding geomorphic features within the waterway (although these are typically between 1:20 and 1:30 slope).

In this style of fishway, large rocks are placed to form a series of small pools and falls at about 2m intervals. Fish ascend the fishway by darting through sections of high water velocity occurring between large "tombstone" rocks, and resting in the pools created by the rock ridges, continuing through to the next section until they exit.

Two variations of this form of fishway are employed in Australia – the partial width rock ramp fishway (below), and the full width rock ramp fishway. As the name implies, the partial width rock ramp fishway only extends part way across the width of a waterway, with water directed down a defined channel; whereas a full width rock ramp fishway extends the entire width of a waterway, with low flows being directed down a defined channel, and moving out from this channel as river flows increase.

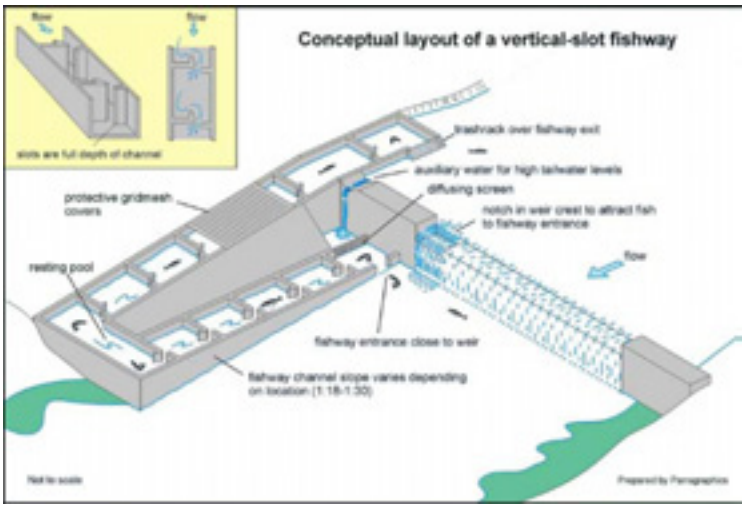
In the Gloucester Shire Council LGA (Hunter/Central Rivers CMA), modified versions of the partial width rock ramp fishway have been employed at causeway road crossings, with the upstream exit of the fishway meeting the downstream edge of the road cap at a depression in the road surface. This modified fishway provides a means for fish to reach the road surface, but fish passage remains limited to rising flows when water depth across the road surface is increased.



Vertical slot fishways
Vertical slot fishways comprise a more engineered and controlled version of a rock ramp fishway where resting pools are essentially concrete cells, with the entrance/exit to/from each of the pools being a vertical slot at either end. The maximum water velocity occurs as water falls through each slot, with the downstream pool acting to dissipate hydraulic energy as well as providing resting areas for ascending fish. The slope of the channel and the interval between slots controls the water velocity through each slot, thus the fishway can be designed to suit the swimming ability of particular ascending fish.

Appendix E – Conceptual Diagrams of Fishways Employed in Australia

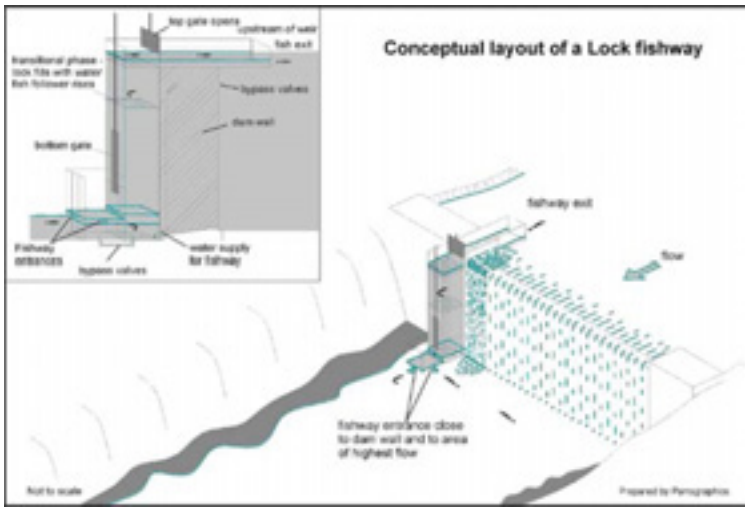
Vertical slot fishways have flexibility of operation over varying headwater and tailwater levels, as well as allowing fish to pass through the fishway at any depth. This type of fishway is more expensive than a rock ramp fishway, and requires larger volumes of water to operate.



Lock fishways

Lock fishways are employed on very large (high) structures where other fishway designs become too expensive to install. Lock fishways operate by attracting fish through an entrance similar to a rock ramp or vertical slot fishway, but instead of swimming up a channel, fish accumulate in a holding area at the base of the lock. This holding area is then sealed and slowly filled with water to reach a level equal to the water upstream of the barrier. Fish are then able to swim out of the lock at the upstream pool level.

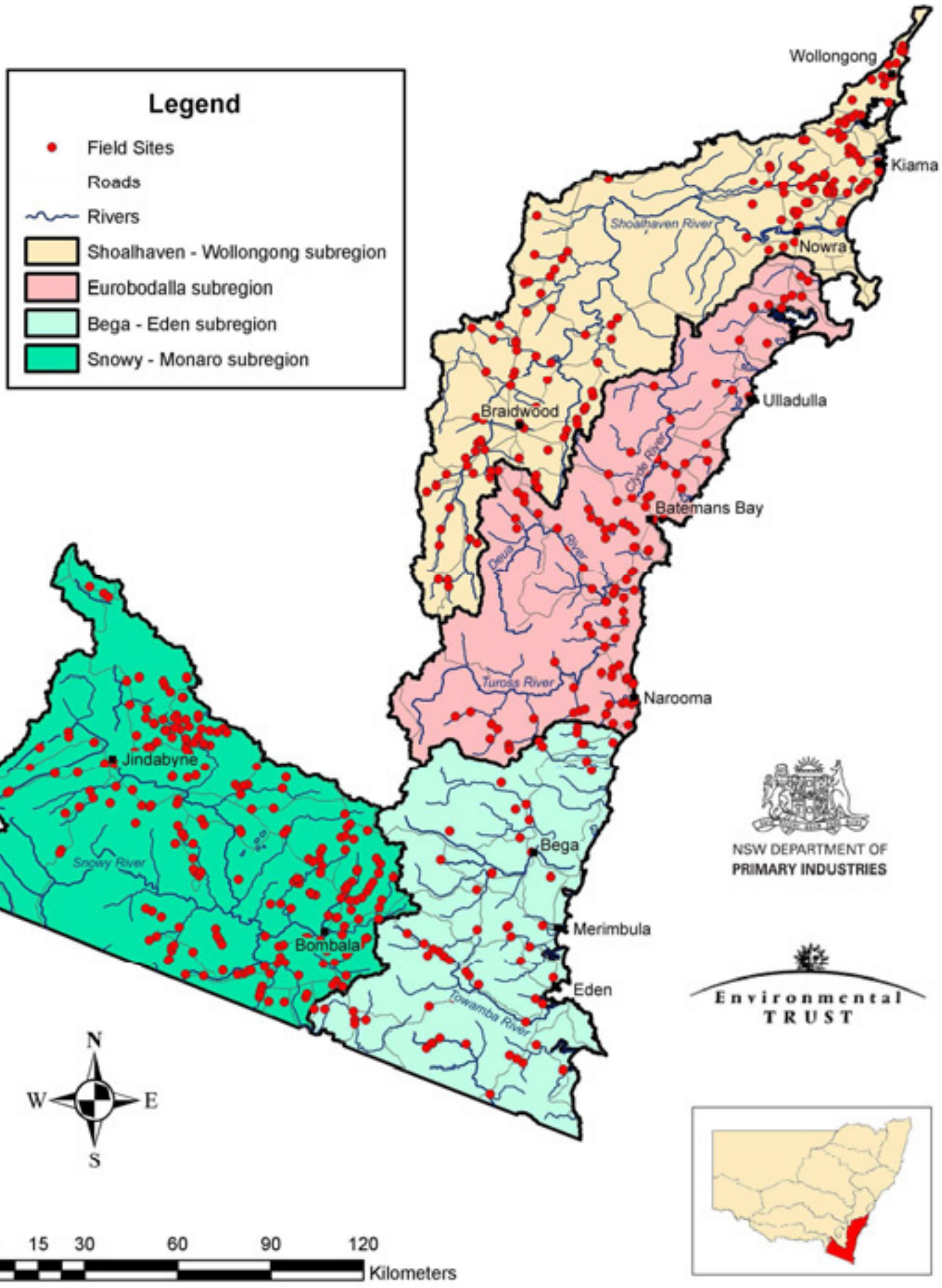
The first lock fishway in New South Wales waters was on the Murray River at Yarrawonga Weir, and has been shown to be effective in transporting fish over the 12m high weir. The Deelder fish lock (or Deelder fishway) is a variation of the lock fishway for use on lower barriers. This type of fishway is proposed for Marsden Street Weir on the Parramatta River at Parramatta, and a functioning Deelder fishway is present on the Murrumbidgee River at Balranald in the state's west.



Reference:

Thorncraft, G. and Harris, J.H. (2000) *Fish passage and fishways in NSW: A Status Report.* Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000.

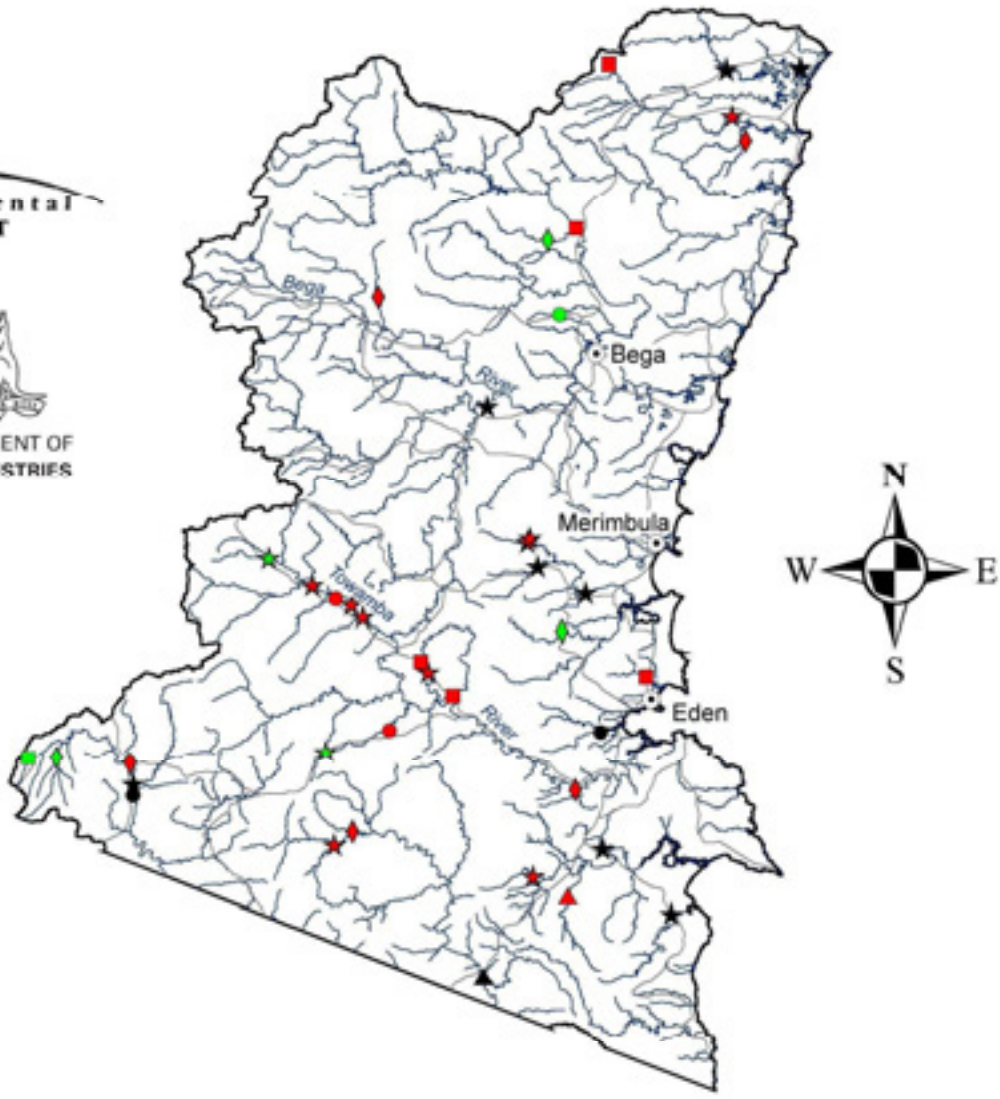
SOUTHERN RIVERS - FIELD SITES



ROAD CROSSING BARRIERS
BEGA - EDEN SUBREGION

Environmental TRUST

NSW DEPARTMENT OF PRIMARY INDUSTRIES



Legend

Structure Type

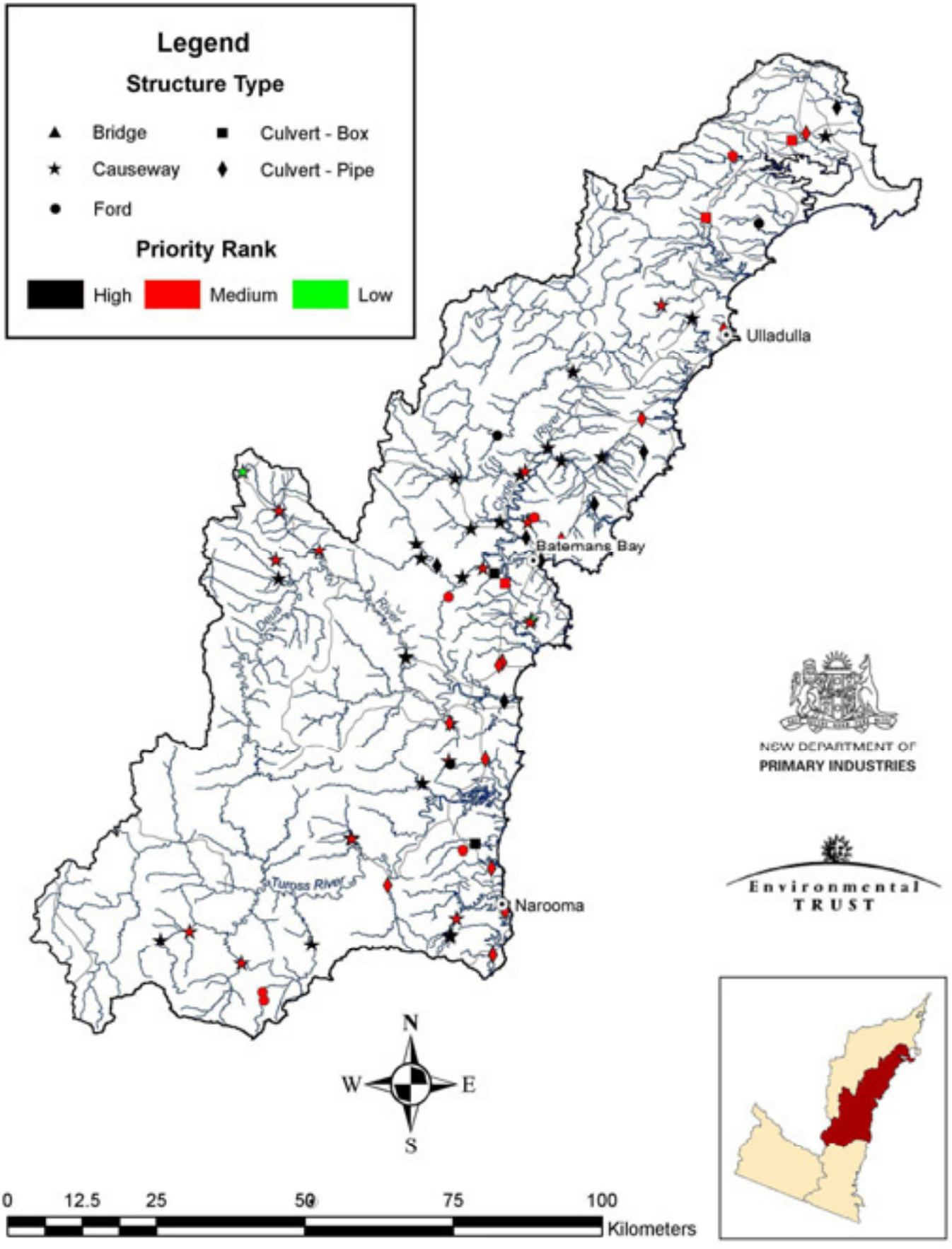
- ▲ Bridge
- ■ Culvert - Box
- ★ Causeway
- ♦ Culvert - Pipe
- ● Ford

Priority Rank

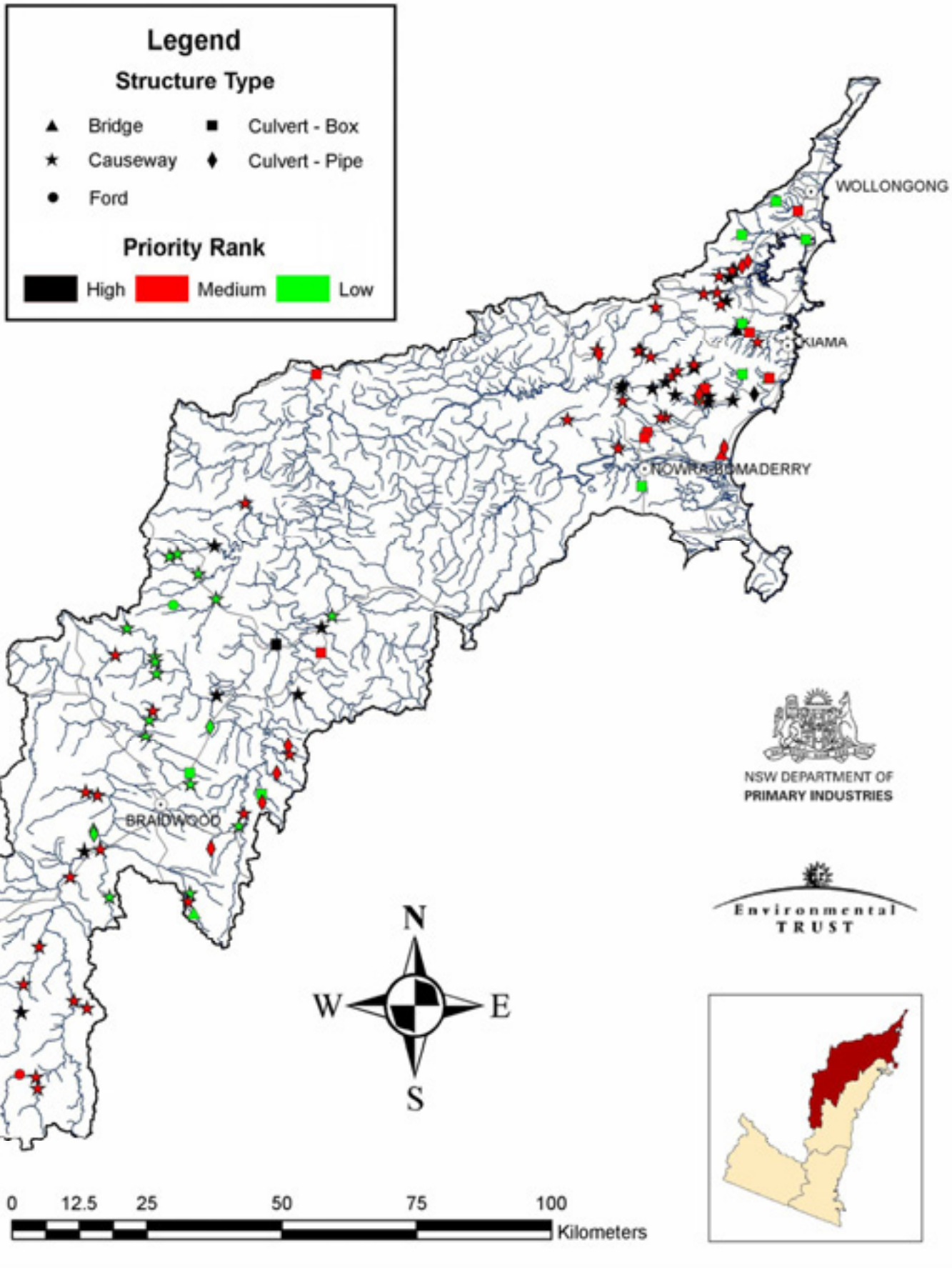
High | Medium | Low

0 12.5 25 50 75 100 Kilometers

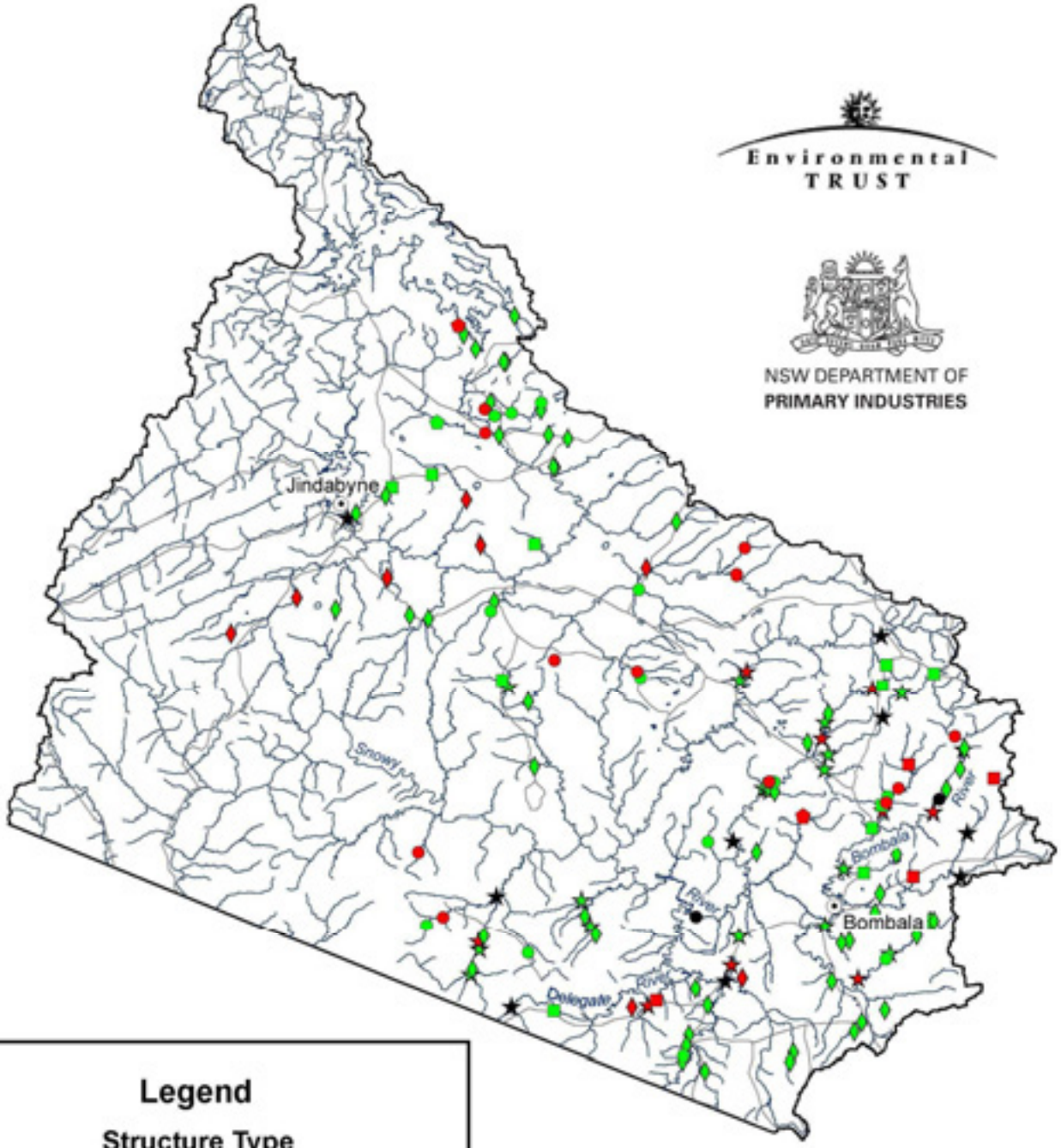
ROAD CROSSING BARRIERS
EUROBODALLA SUBREGION



ROAD CROSSING BARRIERS
SHOALHAVEN - WOLLONGONG SUBREGION



ROAD CROSSING BARRIERS
SNOWY - MONARO SUBREGION



Environmental TRUST

NSW DEPARTMENT OF PRIMARY INDUSTRIES

Legend

Structure Type

- ▲ Bridge
- ■ Culvert - Box
- ★ Causeway
- ♦ Culvert - Pipe
- ● Ford
- ⬟ Other

Priority Rank

High | Medium | Low

N
W E
S

0 12.5 25 50 75 100

Kilometers


aquatic habitat rehabilitation
making more fish
...naturally