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Distribution and conservation status of the endangered Oxleyan pygmy perch *Nannoperca oxleyana* Whitley in New South Wales

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Abbreviations

ANGFA	Australia New Guinea Fishes Association BoM
Australian	Bureau of Meteorology
OEH	NSW Office of Environment & Heritage
EPBC Act	Commonwealth Environmental Protection and Biodiversity Conservation Act 1999
FM Act	NSW Fisheries Management Act 1994
NSW DPI	NSW Department of Primary Industries
IUCN	International Union for Conservation of Nature and Natural Resources NSW New South Wales

Non-technical summary

Distribution and conservation status of the endangered Oxleyan pygmy perch Nannoperca Oxlyeyana Whitles in New South Wales

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Key words

endangered species, freshwater fish, NSW north coast, threats, drought, biogeography

Summary

The Oxleyan pygmy perch is a small freshwater fish listed as 'endangered' under the New South Wales (NSW) *Fisheries Management Act 1994* and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, and as 'vulnerable' under the Queensland *Nature Conservation Act 1992*. Oxleyan pygmy perch are irregularly distributed throughout the lowland, coastal wallum (*Banksia* dominated heath) drainage systems of north-eastern NSW and south- eastern Queensland. A recovery plan has been prepared, which aims to return the species to a position of viability in nature. This report provides details of two fish surveys undertaken in NSW by the Department of Primary Industries (NSW DPI) to determine the distribution and establish the conservation status of Oxleyan pygmy perch. Specific objectives were to establish the distributional limits of the species; document the locations, habitats, relative abundance, and size structure of extant populations; identify potential factors influencing these distribution and abundance patterns; and to provide recommendations for conserving and recovering the species based on the survey information.

NSW locality records for Oxleyan pygmy perch collected since 1990 were largely confined to coastal wallum ecosystems within and adjacent to Broadwater, Bundjalung and Yuraygir National Parks (termed the north coast conservation system). Intensive sampling for the species had been limited to Broadwater National Park and adjacent habitats, in which the species was found to be relatively common. Based on this information, targeted fish fauna surveys were undertaken between May 2001 and September 2004 along approximately 550 kilometres of the NSW north coast from the Queensland border to Myall Lakes National Park. Initially, surveys were aimed at establishing the distributional limits of Oxleyan pygmy perch to the north and south of, and surrounding, the north coast conservation system. The second survey was concentrated within Bundjalung and Yuraygir National Parks.

Fish sampling involved a combination of passive trapping and either active seine netting, electrofishing or dip netting. Information was collected on the numbers, locations, relative abundance, size structure and habitats of Oxleyan pygmy perch populations. A general assessment was also made of human effects at each site sampled during the first survey to assist in identifying factors contributing to the distributional limits of the species.

A total of 93 sites within 90 waterbodies were sampled during the first survey. Oxleyan pygmy perch were captured from only eight sites within seven waterbodies, all of which were located adjacent to the western boundary of the north coast conservation system. The species was recorded from the Coraki and Evans River subcatchments of the Richmond River and the Esk River subcatchment of the Clarence River. Investigation of historical records to the north-west and south of the conservation system revealed that these areas have been extensively cleared and degraded and there was no evidence that Oxleyan pygmy perch persist there. This pattern of presence/absence implies that pygmy perch have a NSW distribution currently restricted to a narrow stretch of sandy coastal lowlands encompassed by the north coast conservation system and bordering habitats.

In the first survey, only 180 Oxleyan pygmy perch were sampled, representing 1.5% of the total catch of fish. Oxleyan pygmy perch were, however, the second most abundant fish sampled from sites supporting the species. Other species co-occurring with Oxleyan pygmy perch, were commonly captured throughout the entire study area, including firetailed gudgeon, striped gudgeon, empire gudgeon, soft-spined rainbowfish and the noxious pest eastern gambusia. Other species sampled included the flathead gudgeon, Duboulay's rainbowfish, olive perchlet, longfinned eel, shortfinned eel, Pacific blue-eye and sea mullet.

A total of 73 sites within 69 water bodies were sampled during the second survey located within Bundjalung and Yuraygir National Parks. Fourteen native fish species were captured: Oxleyan pygmy perch, firetailed gudgeon, striped gudgeon, empire gudgeon, flathead gudgeon, dwarf flathead gudgeon, soft-spined rainbowfish, Duboulay's rainbowfish, olive perchlet, Pacific blue- eye, common jollytail, longfinned and shortfinned eels, and freshwater catfish. Two stocked populations of Australian bass were also sampled along with numerous populations of eastern gambusia. A total of 220 Oxleyan pygmy perch were captured from 20 waterbodies. The species was relatively common within an unclassified subcatchment and the Esk River subcatchment in Bundjalung National Park but displayed a disjunct distribution throughout the Angourie/Redcliffe, Wooloweyah Lake and Wooli River subcatchments in Yuraygir National Park. Fourteen of the 20 waterbodies represented new locality records and another four had recently been documented to support the species. It was also found in Lake Hiawatha and Tick Gate Swamp, two water bodies historically documented to support the species. The status of the species within another historically recorded waterbody, Bookram Creek, remains unclear, as it was not detected despite extensive and intensive sampling of the creek and surrounding drainages.

During both surveys, large variations were recorded in the relative abundance of Oxleyan pygmy perch among sites. The differences possibly may be attributed to factors such as seasonal changes in population size, habitat characteristics, competition with other native and introduced fish species, and/or the extreme drought conditions experienced during the study. Most populations appeared to be recruiting given the presence of both mature and juvenile fish.

Oxleyan pygmy perch were primarily found in lakes, swamps and creeks draining sandy wallum heath as well as in several waterbodies created or modified by sand mining,. Fish were typically captured in sandy, shallow habitats with no visible signs of flow. Aquatic vegetation, plant litter, timber and steep or undercut banks fringed with overhanging vegetation provided instream cover. The waters were acidic (pH < 7) and fresh, had dissolved oxygen levels of 2.50 mg. L^{-1} or higher, ranged in temperature from approximately 11 to 23° C, were clear to darkly stained with organic acids, and were generally not turbid. Slight habitat differences were apparent at three creeks, which drained through a complex of either wallum heath or melaleuca swamp and tall woodland forest and had a compound substratum comprised of sand and clay. A fourth creek flowed through a swamp complex growing on grey acid soil, illustrating that given appropriate instream cover and water quality conditions, the species is capable of inhabiting a variety of freshwater ecotypes. Insights into the environmental tolerances of pygmy perch were gained through sampling within a creek characterised by estuarine waters in its lower reaches and anoxic conditions (extremely low dissolved oxygen concentrations) in its lower and upper reaches. The species was only captured in the middle reaches where waters were fresh and oxygen levels were higher. However the oxygen concentrations were still at a level that generally causes fish stress, suggesting that pygmy perch can tolerate hypoxic but not anoxic conditions. Evidence from other fieldwork suggests the species can also tolerate slightly saline waters.

The majority of Oxleyan pygmy perch populations sampled were relatively secure within National Park estate, although a number of anthropogenic impacts and threats were evident. Populated creeks draining out of reserves became heavily degraded within agricultural land. Disruption to fish passage was also observed. Logging activities occurred at one location. Potential human impacts and water pollution associated with public access also threatened several populations. In addition, 44% of waterbodies that had Oxleyan pygmy perch also supported the noxious pest fish, eastern gambusia. Stocked populations of the predatory Australian bass were also detected within the Lake Hiawatha and Lake Minnie Waters near Wooli. Stream channelisation, proposed urban development, extreme drought conditions intrinsically linked to global warming, wild and prescribed fires, and fire management activities are also considered a threat to the species.

Sites north of the north coast conservation system generally had more anthropogenic disturbance than those to the south or west of this area. However, the waterbodies surveyed to the north and south of the conservation system more closely resembled habitats typically occupied by Oxleyan pygmy perch than those located further west. With approximately half of these habitats considered degraded, human activities may have had a significant influence on the distribution patterns of this species. The apparent absence of the Oxleyan pygmy perch from habitats that would typically support the species, particularly those to the north of the conservation system (i.e. within its overall NSW/Queensland distributional range) suggests that the fish may have either never inhabited this area or have become locally extinct.

The results of this study, in conjunction with other post-2000 survey data reveal that the Oxleyan pygmy perch has been documented from 86 lakes, swamps, creeks and smaller tributary streams within 67 permanently connected, unfragmented (i.e. contiguous) drainage systems in NSW. These systems occur within eight subcatchments of the Richmond and Clarence River systems and are restricted to approximately 104 kilometres of sandy coastal lowlands encompassed by Broadwater, Bundjalung and Yuraygir National Parks and bordering habitats. Occupied waterbodies are typically situated within eight kilometres of the coast at elevations of less than 30 metres above sea level.

On a broader scale, the overall geographic distribution of the Oxleyan pygmy perch is known to encompass approximately 534 kilometres of coastline from Coongul Creek (Fraser Island, Queensland) south to an un-named tributary of the Wooli River, NSW. The species is rarer and has a more fragmented distribution in south-east Queensland than in NSW. The prevalence of populations in NSW has been attributed to the dispersal of fish across expansive low lying plains during high rainfall events or large floods, thereby allowing pygmy perch to colonise new drainage systems or perhaps recolonise previously disturbed areas. However, the Queensland and NSW populations no longer appear to intermix as they are separated by approximately 250 kilometres of coastline. There is also strong evidence of a northward contraction of the southern distributional limit in the last 30 years and this species is no longer found in several localities where it was collected between 1929 and 1976 (Beerwah Forest, Queensland, and Bookram Creek, Cassons Creek and near Coraki, NSW). Since 2000, several localities near Evans Head have also been cleared for development and the subsequent status of affected populations is unknown. There have been opportunities in the recent geological past for the species to spread along the east coast during times of lower sea levels.

Past effects of the Mount Warning shield volcano, recent marine transgressions, climatic conditions such as droughts, and/or anthropogenic impacts may be responsible for current distribution patterns. Research into the tolerances of the Oxleyan pygmy perch to changes in habitat and water quality would assist in understanding factors influencing these distribution patterns.

A number of recommendations are made to assist in effectively managing processes threatening the survival of the Oxleyan pygmy perch. These include formally protecting water bodies supporting the species; restoring fish passage; rehabilitating degraded habitats; working with landowners and local councils to conserve populations located outside of protected areas; increasing public awareness and fostering community ownership and support; mitigating potential impacts of fire management practices; increasing scientific knowledge of the variables driving population fluctuations and persistence; investigating and managing the threats posed by introduced species; and regular monitoring of Oxleyan pygmy perch populations. An intensive survey of Bookram Creek in Yuraygir National Park may be required to assist in determining whether Oxleyan pygmy perch still inhabit this system. Undisturbed potential habitats surrounding the north coast conservation system may also need to be re-surveyed to conclusively validate the absence of the species in these areas.

Introduction

Background

The biological diversity of the world is rapidly changing and declining as a consequence of human activities (Pimm *et al*. 1995; Sala *et al*. 2000). Fresh waters, in particular, are experiencing major losses in biodiversity (Dudgeon *et al*. 2006). Freshwater fishes are recognised as the most highly threatened of all vertebrate groups, with estimates of extinction in excess of 20% of described fish species in the near future (Leidy and Moyle 1998, cited in Duncan and Lockwood 2001). The highly endemic fish fauna of Australia is no exception, with the distributions and abundances of many species declining significantly since European settlement (Wager and Jackson 1993). Lintermans (2013) reported that 74 of the continent's 256 freshwater fish species (approx. 30 %) are listed as threatened under Commonwealth, State and/or Territory legislation.

There are many probable causes of the decline of Australian native freshwater fishes (Lake 1971; Cadwallader 1978; Pollard *et al*. 1980, 1990; Ingram *et al*. 1990; Koehn and O'Connor 1990; Faragher and Harris 1993; Wager and Jackson 1993; Schiller *et al*. 1997; Morris *et al*. 2001; Pusey *et al*. 2004). Pusey *et al*. (2004) classified the processes threatening Australian fishes into seven categories including hydrological alteration; loss of longitudinal and lateral connectivity; changes in habitat structure, quality and chemical composition; interactions with alien species (i.e. introduced from overseas) and translocated native species; overexploitation; global climate change; and inadequate knowledge and understanding. Threatening processes are often interlinked, their effects can be synergistic and cumulative, and rarely is one factor alone responsible for a species' decline (Groom 2006). For example, climate change has been linked to increased aridity (Karoly *et al*. 2003), which in turn may reduce lateral connectivity among drainage systems.

Australian Commonwealth, State and Territory legislation provides for the protection, conservation and recovery of threatened aquatic species, populations and ecological communities. Under the Commonwealth *Environmental Protection and Biodiversity Act 1999* (EPBC Act) and New South Wales (NSW) *Fisheries Management Act 1994* (FM Act) statutory recovery plans have been prepared for some taxa which aim to return each species to a position of viability in nature, and outline the actions that government agencies and other organisations have agreed upon to promote species recovery. Recovery planning largely involves mitigating human impacts by implementing management approaches based on a strong understanding of a species' conservation biology (Dudgeon *et al*. 2006). This includes knowledge of a species' evolution and biogeography, patterns of genetic variation, habitat associations and environmental tolerances, life history, and population dynamics within the context of the biophysical factors and threatening processes influencing its long-term viability (Burgman and Lindenmayer 1998; Meffe *et al*. 2006). Unfortunately, this information is often lacking for many of Australia's threatened fishes (Wager and Jackson 1993; Morris *et al*. 2001; Knight and Butler 2004). Hence, research that generates relevant and strategically-important biological and ecological information forms the basis of the development and implementation of effective recovery programs.

This report provides details of two fish surveys undertaken in NSW by the Department of Primary Industries (NSW DPI) to establish the distribution and conservation status of the Oxleyan pygmy perch *Nannoperca oxleyana* Whitley, a small, freshwater fish listed as 'endangered' at an international, national and state level. The surveys were undertaken to inform the development of a national recovery plan for the species which was adopted by the Commonwealth and NSW Governments in 2006. Specific objectives were to establish the distributional limits of the species; document the locations, habitats, relative abundance, and size structure of extant populations; identify potential factors influencing these distribution and abundance patterns; and to provide management recommendations for conserving and recovering the species based on the survey information.

Oxleyan pygmy perch

Oxleyan pygmy perch (*Nannoperca oxleyana*) is a very small perch-like fish restricted to the Oxleyan faunal region of coastal mid-eastern Australia (Whitley 1940). The species grows to approximately 60 mm in total length (Knight 2000a) and is characterised by a moderately laterally compressed body, one deeply notched dorsal fin and a truncate caudal fin (Figure 1). Dorsal fin counts include six to eight spines and seven to nine rays. Anal fin counts include three spines and seven to nine rays (Whitley 1940; Kuiter and Allen 1986). Further distinguishing features include the absence of a lateral line, a small mouth reaching to just below the eye and enlarged teeth in its lower jaw. The body is covered in ctenoid scales and is light brown to olive in colour, darker on the back, with a conspicuous round black spot with an orange margin at the base of the caudal fin. The fins are mainly clear except during breeding when males develop more intense red and brown fin and body colouration than females, and have jet black pelvic fins (Knight *et al*. 2007a).

Figure 1 The Oxleyan pygmy perch *Nannoperca oxleyana*.

Oxleyan pygmy perch belong to a group of small (< 90mm), freshwater fishes endemic to the freshwater drainage systems of southern Australia. Although previously considered members of the family Nannopercidae, the two genera of pygmy perch *Nannatherina* and *Nannoperca* are now classified as Percichthyids (Jerry *et al*. 2001; Hoese *et al*. 2006). Three of the six described species of *Nannoperca* are currently threatened with extinction nationally (Morris *et al*. 2001; IUCN 2009), with the Oxleyan pygmy perch formerly recognised as the most threatened member of the genus. This species is listed as endangered by the IUCN (IUCN 2009), by the Australian Society for Fish Biology and under the EPBC and FM Acts. The classification, although differing slightly among the various conservation listings and legislation, generally includes those taxa that have suffered a population decline over all or most of their range and are in danger of extinction in the near future unless the factors threatening their survival cease to operate (Crook 1999; NSW Fisheries 1999; IUCN 2000; DEH 2005). The Oxleyan pygmy perch is also listed as vulnerable under the Queensland *Nature Conservation Act 1992*.

Oxleyan pygmy perch has a very restricted and patchy geographic distribution within the coastal, freshwater wallum (*Banksia* dominated heath) ecosystems of northern NSW and southern Queensland (Arthington 1996; Knight 2000a; Pusey *et al*. 2004). Habitat destruction, fragmentation and degradation associated with intensive coastal development in this region over the last 50 to 100 years are considered to have caused severe declines in distribution and abundance, as have adverse interactions with the alien (i.e. introduced from overseas) noxious pest fish, eastern gambusia (*Gambusia holbrooki* Girard), and over-collection for aquarium purposes (Arthington 1996; Kuiter *et al*. 1996; Pusey *et al*. 2004; NSW DPI 2005).

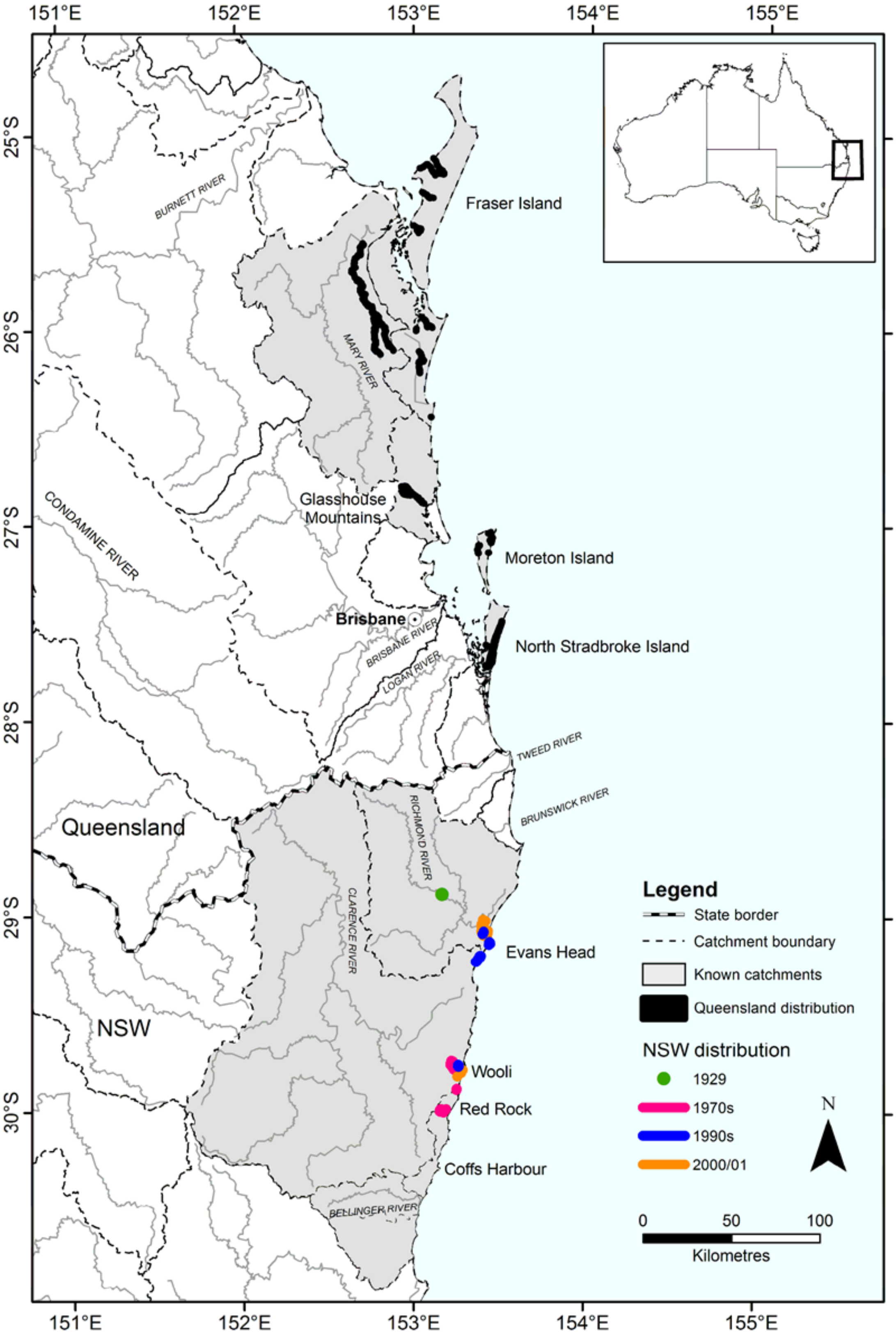
Rationale for the Project

Aspects of the conservation biology of the Oxleyan pygmy perch have been reviewed by Wager and Jackson (1993), Arthington (1996), Kuiter *et al*. (1996), Knight (2000a, 2002), Thompson *et al*. (2000), Morris *et al*. (2001), Pusey *et al*. (2004) and NSW DPI (2005). Based on research priorities identified by Knight (2002), the national recovery plan outlines a number of initiatives designed to fill biological knowledge gaps and gather information necessary to plan recovery actions (NSW DPI 2005). Information is required on the species' distribution and population genetics in NSW, life history, population dynamics, ecology, and the threats posed by introduced species. The current study aimed to address gaps in the knowledge of the distribution and conservation status of populations in NSW. The rationale for undertaking this research is discussed below.

The most serious threat to Oxleyan pygmy perch is habitat degradation, fragmentation and loss associated with residential development, road construction, agriculture, forestry, sand mining, drainage modification, water pollution and tourism activities (Pusey *et al*. 2004; NSW DPI 2005). Management and mitigation of these impacts requires detailed knowledge of the locations and habitats of extant populations. Under provisions of the FM Act, the whole or any part of the habitat critical to the survival of a species, population or endangered ecological community may be declared as Critical Habitat. The FM Act also integrates the conservation of threatened species into development control processes established by the NSW *Environmental Planning and Assessment Act 1979* (EPA Act). As part of the develop assessment process, consent authorities are required to assess development impacts on threatened species, and to consider if activities are a class of development recognised as a threatening process (NSW DPI 2005). Additionally, activities and developments that do not require approval under the EPA Act may require licensing under the FM Act if they are likely to harm a threatened species, population or endangered ecological community, or their habitat. Careful consideration must be given to the effects of proposed developments or activities on threatened species and their habitats. I&I NSW is responsible for providing relevant planning authorities with detailed information regarding the precise locations of known and potential habitats occupied by an aquatic threatened species in NSW.

Numerous limnological and aquatic faunal surveys have documented the fish communities of the coastal heathlands and surrounding catchments of south-eastern Queensland (Arthington 1996). Despite extensive and intensive sampling, Oxleyan pygmy perch has only been recorded from 36 localities since 1990 (Knight and Arthington 2008; D. Richardson, WBM Oceanics, pers. comm.). Populations are restricted to the Mary, Noosa, and Maroochy Basins, and Fraser, Moreton and North Stradbroke Islands (Figure 2). One record also exists for the Pine River Basin (NSW DPI 2005) but this is thought to have been a translocation into a farm dam which now no longer exists (R. Wager, Rocksberg, Queensland, pers. comm.).

Figure 2 Map of the known distribution of Oxleyan pygmy perch prior to the commencement of this study in May 2001. NSW localities are distinguished by time of discovery.



In contrast to the situation in Queensland, relatively few studies have been undertaken of the fish communities within the coastal heathlands of northern NSW (Knight 2000a). Furthermore, prior to the commencement of the recovery planning process for Oxleyan pygmy perch in 2000, there had been limited targeted sampling for this species. Australian Museum records reveal that the species was first collected in 1929 from either the Richmond River or two small adjacent lentic water bodies on private land at Tatham, a rural area 35 km north-west of Evans Head (Whitley 1940; Knight 2000a). In the 1970s, the species was collected from Lake Hiawatha (Llewellyn 1983); Bookram Creek (Llewellyn 1983; believed be 'Wooli Creek' in the Australian Museum database) and Tick Gate Swamp near the township of Wooli (Timms 1982); and from Cassons Creek near Red Rock (G. Schmida, Lower Beechmont, Queensland, pers. comm.) (Figure 2). The species was again captured from the Wooli area in 1995, during a crayfish survey of Lake Minnie Water (Lawrence 1998), and from two swamps surrounding Lake Hiawatha in 2000 (A. Lo, ANGFA NSW, pers. comm.). Three records from the Richmond River catchment also exist near Evans Head, derived from separate surveys during the 1990s (Arthington 1996; Bishop 1999; Walker and Walker 1999; WBM Oceanics Australia 2000). Preliminary sampling undertaken as part of the recovery planning process took place within the wallum habitats to the west and north of Evans Head and resulted in the capture of Oxleyan pygmy perch from 24 previously undocumented localities (Knight 2000a). Prior to the commencement of the current project in May 2001, three more water bodies in this area were found to support the species (NSW DPI Freshwater Fish Research Database).

With the exception of the Tatham area and Cassons Creek, all of the distribution records occur within a large tract of coastal wallum ecosystems within or adjacent to Broadwater, Bundjalung and Yuraygir National Parks (termed the 'north coast conservation system' [Daly and Daly 2000]). Of these, Broadwater National Park and the surrounding heathland is the only area thoroughly surveyed, accounting for 28 (85%) of recent sightings. The well-established presence of Oxleyan pygmy perch within and adjacent to this park makes the reserve one of the most important sites for the long-term conservation of this species. However, large tracts of similar habitat in NSW had not been thoroughly surveyed and it was likely that the known distribution would be expanded upon further investigation (Knight 2000a).

The lack of targeted fish surveys within the coastal wallum ecosystems of northern NSW is highlighted by a review of the available literature on the dune lakes of coastal mid-eastern Australia (Knight 2000b). The review found that the lakes in Bundjalung National Park had been the focus of the least number of limnological studies overall, with only five out of 42 studies having examined aspects of seven lakes (defined as lentic systems > 1 hectare in size) in this area (Timms 1970, 1982, 1992a; Timms and Watts 1981; Arthington 1996). A recent survey by Southern Cross University within Commonwealth Land known as the South Evans Head Weapons Range (Harrison *et al*. 2002) brought the total number of lakes studied in Bundjalung National Park to nine, and hence only 24% of the 38 lakes within this reserve had been studied. Alternatively, there are six dune lakes in Yuraygir National Park, four of which had been the subject of published studies (Timms 1969, 1970, 1982; Timms and Watts 1981; Arthington and Watson 1982; Arthington 1996). Even so, of the limited number of limnological studies within these two national parks, only four studies had undertaken sampling of fish communities (Racek 1954-57 in Timms 1969; Timms 1982; Arthington 1996; Harrison *et al*. 2002). Information on the fish communities of several lakes, swamps and creeks has also been gathered through opportunistic surveys by ANGFA (Gerkin 2001), Australian Museum collections, private consultants and universities, and personal communication with staff based at the Weapons Range.

The situation was similar for the aquatic systems of coastal heathlands occurring outside of the north coast conservation system. A review of published literature accompanied by conversations with staff from the NSW Office of Environment and Heritage (OEH) revealed that only one (Myall Lakes National Park) of five coastal national parks protecting wallum ecosystems from south of Yuraygir National Park to Newcastle, had been surveyed for freshwater fish. The situation is slightly different north of Broadwater National Park, between the township of Broadwater and the Queensland border, with one broad-scale and several small-scale targeted surveys all failing to capture Oxleyan pygmy perch (Arthington 1996; Bishop 1999; Greenloaning Biostudies 2000; FRC Environmental 2001; The Ecology Lab 2002). However, a number of heathland ecosystems both in and outside National Park estate north of Broadwater National Park had not yet been investigated.

There was a need therefore to undertake surveys to locate populations of the Oxleyan pygmy perch inhabiting the areas surrounding the north coast conservation system and in doing so establish the species' distribution limits in NSW. Following this, a survey of Bundjalung and Yuraygir National Parks was required to establish the species' persistence at previously recorded localities and to locate populations in previously unsurveyed habitats. The habitat, relative abundance, and size structure of extant populations were also documented and factors potentially influencing the species' distribution and abundance patterns were identified. Information was also gathered on the distributions of other fish species within the study area.

Methods

The study consisted of two separate surveys. The first survey was an extensive search for Oxleyan pygmy perch to the north, west and south of the north coast conservation system (Broadwater, Bundjalung and Yuraygir National Parks; refer to Introduction for more details). The second survey was an intensive search for the species within Bundjalung and Yuraygir National Parks. The general methodology adopted for both surveys is outlined below. Methods specific to each survey are also detailed where applicable.

Study area

Location and extent of each survey area

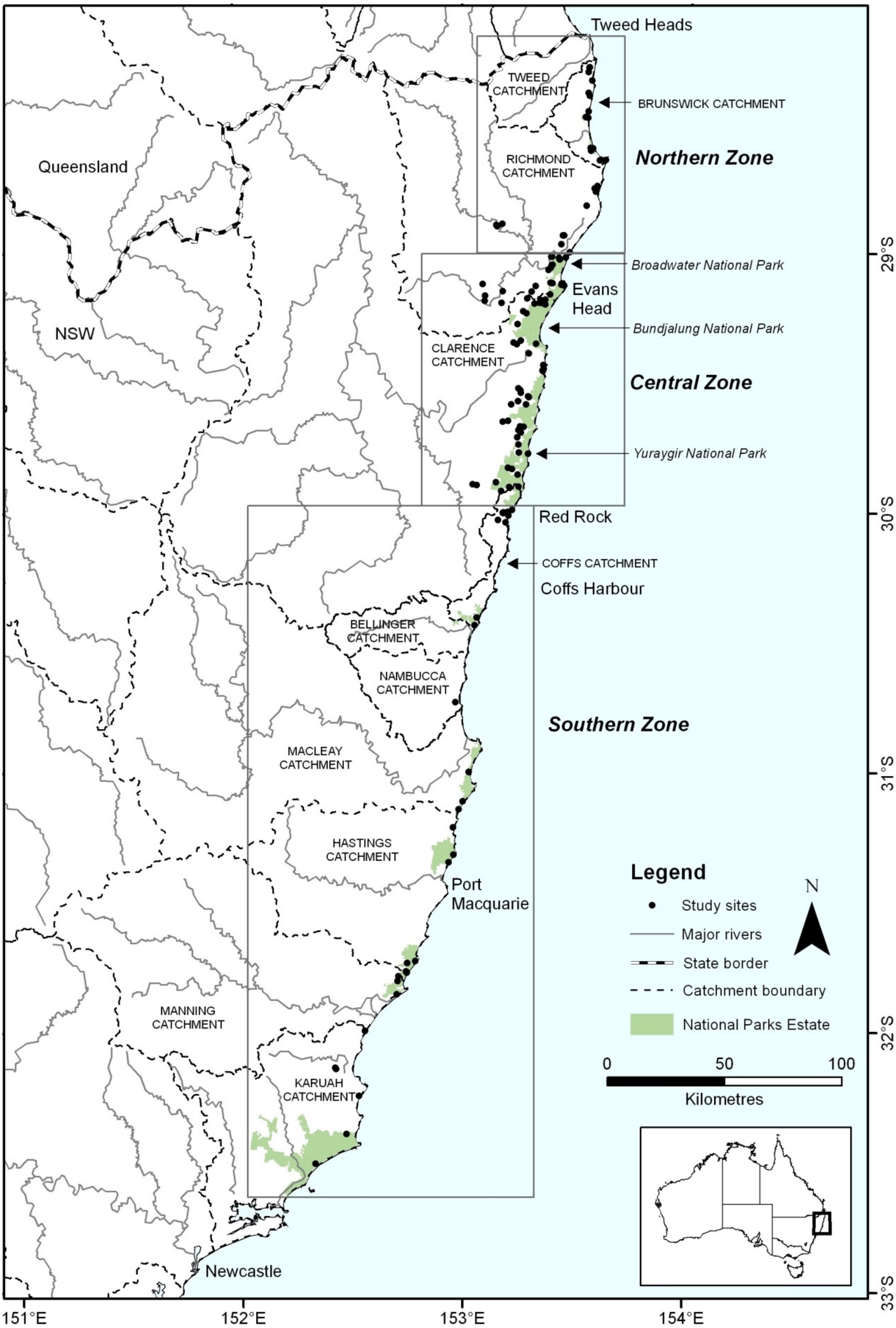
Survey 1

The area of the first survey extended approximately 550 kilometres along the NSW north coast from the Queensland border south to Myall Lakes National Park (28º 10’ S. - 32º 38’ S.; Figure 3). This area encompasses the most concentrated network of dunal waterbodies (freshwater systems occurring on coastal sands) in NSW (Timms 1982). Ten major drainage basins occur within the study area: Tweed, Brunswick, Richmond, Clarence, Bellinger, Nambucca, Macleay, Hastings, Manning and Karuah River systems. Based on historical and recent records, the designated survey area extended 40 kilometres inland within the Richmond and Clarence catchments, but was confined to wallum ecosystems within 10 kilometres of the coast within the remaining catchments. The study area was divided into three survey zones (Figure 3). The northern zone extended from the Queensland border to the northern boundary of Broadwater National Park, the southern zone included the coastal area between the southern boundaries of Yuraygir and Myall Lakes National Parks, while the area in between these two zones constituted the central zone.

Survey 2

Bundjalung and Yuraygir National Parks protect approximately 17,738 and 30,406 hectares of coastal land respectively, between the Evans River, near Evans Head and the township of Red Rock (Wright 1991) (29° 06’S. - 29° 59’S; Figure 3). The two reserves are approximately 12-13 kilometres across at their widest points but average roughly four to eight kilometres in width. The Pacific Ocean fronts the 38 and 60 kilometre eastern boundaries of Bundjalung and Yuraygir National Parks, respectively, while the Pacific Highway generally marks the western boundary. There is a small gap in the study area of approximately seven kilometres, in which the Clarence River and the surrounding townships of Iluka, Woombah and Yamba separate the two reserves. A number of small townships exist to the south of Yamba, including Angourie, Brooms Head, Sandon, Minnie Water, Diggers Camp and Wooli. This survey area falls within three major drainage systems including the Richmond, Clarence and Bellinger River Basins.

Figure 3 **Map of the study area in NSW north of Newcastle including the locations of the sites (black dots) surveyed in the three zones during the first survey round and the locations of Bundjalung and Yuraygir National Parks, which were sampled during the second survey. Refer to Figures 16 to 18 for the locations of the sites sampled in survey 2.**



Environmental characteristics

Sampling was primarily concentrated within the coastal wallum environments within the two survey areas. Wallum water bodies drain over siliceous (quartz dominated) sands and are distinguished by their very low salinity and nutrient status, low magnesium and calcium hardness, low pH (3-7) and a high organic content (Timms 1986; Arthington *et al.* 1990; Arthington 1996). Aquatic plants such as frogsmouth (*Philydrum lanuginosum*), giant sedge (*Lepironia articulata*) and *Baloskion* (ex. *Restio*) *pallens* often proliferate while broad-leaved paperbark (*Melaleuca quinquenervia*), heath banksia (*Banksia ericifolia*), wallum banksia (*Banksia aemula*) and a variety of other species of heath are common around the margins (NPWS 1997; Earley 1999; Griffith *et al*. 2003). Communities dominated by introduced bitou bush (*Chrysanthemoides monilifera*) and horsetail oak (*Casuarina equisetifolia*) also occur in some disturbed areas (Morand 1996).

Coastal floodplain swamps and swamp complexes were also sampled. Swamp complexes are dominated by broad-leaved paperbark and/or swamp oak (*Casuarina glauca*), while rushes (*Juncus* spp.) and common reed (*Phragmites australis*) typically form an understorey where the forests border on open swamps. Swamps include shallow marshes and meadows vegetated by sedges and aquatic herbs (Earley 1999; Lenehan 2000).

In the first survey round, sampling was undertaken further inland in the Richmond River's extensive alluvial floodplain tributaries and oxbow lakes. Siliceous sands, earthy sands, acid soils and some organic grey soils are widespread and allow partially cleared tall open-forest and woodlands, including dry sclerophyll, swamp sclerophyll, heath and gallery forests to dominate. The channel margins and swampy areas are dominated by broad-leaved paperbark, river oak (*Casuarina cunninghamiana*) and swamp mahogany (*Eucalyptus robusta*) (Morand 1994). Waters are often stained with organic acids and have a low pH. Environments sampled further south in the Clarence River catchment were characterised by low hills, rises and drainage plains formed on sandstones and shales. Quartz rich sandy soils support vegetation such as red bloodwood (*Eucalyptus gummifera*), blackbutt (*E. pilularis*), scribbly gums (*E. signata*) and red mahogany (*E. resinifera*), while poorly drained, clayey soils support forests distinctly dominated by spotted gum (*E. maculata*), grey box (*E. moluccana*) and ironbark (*E. crebra*) (Morand 2001). Numerous rivers and creeks drain through tall open-forest communities, while small ponds are also present. Extensively cleared areas are common, and a large proportion of the existing forests are logged.

To provide an overview of the fish fauna of the two study areas, catch data were compiled from the NSW DPI Freshwater Fish Research Database. Four large, three medium and 16 small-bodied native freshwater fish taxa have been recorded to naturally occur within the study areas (Table 1). The Eleotridae is the most specious and widespread family with five of the seven species recorded from all 11 catchments. In contrast, a number of species have only been documented from three or fewer catchments, including the Marjorie's hardyhead (*Craterocephalus marjoriae*), western carp-gudgeon (*Hypseleotris klunzingeri*), mountain galaxias (*Galaxias olidus*), eastern cod (*Maccullochella ikei*) and Oxleyan pygmy perch. Records for the Oxleyan pygmy perch exist from the Richmond and Clarence River systems, but the species has also been historically recorded from the Bellinger River catchment (see Introduction). Similarly, the endangered eastern cod has a distribution restricted to the Richmond and Clarence River catchments. Three medium-bodied Australian native species have also been translocated from outside their natural ranges into the two catchments. An additional seven alien species have been introduced throughout the study area from outside of Australia. Apart from the eastern gambusia, these fish are not widely recorded.

Table 1 **Freshwater fish species recorded in each catchment within the study area. L and S = large- (> 300 mm) and small-bodied species (< 300 mm); E = endangered species; A = alien species; T = translocated species. Data sourced from the NSW DPI Freshwater Fish Research Database, except for the Oxleyan pygmy perch record from the Bellinger catchment which was provided by G. Schmida (Lower Beechmont, Queensland, pers. comm.).**

Family	Scientific name	Common name (Size, Status)	Tweed	Brunswick	Richmond	Clarence	Bellinger	Nambucca	Macleay	Hastings	Manning	Karuah
Ambassidae	*Ambassis agassizii*	Olive perchlet (S)	X	X	X	X						
Anguillidae	*Anguilla australis*	Shortfinned eel (L)		X	X	X			X	X	X	X
	Anguilla reinhardtii	Longfinned eel (L)	X	X	X	X	X	X	X	X	X	X
Atherinidae	*Craterocephalus marjoriae*	Marjorie's hardyhead (S)	X			X						
	Craterocephalus stercusmuscarum	Unspecked hardyhead (S)	X									
Cichlidae	*Rocio octofasciatum*	Jack Dempsey cichlid (S, A)				X						
	Geophagus	Pearl cichlid (S, A)	X									
Clupeidae	*Potamalosa richmondia*	Freshwater herring (S)	X		X	X	X	X	X	X	X	
Cyprinidae	*Carassius auratus*	Goldfish (L, A)			X	X						X
	Cyprinus carpio	Common carp (L, A)	X		X				X			
Eleotridae	*Gobiomorphus australis*	Striped gudgeon (S)	X	X	X	X	X	X	X	X	X	X
	Gobiomorphus coxii	Cox's gudgeon (S)	X	X	X	X	X	X	X	X	X	X
	Hypseleotris	Empire gudgeon (S)	X	X	X	X	X	X	X	X	X	X
	Hypseleotris galii	Firetailed gudgeon (S)	X	X	X	X	X	X	X	X	X	X
	Hypseleotris klunzingeri	Western carp gudgeon (S)			X							
	Philypnodon	Flathead gudgeon (S)	X	X	X	X	X	X	X	X	X	X
	Philypnodon macrostomus	Dwarf flathead gudgeon (S)		X	X	X	X	X		X	X	X
Galaxiidae	*Galaxias maculatus*	Common jollytail (S)					X	X				X
	Galaxias olidus	Mountain galaxias (S)				X			X			
	Galaxias brevipinnis	Climbing galaxias (S)				X	X					
Melanotaeniidae	*Melanotaenia duboulayi*	Doboulay's rainbowfish (S)	X	X	X	X	X	X	X	X		
	Rhadinocentrus	Soft-spined rainbowfish (S)		X	X	X	X					
Mordacidae	*Mordacia spp.*	Unidentified lamprey (S) ammocoetes			X				X			
Mugilidae	*Trachystoma petardi*	Freshwater mullet (S)	X	X	X	X	X	X	X	X	X	X
Percichthyidae	*Maccullochella ikei*	Eastern cod (L, E)			X	X						
	Macquaria ambigua	Golden perch (L, T)			X	X						
	Percalates novemaculeata	Australian bass (L)	X	X	X	X	X	X	X	X	X	X
	Nannoperca oxleyana	Oxleyan pygmy perch (S, E)			X	X	X					
Percidae	*Perca fluviatilis*	Redfin perch (L, A)							X			
Plotosidae	*Tandanus tandanus*	Freshwater catfish (L, T)										X
	Tandanus sp1	Willung (L)					X	X	X	X	X	
	Tandanus sp2	North coast freshwater catfish	X	X	X	X						
Poeciliidae	*Gambusia holbrooki*	Eastern gambusia (S, A)	X	X	X	X	X	X	X	X	X	X
	Xiphophorus helleri	Green swordtail (S, A)		X								

Family	Scientific name	Common name (Size, Status)	Tweed	Brunswick	Richmond	Clarence	Bellinger	Nambucca	Macleay	Hastings	Manning	Karuah
Pseudomugilidae	*Pseudomugil signifier*	Pacific blue-eye (S)	X	X	X	X	X	X	X	X	X	X
Retropinnidae	*Retropinna semoni*	Australian smelt (S)	X	X	X	X	X	X	X	X	X	X
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout (L, A)				X			X	X	X	
Terapontidae	*Amniataba percoides*	Banded grunter (S, T)				X						
	Bidyanus bidyanus	Silver perch (S, T)				X						

Land use

Survey 1

Land use within the area of the first survey is varied and largely consists of urban and tourism development, agriculture, forestry, conservation areas and scattered areas of vacant and reserved Crown Land. Population growth on the north coast has increased considerably in the last few decades, resulting in the clearing, degradation and fragmentation of large areas of coastal habitat (Morand 1994, 1996; Zann 1996; Atkinson 1999; Milford 1999). Preceding this, however, the mining of mineral sands was one of the most significant activities. Mining for heavy metals such as rutile and zircon occurred in most of the coastal environments from 1932 onwards (Morley 1981; NPWS 1998). Extensive areas of dunes and back-barrier aquatic ecosystems were dredged, resulting in the natural system being highly altered. Environmental concerns led to most sand mining gradually being phased out by 1983 through the non-renewal of leases (Wright 1991), with current operations restricted to only a few small areas (Zann 1996). However, significant areas of the north coast remain disturbed and partially cleared as a legacy of past mining activities (Zann 1996; Wright 1991). It is believed that sand mining has had a major impact on the habitat of the Oxleyan pygmy perch and may have played a significant role in population declines (NSW DPI 2005).

Survey 2

Bundjalung and Yuraygir National Parks were gazetted in 1980 and were formed from the amalgamation of smaller reserves within the areas and adjoining lands (Wright 1991). The Commonwealth government retained a large portion of land in the north of Bundjalung National Park which has been utilised since 1940 for military purposes as a target practice area for weapons systems (Morand 2001; Harrison *et al*. 2002). The National Parks have protected habitats from the intensive development experienced along much of the NSW north coast, although certain areas have still been degraded by human activities. Historical land use practices within the area included gold mining, alluvial mining, bee keeping, and the agistment of cattle during droughts and floods (NPWS 1993, 1997; Daly and Daly 2000). Sand mining for heavy metals was also once widespread throughout the area but did not occur within the 'Weapons Range' (Wright 1991; Morand 2001). Fire has also modified the environments within the parks. In particular, Bundjalung National Park has had a high incidence of deliberately lit fires with 43 fires occurring in the park between 1975 and 1997. This high fire frequency is at a level that is reportedly degrading the vegetation communities (NPWS 1997). It is well known that fire may have negative effects on native fish populations (e.g. Chessman 1986; Bozek and Young 1994; Gerla and Galloway 1998), but it remains unclear whether natural, prescribed or deliberately lit fires have influenced the distribution of Oxleyan pygmy perch. Other impacts within the parks have occurred via the introduction of a number of feral animal species and exotic plants such as foxes, pigs, horses and bitou bush (NPWS 1997).

Despite these impacts, the reserves are considered of high conservation value, affording protection to geologically significant landscapes, cultural heritage sites, diverse terrestrial and aquatic habitats, and numerous threatened and non-threatened plants and animals (NPWS 1993, 1997; Daly and Daly 2000). For example, they protect headlands, fore dunes, rivers, lagoons, creeks, wetlands, heathlands, coastal forests and tidal lakes. In addition, the national parks cover a large portion of one of the two extensive sandy coastal lowlands in NSW (Timms 1982). Significant water bodies within the national parks include the estuarine and freshwater systems of the Esk River, Jerusalem Creek and Oyster Creek in Bundjalung National Park, and the Wooli River, Sandon River, Lake Arragan and Lake Cakora in Yuraygir National Park. In addition, Lake Minnie Water and Lake Hiawatha, two large freshwater dune lakes, are located near Wooli. Numerous relatively disturbed, small freshwater creeks, ponds, lakes and swamps are also distributed throughout the wallum ecosystems on the coastal sandy lowlands and surrounding high country.

Site selection

General site selection procedures

A variety of waterbodies including rivers, creeks, smaller branching tributaries, lakes, ponds and swamps were surveyed, as they have all been documented to support populations of Oxleyan pygmy perch (Arthington 1996; Knight 2000a). Typically, one site was surveyed in each waterbody selected. Survey sites were initially identified through examination of 1:25,000 topographic maps and aerial photographs. Areas of coastal heath or similar plant communities were targeted both within and outside national park estate. Priority was given to waterbodies that shared similar characteristics to those known to support Oxleyan pygmy perch (Table 2; Figure 5). To assist in identifying suitable sampling sites, information on soil types and vegetation communities was sourced from reference material by Morand (1994, 1996, 2001), Atkinson (1999) and Milford (1999). Similar information was also derived from consultation with landowners and staff from NSW DPI and OEH. Site selection was finalised in the field. Accessibility influenced the extent to which some areas were sampled. In addition, waterbodies too shallow or congested with macrophytes to be effectively sampled were excluded from sampling, as were those that lacked obvious freshwater fish habitat.

Table 2 Distinguishing characteristics of waterbodies inhabited by Oxleyan pygmy perch (adapted from Arthington 1996; Knight 2000a; Thompson *et al.* 2000). Refer to Knight (2000a) for comprehensive lists of aquatic and riparian flora species.

Parameters	Characteristics
Riparian vegetation	Broad-leaved paperbark (Melaleuca quinquenervia), Heath banksia (Banksia ericifolia), Coral fern (Gleichenia dicarpa), sedge (Baloskion (ex. Restio) tetraphyllus), Saw-sedge (Gahnia sieberiana), Lance beard-heath (Leucopogon lanceolatus)
Aquatic vegetation	Frogsmouth (Philydrum lanuginosum), Giant sedge (Lepironia articulata), Spike rush (Eleocharis spp.), aquatic moss (Sphagnum falcatulum), Jointed twig rush (Baumea articulata), sedge (Baloskion (ex. Restio) pallens), Small bog rush (Schoenus brevifolius), Saw-sedge (Gahnia sieberiana), rushes (Juncus spp.), Stonewort (Chara spp.), Bladderwort (Utricularia spp.)
Physical features	Depth < 1.5 m; Flow < 0.3 m. sec-1; Substrate: sand, mud/detritus
Instream cover	Undercut/steep banks, overhanging vegetation, aquatic plants, algae, aquatic moss, leaf litter, snags
Water quality	Temp: >12ºC; Dissolved oxygen: >2.15 mg. L-1; Conductivity: ≤ 353 μS.cm-2; pH: 3.3 – 6.5
Water Colour	Clear to darkly stained with organic acids
Indicator fauna	Soft-spined rainbowfish, honey blue-eye (Pseudomugil mellis; known only from Queensland), freshwater crayfish (Cherax cuspidatus)

Figure 4 Lake habitat of the Oxleyan pygmy perch in Broadwater National Park.

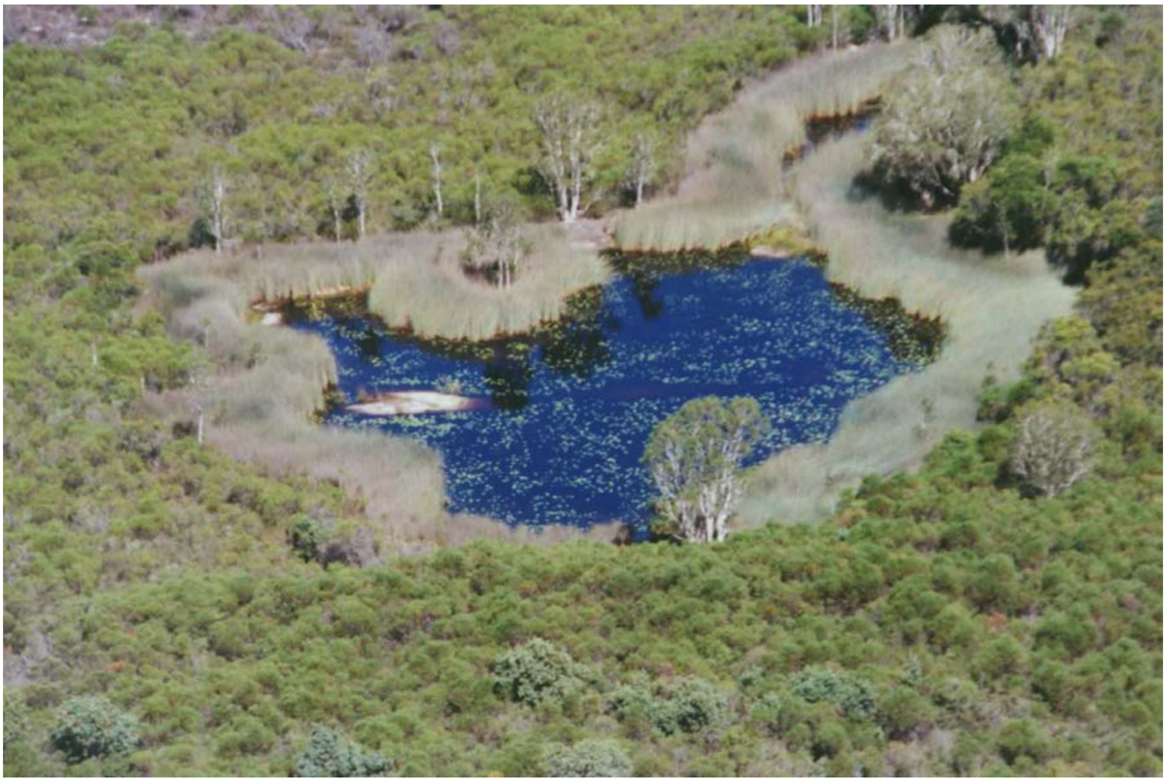
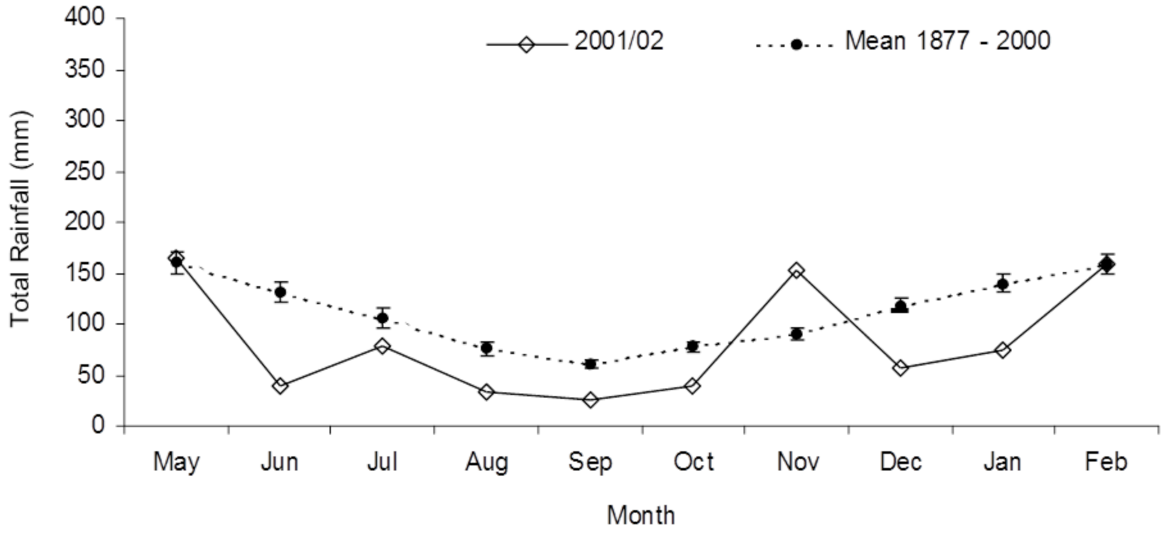


Figure 5 Swampy creek habitat of the Oxleyan pygmy perch in Broadwater National Park.

Sites sampled for survey 1

Initially, broad-scale surveys of 70 waterbodies were undertaken between May and August 2001. Following analysis of these data, a further 50 waterbodies were surveyed in the central zone between November 2001 and February 2002. Whilst in the majority of waterbodies only one site was surveyed, two sites were surveyed in each of two lotic water bodies found to support Oxleyan pygmy perch in an attempt to determine the limits of the species distribution within these systems. In addition, following new information regarding the historical record for Cassons Creek, a further six sites were surveyed within five waterbodies in the southern zone in August-September 2004. In 2002, Australia experienced extreme drought conditions (Karoly *et al.* 2003), with below average rainfalls in the study area during the survey period. For example, only 821 mm fell at Yamba during the main sampling period between May 2001 and February 2002, compared to the long-term average for this period of 1,117 mm (Figure 6). Consequently, 25 of the 128 survey sites were dry. Of the 103 wetted sites, a total of 93 sites within 90 waterbodies were deemed suitable for fish sampling.

Figure 6 **Total monthly rainfall (mm; ± standard error) recorded during the main survey period of May 2001 to February 2002 plotted against the long-term mean values for Yamba (BoM 2006).**



A breakdown of the numbers of sites visited, assessed and sampled in each zone is provided in Table 3. Details regarding the locations of sites within the study area of survey 1 are listed in Appendix 1, and their geographic positions are illustrated in Figure 3. Sites are numbered in a north to south and west to east direction.

Table 3 **Numbers of sites visited, assessed and sampled within each survey zone of the first survey.**

Sites	North Zone	Central Zone	South Zone	Total
Visited	28	70	30	128
Assessed	26	50	27	103
Sampled	24	44	25	93

Sites sampled for survey 2

An aerial survey was undertaken on 14 April 2002 to assist with selecting sites in Bundjalung and Yuraygir National Parks. In total, 92 sites were surveyed within 88 waterbodies. Initially, 62 waterbodies were surveyed in August-September 2002. Following analysis of these data, a further 26 waterbodies were surveyed between May and September 2004. Whilst most waterbodies were only surveyed at one locality, two sites were surveyed in one creek recorded in this study to be inhabited by Oxleyan pygmy perch and six sites were surveyed in five waterbodies recently documented to support the species by other researchers. Three sites were also surveyed within Lake Hiawatha, which was historically documented to support Oxleyan pygmy perch in the 1970s. Other historical records investigated included Tick Gate Swamp and the tributaries of Bookram Creek. As occurred in the first survey, extreme drought conditions prevailed at the time of surveying Bundjalung and Yuraygir National Parks. The mean annual rainfall for Evans Head, Yamba and Wooli of 926 mm was considerably lower than the long-term average of 1,405 mm. Higher rainfall was recorded in 2004 but was still 281 mm below average (BoM 2006). Consequently, 17 of the 92 sites were dry. Of the 75 wetted sites, 73 sites within 69 water bodies were deemed suitable for fish sampling. Details of each site surveyed are listed in Appendix 2 and their geographic positions are illustrated in Figures 16 to 18.

Fish sampling protocol

Sampling to detect rare species typically requires a large amount of sampling effort using multiple techniques (Angermeier and Smogor 1994; Jackson and Harvey 1997). As all fish sampling techniques may be biased towards particular species, the use of multiple gears provides an opportunity to catch a broader representation of species within the study area than would be possible using only one method (Weaver *et al*. 1993; Jackson and Harvey 1997; Harris and Gehrke 1997). Hence, in order to achieve a comprehensive record of the distribution of the Oxleyan pygmy perch and other fish species in the study area, a combination of passive trapping and either active seine netting or backpack electrofishing techniques were employed. In addition, two large lakes were sampled with an electrofishing boat, whereas dip netting was employed at sites too shallow or small to adequately sample with other methods

Fish sampling was based on the results of pilot experiments undertaken to identify a standardised, non-destructive sampling protocol that effectively and efficiently targeted Oxleyan pygmy perch. These methods were tested further in the field during this study and then published in the scientific literature (Knight *et al*. 2007b). Briefly, fish traps used were similar to those used in previous studies of Oxleyan pygmy perch and other small-bodied fishes (Arthington and Marshall 1993; Arthington 1996; Bishop 1999; Balcombe and Closs 2000; Knight 2000a). Traps measured 250 x 250 x 450 mm and constructed of 3 mm nylon mesh covering a rectangular, collapsible wire frame with an open, inverted funnel at each end with 40 mm openings. Traps were set for a period of 30 minutes (Knight *et al*. 2007b). Depending on site conditions, a maximum of 40 unbaited traps were set at 1.5-2.0 metre intervals on the substratum within a variety of microhabitats including aquatic vegetation, steep or undercut banks fringed with overhanging vegetation and open waters.

Backpack electrofishing and seine netting were also employed within similar microhabitats as traps, but were restricted in heavily vegetated or deep habitats. Site conditions (e.g. conductivity, depth, woody debris) generally dictated which active technique was used. The seine net, which was specifically designed to sample the narrow, overgrown drainage systems typical of the wallum ecosystems, was constructed from 3 mm, knotless (i.e. non-abrasive), polyester nylon mesh, measured 4 x 1.5 m, with a central pocket 1 m in length, a weighted foot-rope and a floating head- rope. Electrofishing was done with a Smith-Root model 12B, battery powered, backpack electrofisher, using a 280 mm diameter aluminium anode ring attached to a fibreglass handle, and a rat-tail cable cathode. Depending on conductivity, electrical output ranged from 200 to 500 volts of pulsed direct current (DC) at a fixed pulse rate of 60 Hz. Boat electrofishing was undertaken with a small 2.5 m aluminium punt fitted with a 2.5 kW Smith-Root model GPP 2.5 H/L generator. Output was set at low voltage (0-500) of 120 Hz pulsed DC at a 60% duty cycle. Affected fish were collected using a dip net. Conditions affected the amount of active sampling effort but, where possible, consisted of 2-3 seine shots or 10 minutes (elapsed time rather than electrofisher ‘on’ time) of electrofishing. Boat electrofishing consisted of 15 operations of 2 minutes (elapsed time) of electrofishing. Dip netting (without electricity) was undertaken for a period of 10 minutes.

At the completion of each operation (trapping, electrofishing, seine netting or dip netting), captured fish were identified to species level and counted. The weight (± 0.1 g) and total and standard length (± 0.5 mm) for all or a subset of Oxleyan pygmy perch specimens were recorded and genetic samples (fin clips) collected for future analysis. Following this, most fish were returned to the water unharmed. If large numbers of Oxleyan pygmy perch were captured at a previously unrecorded locality, a voucher specimen was sent to the Australian Museum. Permits pertaining to the collection of Oxleyan pygmy perch and to sampling within national park estate were obtained from NSW DPI and OEH, respectively.

Habitat assessment

General habitat assessment

A qualitative description of the habitat and water quality testing were undertaken at each site. Water depth and site width were estimated. Habitat values for riparian vegetation, mesohabitat (pool, run, riffle, rapid), flow, substratum composition, and instream vegetation and cover were scored using an AFOR scale (Abundant, Frequent, Occasional or Rare). The surrounding riparian communities and sedge and macrophyte assemblages were also identified to species level where possible. Temperature (°C), dissolved oxygen (mg. L^{-1}), pH, conductivity (µS. cm^{-1}) and turbidity (NTU) were recorded using a Horiba U10 water quality meter. Water colour was visually assessed and classified following criteria developed by Arthington (1996) as clear, light tannin, medium tannin, dark tannin, translucent/cloudy, or heavy suspended solids. Photographs were also taken to provide a permanent visual record of each site.

Assessment of Oxleyan pygmy perch habitat

A general assessment of human effects was made at each site supporting Oxleyan pygmy perch following criteria adapted from Arthington (1996) (Table 4). The five criteria (degree of disturbance, accessibility, threats to fish populations, abundance of introduced fish species and the land use status of the area) were ranked on a scale of one to five with the highest number representing no observable human effects.

Table 4 Criteria for ranking human effects at each site supporting Oxleyan pygmy perch. Criteria adapted from Arthington (1996).

Category	Rank	Description of Rank
Disturbance	5	Undisturbed, non-polluted, no clearing, no catchment input (pollution, sediment, etc.)
	4	Minimal clearing (<25% cleared), minor catchment input
	3	Some clearing (25-50% cleared), sand mining disturbance, some pollution, limited housing, minimal agriculture
	2	Moderate clearing (50-80% cleared), moderate pollution, forestry, some surrounding industry, agriculture and housing
	1	Major clearing (>80% cleared), heavy pollution, full industry, agriculture and housing
Access	5	Permission or permit necessary to enter area and accessible by walking only
	4	Permission or permit necessary to enter area and accessible by vehicle/boat
	3	General public access but 4WD or boat necessary
	2	Normal road outside of urban area
	1	Near urban area
General Threats	5	None, no catchment input
	4	Minor catchment input, access tracks
	3	Some catchment input, vehicle access, full camping facilities
	2	Some surrounding development and/or obstruction to fish passage
	1	Full industry, agriculture, housing
Introduced Fish	5	None captured or observed
	3	Small number captured or observed
	1	Large number captured or observed
Land Use Status	5	National Park
	4	Uncleared rural land
	3	Forestry or partially cleared rural land
	2	Cleared rural land
	1	Urban area

Additional habitat assessment undertaken during survey 1

In addition to the assessment of human effects made at Oxleyan pygmy perch capture sites (Table 4), the aquatic and riparian characteristics of each survey site throughout the study area of the first survey (excluding dry sites) were recorded. These data were used to assess the similarity of each site with the known features of water bodies typically supporting Oxleyan pygmy perch (Table 2) to assist in identifying factors contributing to distributional limits of the species in NSW. An assessment of the condition of each site was also made using the disturbance criterion from Table 4. The three habitat assessment criteria, including habitat similarity, water quality similarity, and site condition, were ranked on a scale of one to five, with the highest number representing highly similar habitat and water quality characteristics, and undisturbed habitat (Table 5). Sites with minimum scores of four for habitat similarity and water quality similarity, and that were not documented to support Oxleyan pygmy perch, were considered potential habitat for the species. Similarly, sites with minimum disturbance scores of four were considered relatively undisturbed habitats. Scores for habitat and water quality similarity, and site condition were averaged to provide comparisons among the three survey zones.

Table 5 **Criteria for ranking the habitat assessment scores of each wetted site surveyed in the first survey. Scale ranked 1-5 with 5 representing highly similar habitat and water quality features to those of water bodies typically supporting Oxleyan pygmy perch and relatively undisturbed sites. The typical characteristics of habitat occupied by the sites are given in Table 2.**

Category	Rank	Description of Rank
Habitat similarity	5	Highly similar veg., physical and cover habitat features (L>80% similarity)
	4	Moderate similarities in veg., physical and cover habitat features (60-80% similarity)
	3	Some similarities in veg., physical and cover habitat features (40-60% similarity)
	2	Limited similarities in veg., and cover habitat features (20-40% similarity)
	1	Veg. Dissimilar (<20% similarity); No cover habitat features
Water quality	5	Water quality within known ranges (pH 3.3-6.5, Cond. ≤353μS. cm-2, D.O >2mg. L-1)
	4	Moderate water quality similarity
	3	Some water quality similarity (pH>7, Cond. ≤1000μS. cm-2, D.O >2mg. L-1)
	2	Limited water quality similarity (pH>7, Cond. ≤2500μS. cm-2, D.O <2mg. L-1)
	1	Water quality dissimilar (pH>7, Cond. >2500 μS. cm-2, D.O <2mg. L-1)
Site condition	5	Undisturbed, non-polluted, no clearing, no catchment input (pollution, sediment, etc.
	4	Minimal clearing (<25% cleared), minor catchment input
	3	Some clearing (25-50% cleared), sand mining disturbance, some pollution, limited housing, minimal agriculture
	2	Moderate clearing (50-80% cleared), moderate pollution, forestry, some surrounding industry, agriculture and housing
	1	Major clearing (>80% cleared), heavy pollution, full industry, agriculture and housing

Data management

All data were recorded by the senior operator at the completion of each operation. Data recorded included fish and habitat information and time of sampling. Sampling effort including the number of traps set, area (m^2) seined, electrofishing settings and sampling time (both elasped time and electrofishing on time) was also recorded. Data were entered into the NSW DPI Freshwater Fish Research Database. Within this data storage system, data were first entered into intermediate tables by technical staff. The data were then run through a series of 50 range checks to identify any outliers and inconsistencies in data recording. All potential errors were referred to the senior operator responsible for data collection at that site for confirmation and/or correction. The corrected intermediate tables were then appended into the database for storage.

Trapping accompanied by seine netting, electrofishing or dip netting provided data on the occurrence of fish species on each sampling occasion. Trapping data were also analysed to provide a measure of the relative abundance of Oxleyan pygmy perch. To allow for comparisons of relative abundance to be made among sites, catch was standardised in terms of the number of traps set within a site.

Survey 1: Distributional Limits of the Oxleyan Pygmy Perch in New South Wales

Distribution, total catch and sampling effectiveness

Fish species captured and their recorded frequency of occurrence within each subcatchment are given in Table 6. Of the 90 locations sampled, Oxleyan pygmy perch were caught from only eight sites within seven waterbodies. These water bodies were all located in the western zone directly adjacent to the north coast conservation system. Of the 31 subcatchments surveyed, Oxleyan pygmy perch were only found within the Coraki (sites 29, 30, 34), and Evans River (site 43) subcatchments of the Richmond River and the Esk River (sites 51, 52, 58, 59) subcatchment of the Clarence River (Figure 7). The species had previously been recorded from these subcatchments.

Equally as important as the new locality records is the apparent absence of the Oxleyan pygmy perch from the majority of the subcatchments surveyed. This is particularly noteworthy in the northern zone, as this area is situated within the overall NSW/Queensland geographic range of the species. This trend has also been reported in other surveys, which have also failed to find the species within the Tweed and Brunswick River catchments and northern two-thirds of the Richmond River catchment (Arthington 1996; Bishop 1999; FRC Environmental 2001; Greenloaning Biostudies 2000; The Ecology Lab 2002). Investigation of the historical record at Tatham (sites 22-24) revealed that the area has been extensively cleared and degraded and there was no evidence that the species continued to persist there. Similarly, in the southern area of the species' distribution, targeted sampling of the area in and around Cassons Creek (sites 99–106) and extensive and intensive surveying of coastal water bodies further south failed to detect the species. Interestingly, these locations had soil types and would have once supported vegetation communities atypical of those associated with wallum ecosystems. Nevertheless, this presence/absence pattern implies that the Oxleyan pygmy perch has a distribution currently restricted to a narrow stretch of sandy coastal lowlands encompassed by the north coast conservation system and bordering habitats. The spatial pattern and ongoing accumulation of new records suggests that the species may be well established throughout this area.

In addition to the Oxleyan pygmy perch, eleven native freshwater species were sampled (Table 6) along with the alien eastern gambusia. The occurrence of all these species conforms to their known distributions in Australia (McDowall 1996; Table 1). Several members of the family Eleotridae were widely distributed throughout the study area, being recorded from all ten catchments. The Firetailed gudgeon (*Hypseleotris galii*) was the most widely distributed species being captured from 62 water bodies within 25 of the 31 subcatchments. Similarly, striped gudgeon (*Gobiomorphus australis*) and empire gudgeon (*H. compressa*) were recorded from 52 water bodies within 26 subcatchments and 47 sites within 25 subcatchments, respectively. The eastern gambusia was also relatively common, being detected from 48 water bodies within 22 subcatchments spread across all ten catchments. These four species dominated the total catch, representing 92% of the 12,096 fish caught during the study (Figure 8a). These trends reflect characteristics typical of the freshwater fish communities inhabiting the north coast of NSW (Grant 1987; Allen 1989; Schiller *et al*. 1997; Faragher and Lintermans 1997).

Table 6 Fish species recorded throughout the study area and their frequency of occurrence within each subcatchment sampled. Refer to Table 1 for the scientific names.

Catchment	Subcatchment	No. water bodies sampled	Firetailed gudgeon	Striped gudgeon	Eastern gambusia	Empire gudgeon	Soft-spined rainbowfish	Oxleyan pygmy perch	Duboulay's rainbowfish	Flathead gudgeon	Olive perchlet	Longfinned eel	Shortfinned eel	Unidentified eel	Sea mullet	Pacific blue-eye
Tweed River	Cudgen Lake	3	3	1	0	0	1	0	0	0	0	0	0	1	0	0
	Mooball Creek	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0
	Lower Burringbar River	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Brunswick River	Lower Marshall Creek	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0
	Belongil Creek	5	4	2	4	1	1	0	0	0	0	0	0	1	0	0
	Tallow Creek	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Richmond River	Lennox Area	5	4	2	1	0	3	0	0	0	0	0	0	0	0	0
	Coraki Area	5	4	1	3	2	0	2	0	0	1	0	0	0	0	0
	Broadwater Area	7	3	7	4	6	2	0	0	0	0	0	0	1	0	0
	Evans River	4	0	3	0	3	2	1	0	1	0	1	1	0	0	0
	'unclassified'	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Double Duke Area	4	4	4	4	4	0	0	1	2	2	0	0	0	0	0
Clarence River	Esk River	6	5	3	3	1	3	4	0	0	0	0	0	0	0	0
	Clarence Coastal	3	2	3	3	2	0	0	0	0	0	1	0	0	1	1
	Wooloweyah Lagoon	6	5	2	5	2	1	0	0	0	0	0	0	0	0	0
	Shark Creek	3	3	2	0	2	3	0	0	0	0	0	0	0	0	0
	Coldstream Creek	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0
	Sandon River	5	2	4	1	4	1	0	3	0	0	0	0	1	0	0
	Wooli River	1	1	1	0	1	1	0	0	0	0	0	0	0	0	0
	Mid Orara River	2	2	2	2	2	0	0	1	1	0	0	0	1	0	0
Bellinger	Red Bank River	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
	Corindi River	3	3	2	3	3	1	0	0	0	0	0	0	0	0	0
	Arrawarra Creek	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0
	Pine-Bundageree Creek	2	0	0	0	2	0	0	0	1	0	0	0	0	0	0
Nambucca River	Coastal Nambucca	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Macleay River	Coastal Macleay	2	2	1	2	1	0	0	0	0	0	0	0	0	0	0
Hastings River	Limeburners Creek	3	2	0	2	0	0	0	0	0	0	0	0	0	0	0
	'unclassified'	4	3	2	3	1	0	0	0	0	0	0	0	0	0	0
Manning River	Manning Estuary	3	3	2	1	2	0	0	0	0	0	0	1	0	0	0
Karuah River	Wallis	3	0	1	0	1	0	0	0	1	0	0	0	0	0	0
	Myall	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Total		**90**	**62**	**52**	**48**	**47**	**20**	**7**	**6**	**6**	**3**	**2**	**2**	**5**	**2**	**1**

Figure 7 Distribution of the Oxleyan pygmy perch sampled in the first survey round, together with all other known localities.

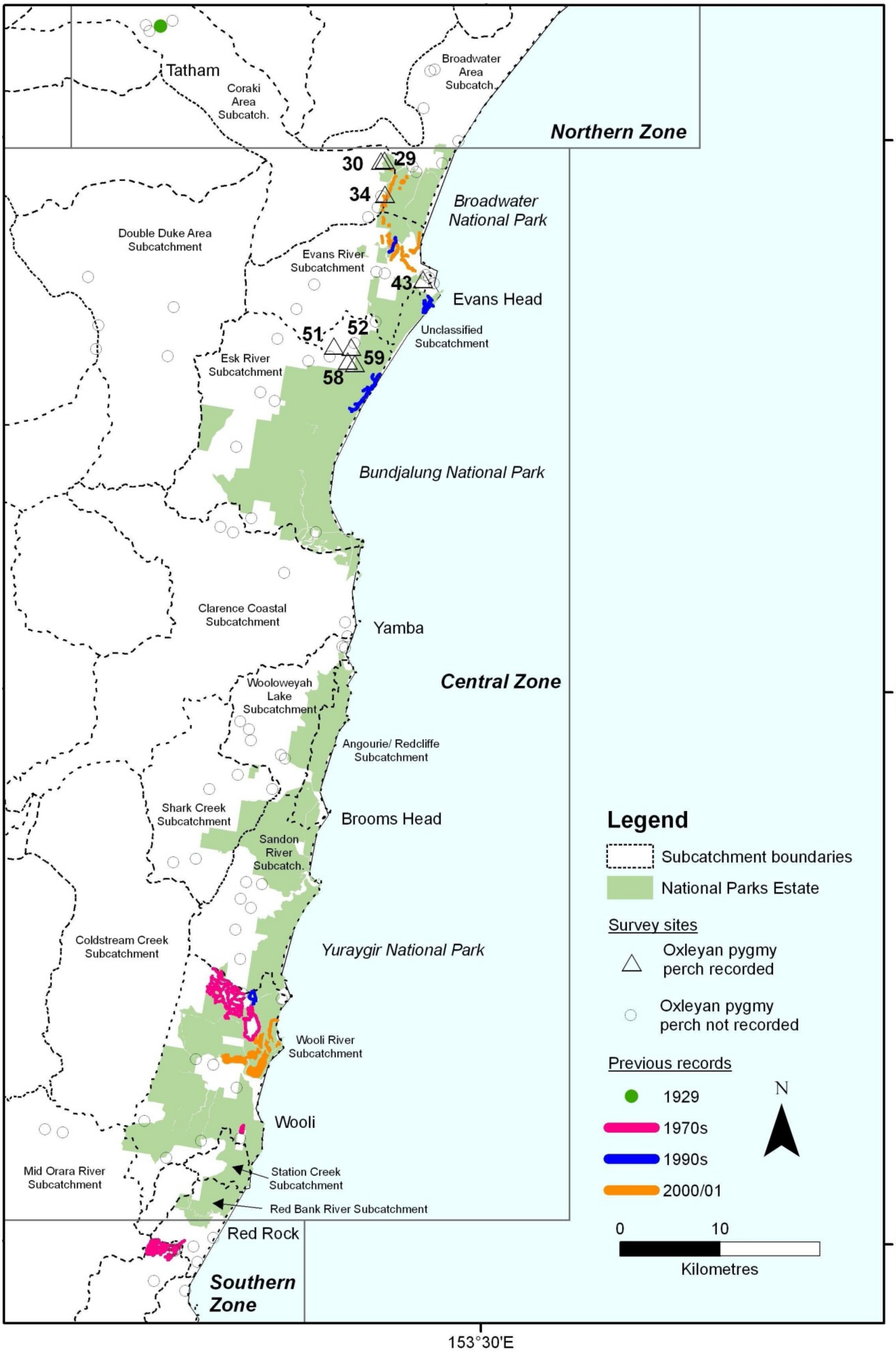
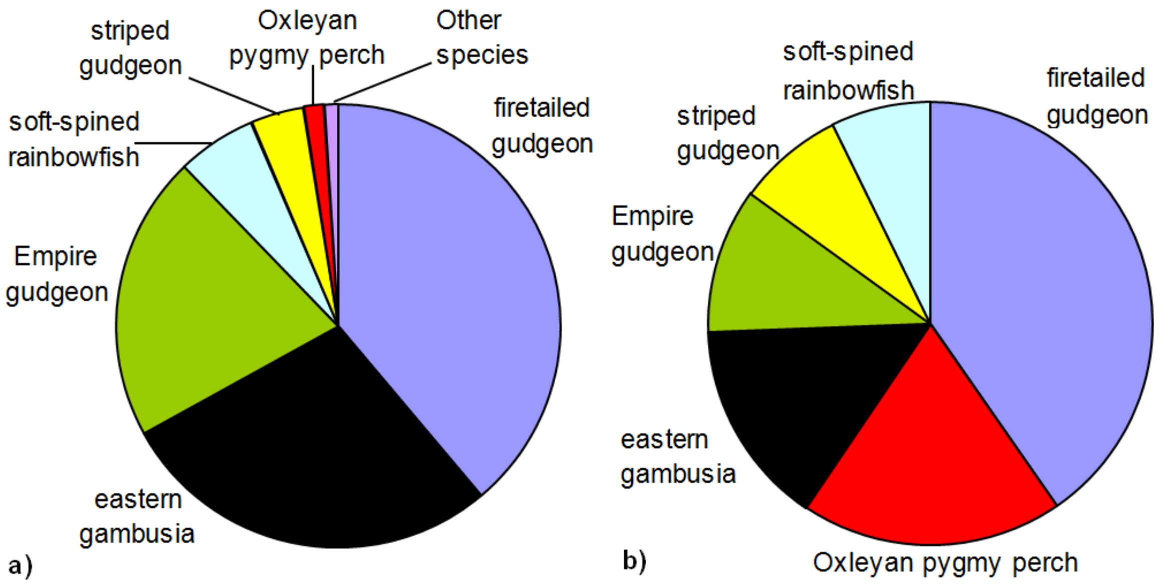


Figure 8 Contribution of each species to the total catches for a) all sample sites and b) sites that had Oxleyan pygmy perch. n = 12,096 for a), n = 929 for b).

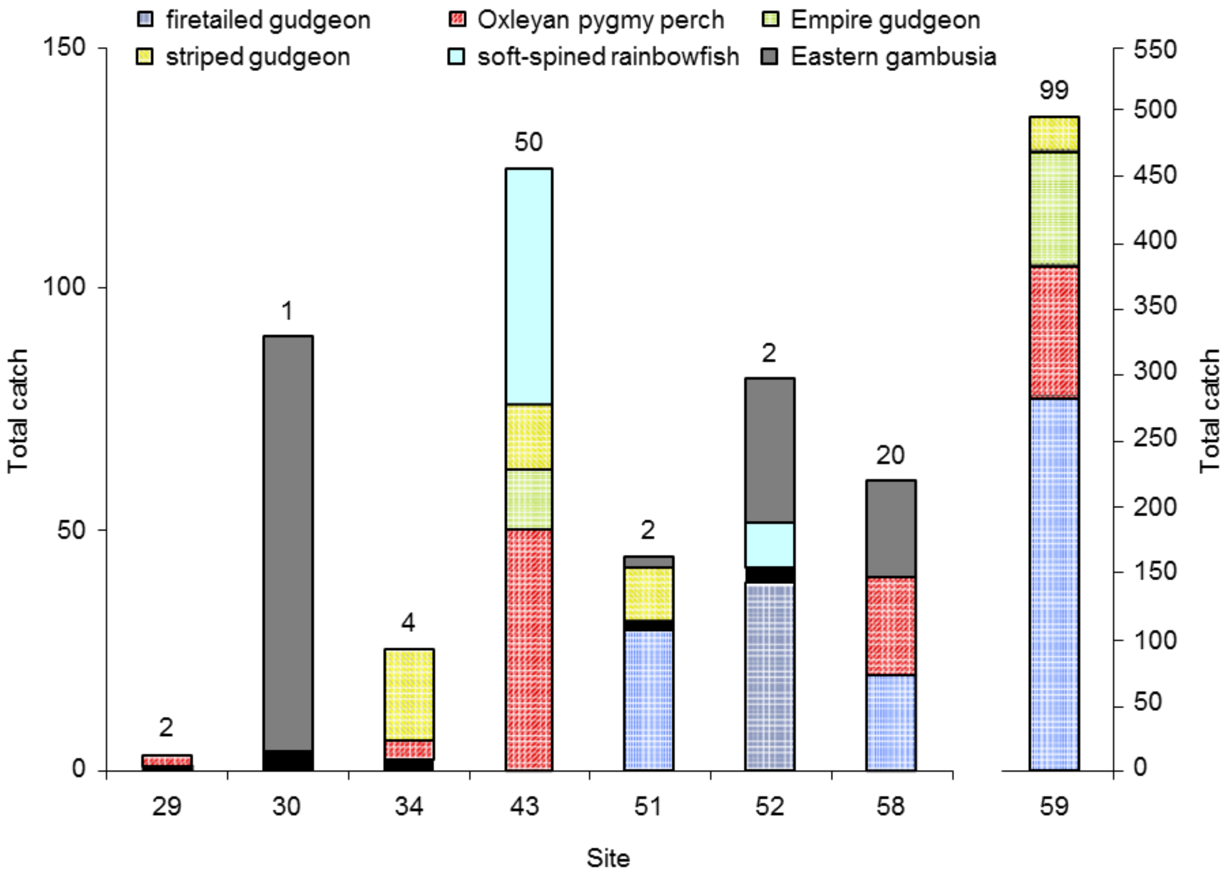


The soft-spined rainbowfish (*Rhadinocentrus ornatus*) was the fourth most abundant native species sampled and was relatively common in the catchments between the Queensland border and the Bellinger catchment, but it was not found further south (Table 6; Figure 8a). This species has a similar distribution to the Oxleyan pygmy perch, being restricted to the coastal catchments of south-eastern Queensland and north-eastern NSW (Morris *et al*. 2001; Pusey *et al*. 2004). The capture of soft-spined rainbowfish within the Tweed River catchment constitutes the first NSW DPI record of this species within this catchment (Table 1). Further, it has recently being found as far south as the Pine-Bundageree Creek subcatchment (J. Knight, unpublished data).

The remaining seven species, including the Duboulay's rainbowfish (*Melanotaenia duboulayi*), flathead gudgeon (*Philypnodon grandiceps*), olive perchlet (*Ambassis agassizii*), longfinned eel (*Anguilla reinhardtii*), shortfinned eel (*Anguilla australis*), sea mullet and Pacific blue-eye (*Pseudomugil signifer*) were not common within the waterbodies sampled. These species were only captured from a maximum of six waterbodies within five subcatchments spread across four catchments (Table 6) and only contributed a combined total of 1.1% to the total catch (Figure 8a). In addition, 21 of 33 freshwater fish species recorded by NSW DPI as inhabiting the catchments within the study area (Table 1) were not detected. As the sampling methods deployed in this study primarily targeted small-bodied fishes within small, coastal tributaries, swamps and ponds, larger sized species with restricted distributions, and/or those that more typically inhabit other ecotypes such as large rivers and lakes were unlikely to have been sampled during this study. While the absence or infrequent capture of these species provides little insight into their distributions, data on the species that were detected contribute to a more thorough understanding of fish communities of the wallum ecosystems on the north coast of NSW. The catch composition recorded from each site is provided in Appendix 3.

Oxleyan pygmy perch only represented 1.5% of the total catch (Figure 8a); however, it was one of the most abundant fish sampled from those sites supporting the species (Figure 8b). In addition to the Oxleyan pygmy perch, the catch from these eight sites was comprised of those species most commonly captured throughout the entire study area including the firetailed gudgeon, empire gudgeon, striped gudgeon, soft-spined rainbowfish and eastern gambusia. All four indigenous species are recognised as the most common fish associated with Oxleyan pygmy perch, while eastern gambusia are also known to have invaded many of these habitats (Arthington and Marshall 1993; Arthington 1996; Knight 2000a). Of the 180 pygmy perch caught, 55% were collected from site 59, 27% from site 43 and 11% from site 58 (Figure 9). The species comprised between 20 and 40 % of the total catch at these sites. Smaller numbers were collected from site 29, from within the same drainage system further downstream at site 30, and from sites 34, 52 and 51. This trend has been observed in other studies, with Oxleyan pygmy perch being relatively prominent in the fish communities of some water bodies while being rare in others (Arthington 1996; Knight 2000a; Pusey *et al*. 2004). The eastern gambusia was captured in high numbers at site 30, which may be related to the degraded condition of this site (see Assessment of habitats supporting Oxleyan pygmy perch).

Figure 9 Total catch of each species from sites supporting Oxleyan pygmy perch. Total catch of Oxleyan pygmy perch is shown above each bar.



The effectiveness of the sampling regime is further illustrated in Table 7. Of the eight sites supporting Oxleyan pygmy perch, the species was caught in traps in five of the six sites in which this sampling technique could be employed. Sites 29 and 30 were too shallow and/or overgrown with vegetation to be sampled with traps, but the species was detected with the backpack electrofisher. Oxleyan pygmy perch were also captured by electrofishing at site 51, whereas trapping failed to detect the species. Both techniques detected pygmy perch from site 59, which supported a relatively large population (Figure 9; Relative abundance and population structure of Oxleyan pygmy perch). In addition to being sampled with traps, sites 52 and 58 were also seined. While the Oxleyan pygmy perch was caught in traps at these two sites, seine netting only succeeded in catching it at site 58. Sites 34 and 43 could only be sampled with traps. These data highlight the difficulty in effectively sampling wallum ecosystems and the need to employ multiple sampling techniques to adequately document the presence/absence patterns of this endangered species (Knight *et al*. 2007b).

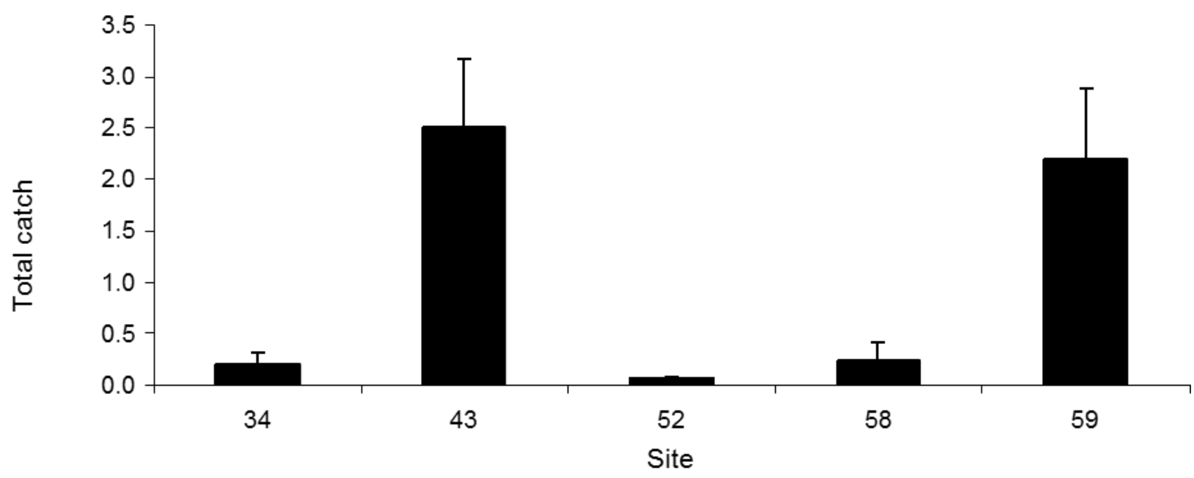
Table 7 **Detection of the Oxleyan pygmy perch by the sampling techniques deployed within sites supporting the species. √ = successfully detected the species. X = failed to detect the species. Blank cell = technique not used.**

Site	Traps	Seine net	Backpack electrofishing
29			√
30			√
34	√		
43	√		
51	X		√
52	√	X	
58	√	√	
59	√		√

Relative abundance and population structure of Oxleyan pygmy perch

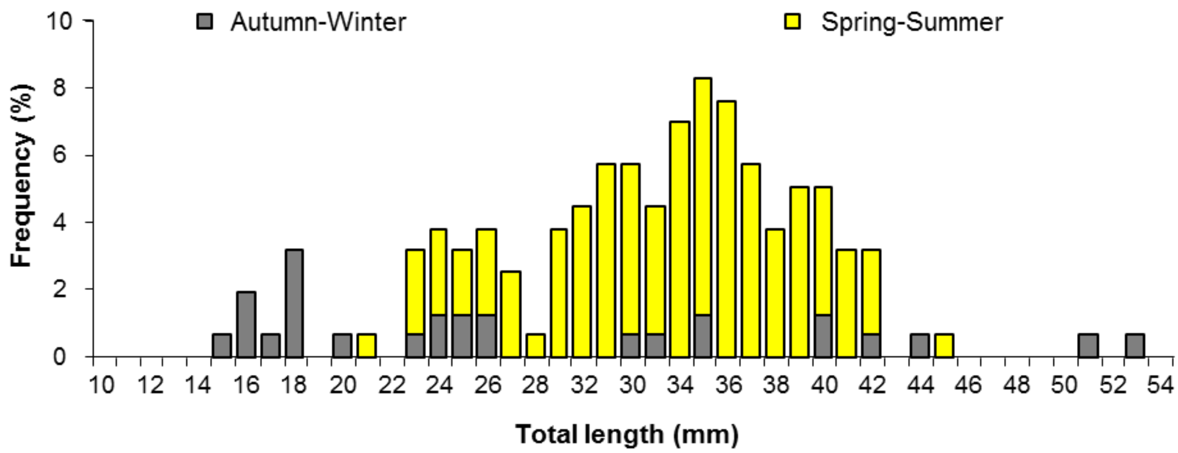
In order to directly compare relative abundances of Oxleyan pygmy perch, trapping catch data were standardised to account for the variation in sampling effort among sites. The catch per trap was relatively high at sites 43 and 59 and low at sites 34, 52 and 58 (Figure 10). This pattern reflects the large variations in its relative abundance (Arthington 1996; Knight 2000a). Trapping data are considered to accurately reflect spatial and temporal variations in fish abundance (Bloom 1976; Balcombe & Closs 2000). Differences in the relative abundance of Oxleyan pygmy perch have been statistically related to habitat characteristics (Arthington 1996; Knight 2000a), but may also be influenced by numerous other factors such as competition, threatening processes or stochastic events (Gorman and Karr 1978; Evans *et al*. 1987; Wootton 1992). As sampling was undertaken over a seven month period, the variation may also be a result of seasonal changes in population abundance. Sites 43 and 59 were sampled in summer whereas sites 34, 52 and 58 were sampled in winter. In Queensland, the highest numbers of fish were recorded in spring and summer, which coincided with spawning activity and recruitment (Arthington 1996).

Figure 10 **Catch per trap (± standard error) for Oxleyan pygmy perch.**



Length frequency analysis also provides insights into the temporal variation among the populations sampled (Figure 11). The smallest individuals were captured in the autumn and winter months. As larvae metamorphose into fully scaled juveniles at a minimum total length of approximately 10 mm (Knight and Trnski 2011) these fish are likely to be small juveniles recruiting into the population from the previous 2000/01 spawning season. The species reaches sexual maturity at approximately 24 to 29 mm (Knight *et al*. 2007a); hence larger juveniles were also present in samples collected in spring and summer. Juveniles were captured at all localities sampled except for sites 51 and 52, in each of which only two individuals were captured (Figure 9). The overall size structure is similar to that of populations previously studied, with the most abundant size classes comprised of fish at or slightly larger than the size of maturity. The species is known to attain a maximum length of approximately 60 mm but fish greater than 40 mm in length are relatively rare (Arthington 1996; Knight 2000a). Hence, most populations appeared to be recruiting given the presence of mature fish and juvenile fish from the previous breeding season. Relationships between total length and standard length and total length and body weight are provided in Appendix 4.

Figure 11 Length frequency distribution of Oxleyan pygmy perch collected during autumn- winter 2001 and spring-summer 2001/02.



Assessment of habitats supporting Oxleyan pygmy perch

An overview of the water quality characteristics of all sites sampled and of sites inhabited by Oxleyan pygmy perch is provided in Table 8. Water temperatures ranged widely for all sites sampled and for Oxleyan pygmy perch sites, primarily reflecting seasonal climatic changes during the survey periods as well as the time of day each site was sampled. Mean dissolved oxygen concentrations were similar. The main difference was that dissolved oxygen levels at Oxleyan pygmy perch sites were not recorded below 3.8 mg. L^{-1}, whereas some sites not inhabited by the species had anoxic waters. Mean pH and conductivity levels were relatively low for all sites sampled and for Oxleyan pygmy perch sites, although the means and upper ranges of each of these parameters were much lower in those sites inhabited by the species. In addition, these water bodies were all stained lightly to darkly with organic acids, lacked heavy suspended solids and were generally not turbid. The measured water quality parameters of water bodies supporting populations were all within the recorded ranges for the species (Table 2).

Table 8 **Summary of water quality parameters recorded from all sites sampled and from sites supporting Oxleyan pygmy perch. Water colour abbreviations: Cl = clear, Lt = light tannin, Mt = medium tannin, Dt = dark tannin, Tr = translucent/cloudy, Hs = heavy suspended solids.**

Parameter	All sample sites (n=73)			Pygmy perch sites (n = 22)		
	Range	Mean	SE	Range	Mean	SE
Temperature (°C)	9.6-29.9	17.36	0.531	11.8-28.3	17.75	2.169
Dissolved oxygen (mg L^{-1})	0.4-14.1	4.65	0.260	3.8-6.7	4.63	0.530
pH	3.30-7.97	5.301	0.1247	3.36-5.38	4.316	0.2454
Conductivity (µS cm^{-2})	34-15100	414.0	161.58	109-230	168.8	15.70
Turbidity (NTU)	0-118	17.8	3.33	4-51	12.6	6.47
Water colour	Cl-Dt; Tr; Hs	---	---	Lt-Dt	---	---

The habitat characteristics of waterbodies supporting Oxleyan pygmy perch populations were generally similar to those of water bodies typically inhabited by the species (Table 9). In particular, sites 29, 34 and 43 were located within narrow, shallow drainage systems characterised by a siliceous sand substratum and very slow flow conditions. Emergent vegetation such as giant sedge and frogsmouth along with aquatic moss, plant litter and timber provided instream cover. Where thick beds of aquatic vegetation were absent, the species was captured near steep or undercut banks fringed with overhanging vegetation including coral fern, the sedge *Baloskion tetraphyllus* and saw-sedge. The surrounding vegetation community consisted of broad-leaved paperbark, heath banksia, wallum banksia and various other heath species.

Sites 51, 52, 58 and 59 were located within close proximity to each other within the Esk River subcatchment. Three of these creeks drained through a complex of either wallum heath or melaleuca swamp and tall woodland/forest and had a compound substratum comprised of sand and clay (Table 9). The fourth creek (site 59) flowed through a swamp complex dominated by broad- leaved paperbark, swamp mahogany and an assemblage of littoral rainforest species growing on acidic grey soil (Figure 12). While Oxleyan pygmy perch are not usually found in these environments, all four creeks contained microhabitats often inhabited by the species such as sedges, macrophytes and undercut banks and supported a fish community typical of wallum waterbodies (Figure 9). Indeed, the species appeared to proliferate in one system with relatively high abundances sampled at site 59. As these creeks drain into wallum swamps within Bundjalung National Park it is plausible that the fish may have become established at the survey sites through migration upstream out of its typical habitat. Nevertheless, it is apparent that, given appropriate water quality conditions and microhabitats, the species is capable of inhabiting a variety of freshwater environments. A further example of this occurs in Queensland where the species inhabits a small dystrophic creek on North Stradbroke Island which, although being situated within a wallum catchment, has an immediate riparian zone comprised of rainforest species growing on peaty soils. The historical localities at Tatham and Cassons Creek lend support to the notion that the species has the ability to occupy a broader niche than its current distribution patterns suggest.

The majority of sites supporting populations were in a relatively healthy condition with little or no obvious signs of disturbance; were relatively inaccessible to the general public; and generally free from threatening processes (Table 9). This may be at least partly attributed to most sites occurring on uncleared or partially cleared rural land directly adjacent to national park estate. However, site 30 scored poorly for all human effects criteria. This tributary of the

Richmond River flows out of an undisturbed wallum swampy drainage (site 29) and through a culvert pipe before draining on to a sugar cane plantation situated on an alluvial floodplain (site 30). One specimen was captured within this extremely degraded environment (Figure 13) in a small pool below the culvert pipe, which due to the pipe's elevated position, impeded upstream fish passage. This is regarded as a significant threat as the upstream population is likely to be continually depleted as fish, which move downstream either voluntarily or during high flow events are unable to swim back upstream into the undisturbed environment. This is plausible, as the displacement of Oxleyan pygmy perch and other small-bodied fishes downstream and below natural barriers to fish passage is well documented (Semple 1991; Arthington 1996; Knight 2000a).

Table 9 **Habitat characteristics and human effects associated with sites supporting Oxleyan pygmy perch. Values for aquatic vegetation (% cover) include for the whole site and for the location of capture (in parentheses). UC bank = steep/undercut bank fringed with overhanging vegetation. Human effects: D = Disturbance, A = Access, T = Threats, I = Introduced fish species, S = Land use status. Refer to Table 4 for scoring of human effects.**

Site	Riparian veg	Depth (m)	Flow (m s^{-1})	Substratum	Aquatic cover	Aquatic veg (% cover)	Human effects				
							D	A	T	I	S
29	Wallum scrub	0.1	<0.1	Sand	Sedges, aquatic moss, plant litter	90 (90)	5	4	5	5	4
30	Sugar cane	0.2	<0.1	Sand, clay	Sedges, plant litter	50 (50)	1	2	1	1	2
34	Wallum scrub	0.3	<0.1	Sand	Sedges, UC bank, timber, aquatic moss, plant litter	5 (0)	5	4	2	5	3
43	Wallum scrub	0.2	<0.1	Sand	Sedges	70 (70)	5	2	4	5	4
51	Woodland / melaleuca swamp	0.5	<0.1	Sand, clay	Sedges, UC bank, timber, plant litter	30 (70)	4	4	4	3	3
52	Wallum scrub / woodland	0.8	<0.1	Sand, clay	Sedges, macrophytes, UC bank, timber, plant litter	10 (0)	4	4	4	3	3
58	Wallum scrub / woodland	0.3	<0.1	Sand, clay	Sedges, macrophytes, UC bank, plant litter	50 (10)	4	4	4	3	3
59	Swamp complex	0.5	<0.1	Grey acid soil, sand	Macrophytes, UC bank, timber, plant litter	60 (90)	5	5	5	5	4

Figure 12 Swamp complex inhabited by Oxleyan pygmy perch (site 59) adjacent to Bundjalung National Park.

Figure 13 Degraded habitat of the Oxleyan pygmy perch (site 30) west of Broadwater National Park.

Site 34 was located in a tributary that also drains through undisturbed wallum scrub towards a cane drain named McDonalds Creek (site 35). However, at the time of sampling the tributary had dried up within partially cleared rural land before reaching the main creek channel. Oxleyan pygmy perch may, at least temporally, be restricted to the wallum section of the creek as sampling within McDonalds Creek only revealed one gudgeon species and eastern gambusia (Appendix 3). Site 43 was located in a tributary of the Evans River that flows out of Bundjalung National Park and is intersected by a gravel road. Threats posed by public access to this site are considered to be minimal however, as the road leads to Commonwealth Land that is inaccessible to the general public and hence rarely used. The remaining four sites in the Esk River subcatchment all occur on uncleared or partially cleared rural land bordering Bundjalung National Park. These properties are only accessible with permission from the landowners and are difficult to access (Table 9).

The alien eastern gambusia was captured at three sites that had been partially cleared: sites 51, 52 and 58, and were quite prevalent in the degraded site 30 (Figure 9, Table 9). This species is listed as a noxious species under the FM Act and is known to proliferate in disturbed environments (Arthington *et al*. 1983; Arthington and Lloyd 1989; NPWS 2003). It is the only alien species known to have established self-maintaining populations in the wallum, freshwater ecosystems of NSW and has been implicated in the decline of Oxleyan pygmy perch (NSW DPI 2005). The presence of this pest fish is therefore considered a significant threat to the Oxleyan pygmy perch populations inhabiting these sites.

Additional habitat assessment of all sites

The mean total habitat assessment scores for each survey zone are illustrated in Figure 14. While the scores were relatively similar, the southern zone received the highest mean score of 11.1, followed by the central and northern zones with scores of 10.9 and 10.7, respectively. These scores were not significantly different (Single Factor ANOVA, $F=0.19$, $P>0.05$). The score for the northern zone was affected by a low average score for site condition (Figure 15). Although overall differences in site condition among zones were not significant (Single Factor ANOVA, $F = 0.95$, $P > 0.05$), only 35% of sites within the northern zone were relatively undisturbed (scores of ≥ 4) compared to 56% in the central zone and 41% in the southern zone (Table 10). Conversely, 23% of sites in the northern zone were heavily degraded (score of 1) compared to 18% and 15% of sites in the central and southern zones, respectively. The northern zone did, however, receive the highest score for habitat similarity, followed closely by the southern zone. This indicates that the water bodies surveyed in these two zones more closely resembled habitats inhabited by Oxleyan pygmy perch than those in the central zone. Water bodies to the west of the north coast conservation system possessed some indicative water quality and vegetation characteristics, but generally lacked wallum communities and varied widely in substrate composition. Differences in habitat similarity among zones, however, were not significant (Single Factor ANOVA, $F = 0.38$, $P > 0.05$). This may be due to a number of other coastal environments other than wallum habitats being investigated within the northern and southern coastal zones. Oxleyan pygmy perch were not detected in swamp complexes and coastal foredune wetlands sampled within these zones. These areas are known to have been heavily sand mined, with most native vegetation removed and replaced by bitou bush and horsetail oak (Morand 2001).

Figure 14 Mean total habitat assessment scores (± standard error) for each survey zone.

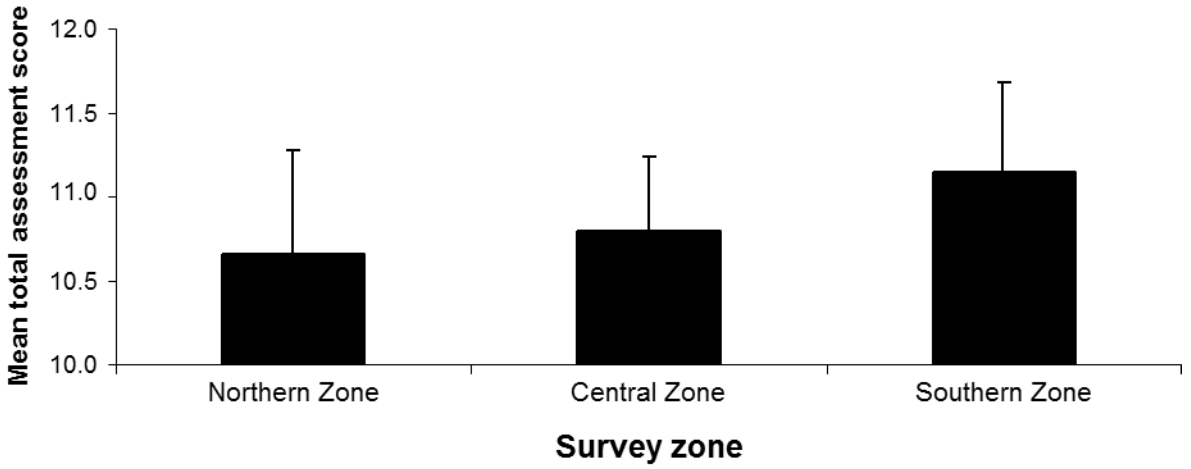


Figure 15 Mean habitat similarity, water quality similarity and site condition scores (± standard error) for each survey zone.

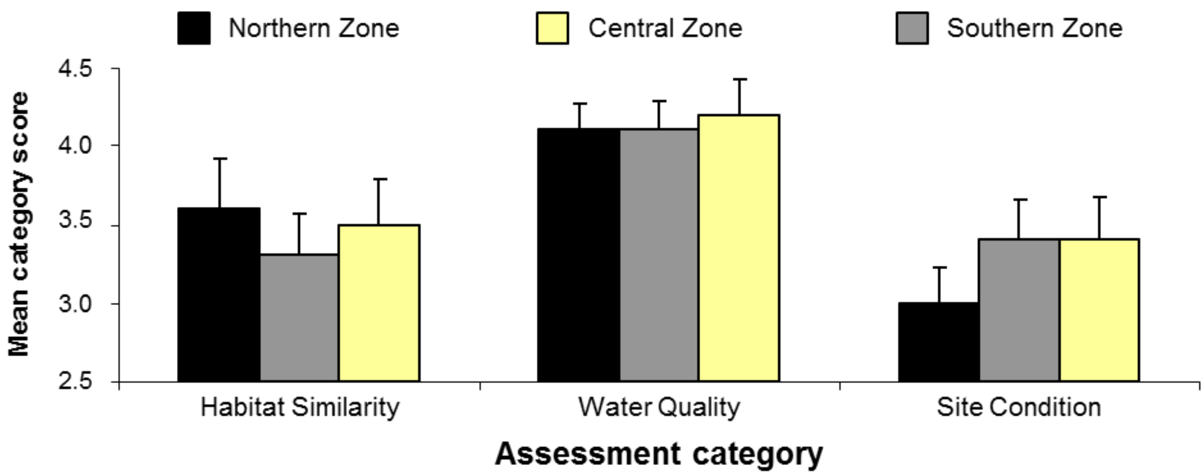


Table 10 Conservation status of sites assessed throughout the study area.

Site Status	Zone						Entire Study Area	
	Northern		Central		Southern			
	#	%	#	%	#	%	#	%
Total # of sites assessed	26	100	50	100	27	100	103	100
Total # of undisturbed sites	9	35	28	56	11	41	48	47
Identified pygmy perch habitat	0	0	8	16	0	0	8	8
Undisturbed identified pygmy perch habitat	0	0	7	14	0	0	7	7
Potential pygmy perch habitat	14	54	14	28	12	44	40	39
Undisturbed potential pygmy perch habitat	6	23	8	16	8	30	22	21

Mean scores for water quality similarity varied little among the three zones, were not significantly different (Single Factor ANOVA, $F = 0.11$, $P > 0.05$), and were relatively high, averaging 4.1 (Figure 15). Hence, 54% of sites in the northern zone and 44% in the southern zone were considered to be potential habitat for Oxleyan pygmy perch (the species not recorded and scores of 4 or 5 for habitat and water quality similarity), compared to only 28% in the central zone (Table 10). Throughout the entire study area, 45% of these potential habitats were classified as degraded. Therefore, it is possible that human activities may have had a significant influence on the distribution pattern of the species. This may particularly be the case within the northern zone where 57% of potential habitat sites were degraded (Table 10). The history of human impacts within this area via sand mining, forestry, agriculture, urban expansion and tourism is well established, with numerous studies documenting the modification, fragmentation and destruction of coastal environments and associated wetlands (e.g. Timms 1977a, 1977b, 1986, 1992b; Morand 1994, 1996, 2001; Graham 2004a). Environmental degradation is still continuing with, for example, sites 1, 2 and 3 located in an area recently cleared for residential development. Similar impacts were observed in the southern zone. For example, most of the coastal heathlands south of Yuraygir National Park to Coffs Harbour have been heavily disturbed by mining or cleared for urban or agricultural development.

Despite the fact that the Oxleyan pygmy perch was only recorded at a limited number of locations, a further 22 sites were identified which appeared to provide undisturbed potential habitat for the species (Table 10). These sites are listed in Appendix 5. Nine of these sites are protected within National Park estate while the remainder are either situated on private property, crown land or in state forest. The highest concentration of undisturbed potential habitats occurred within Newrybar Swamp. This area of crown land is located within the Lennox subcatchment of the Richmond River, and supports approximately 1,100 hectares of wallum scrub, which is similar in both subformation and floristic composition to the wallum communities dominating Broadwater National Park (Griffith *et al*. 2003). The creeks and swamps sampled within Newrybar Swamp were also considered to be highly similar in terms of typical pygmy perch habitat and water quality features, and supported an aquatic faunal community similar to that of the drainage systems within Broadwater National Park (Knight 2000a). With much of the heathland outside national park estate fragmented and degraded, and most of the wallum habitat within Newrybar Swamp having escaped sand mining operations (Corkery and Co 1991), this area represents possibly the largest unprotected community of wallum scrub remaining on the far north coast of NSW. As this part of the State is rapidly being developed (Morand 1994, 1996; Zann 1996), the possibility that Newrybar Swamp may be cleared or impacted by future urban expansion is of concern. In fact, all the undisturbed potential habitat sites outside national park estate may be considered vulnerable to future anthropogenic disturbances.

Knight (2000a) noted that Oxleyan pygmy perch has reportedly disappeared from several water bodies for long periods of time before being recaptured, and suggested that these trends may reflect the unpredictability of sampling small populations or populations that fluctuate widely in relation to environmental variability. Consequently, one cannot assume that the species does not exist at a locality based on a single sampling event. However, given the intensive sampling effort deployed in this study, the numerous sites sampled for the species both in this study and in others north of Broadwater National Park, and the concomitant lack of historical or recent sightings, it is reasonable to assume that the Oxleyan pygmy perch either never existed or no longer exists within the Tweed, Brunswick and northern two-thirds of the Richmond River catchment. The undisturbed potential habitats to the north of and surrounding the north coast conservation system may, however, require a series of repeated surveys to conclusively validate the non-occurrence of the species.

Survey 2: Distribution of the Oxleyan Pygmy Perch in Bundalung and Yuraygir National Park

Distribution and total catch

Fish species recorded within the study area are listed in Table 11. Twelve small-bodied and four large-bodied fish species belonging to nine families were captured. All are indigenous to Australia except for the noxious pest fish, eastern gambusia. The occurrence of these species conforms to their known distributions in Australia (McDowall 1996; Table 1). Likewise, most species had been previously recorded from the wallum waterbodies of Bundjalung and/or Yuraygir National Parks (Appendix 6). Exceptions include the olive perchlet, which were recorded for the first time in Bundjalung National Park, and the longfinned eel and Australian bass (*Percalates novemaculeata*), which have not previously been documented from Yuraygir National Park. The latter species is likely to have been stocked (see Assessment of habitats supporting Oxleyan pygmy perch). All species are considered freshwater fishes, although most species including the short and longfinned eel, common jollytail, eastern gambusia, striped gudgeon, empire gudgeon, Australian bass, flathead gudgeon, dwarf flathead gudgeon (*Philypnodon macrostomus*) and Pacific blue- eye either have the ability to inhabit or spend at least part of their lifecycle in estuarine to marine environments (McDowall 1996). The Oxleyan pygmy perch is the only species known to be largely restricted to freshwater, wallum ecosystems. Other aquatic organisms commonly collected as by-catch included freshwater crayfish (*Cherax cuspidatus*) and atyid shrimp (cf. *Caridina indistincta* or *C. mccullochi*). Long-necked turtles (*Chelodina longicollis*) were also occasionally captured while freshwater prawns (*Macrobrachium australiense*) were caught in high numbers in Lake Hiawatha (sites 72, 76, 77).

Oxleyan pygmy perch were recorded from 22 sites within 20 of the 69 waterbodies sampled (Table 11; Figure 16-18). This includes 13 of the 30 waterbodies (43%) sampled within an unclassified subcatchment and the Esk River subcatchment in Bundjalung National Park and from seven of the 27 water bodies (26%) sampled within the Angourie/Redcliffe, Wooloweyah Lake and Wooli River subcatchments in Yuraygir National Park. The species has historically and/or recently been documented from most of these subcatchments, although this study provides the first record of Oxleyan pygmy perch occurring within the Angourie/Redcliffe subcatchment. The species is widely distributed within the unclassified and Esk River subcatchments but has a disjunct distribution throughout the subcatchments in Yuraygir National Park.

Table 11 Fish species recorded throughout the study area and their frequency of occurrence within Bundjalung and Yuraygir National Park. Refer to Table 1 for the scientific names of each species.

National park / catchment	Subcatchment	No. water bodies sampled	Firetailed gudgeon	Empire gudgeon	Striped gudgeon	Eastern gambusia	Soft-spined rainbowfish	Oxleyan pygmy perch	Longfinned eel	Duboulay's rainbowfish	Pacific blue-eye	Shortfinned eel	Flathead gudgeon	Olive perchlet	Dwarf flathead gudgeon	Common jollytail	Australian bass	Freshwater catfish	Unidentified eel
Bundjalung National																			
Richmond River	Evans Creek	2	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	'unclassified'	4	2	2	2	0	2	3	0	0	0	0	0	0	0	0	0	0	0
Clarence River	Esk River	26	1	8	8	1	7	1	0	1	0	0	1	1	1	0	0	0	0
Yuraygir National Park																			
Clarence River	Clarence Coastal	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Angourie/Redcliffe	8	5	5	5	2	1	1	1	0	2	2	1	0	0	0	0	0	0
	Wooloweyah Lake	4	4	2	2	2	1	2	0	0	0	0	0	0	0	0	0	0	0
	Sandon River	7	6	7	6	3	1	0	3	2	0	1	0	0	0	0	0	0	2
	Wooli River	15	1	8	8	1	9	4	2	3	2	1	2	2	2	2	2	2	0
Bellinger	Station Creek	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Red Bank River	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Total		**69**	**4**	**3**	**3**	**2**	**2**	**2**	**7**	**6**	**5**	**4**	**4**	**3**	**3**	**2**	**2**	**2**	**2**

Figure 16 Distribution of Oxleyan pygmy perch within Bundjalung National Park recorded in this study, together with all other known localities. Survey sites are numbered in a north to south and west to east direction.

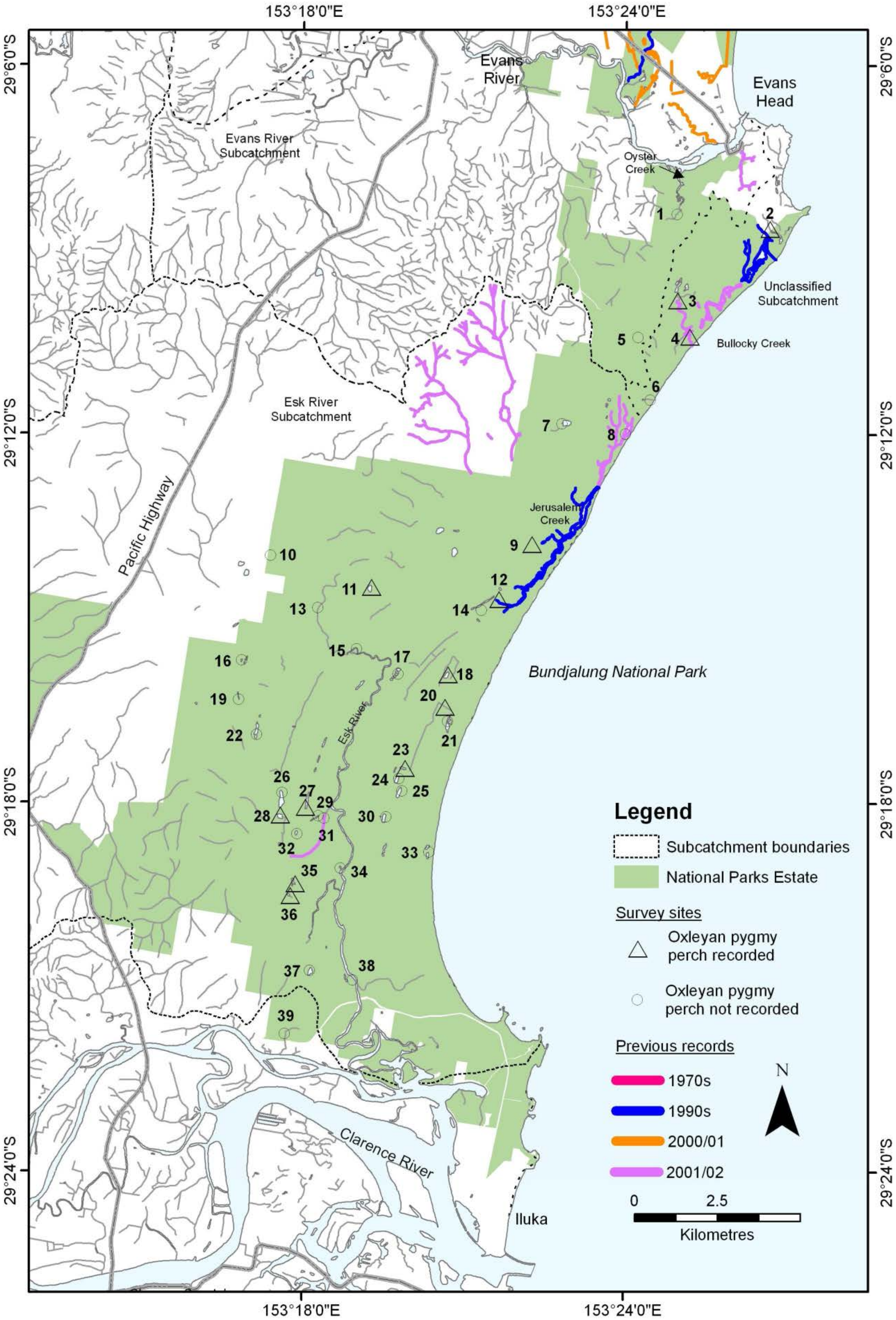


Figure 17 Distribution of Oxleyan pygmy perch recorded in this study north of the Sandon River, Yuraygir National Park, together with all other known localities. Survey sites are numbered in a north to south and west to east direction.

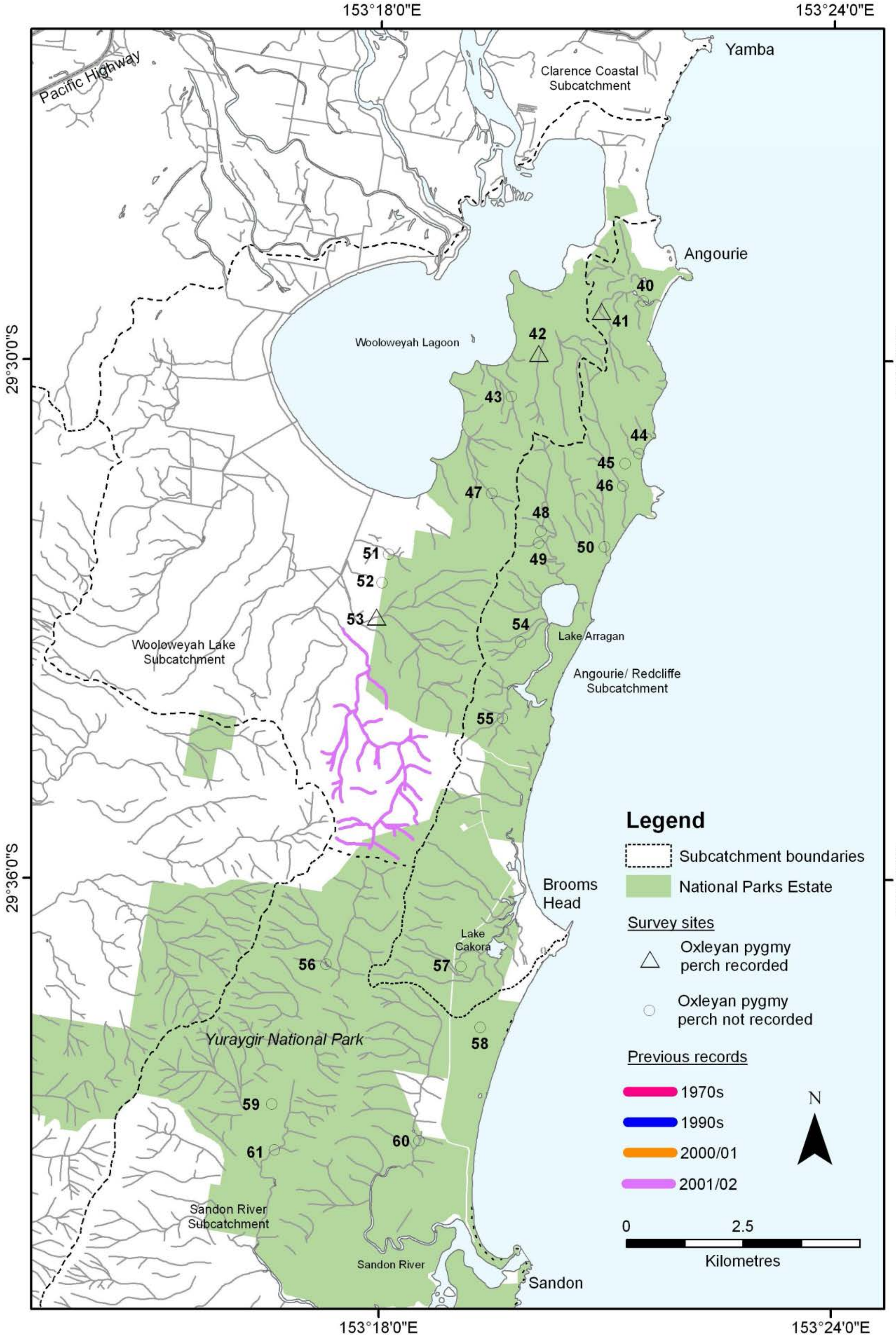
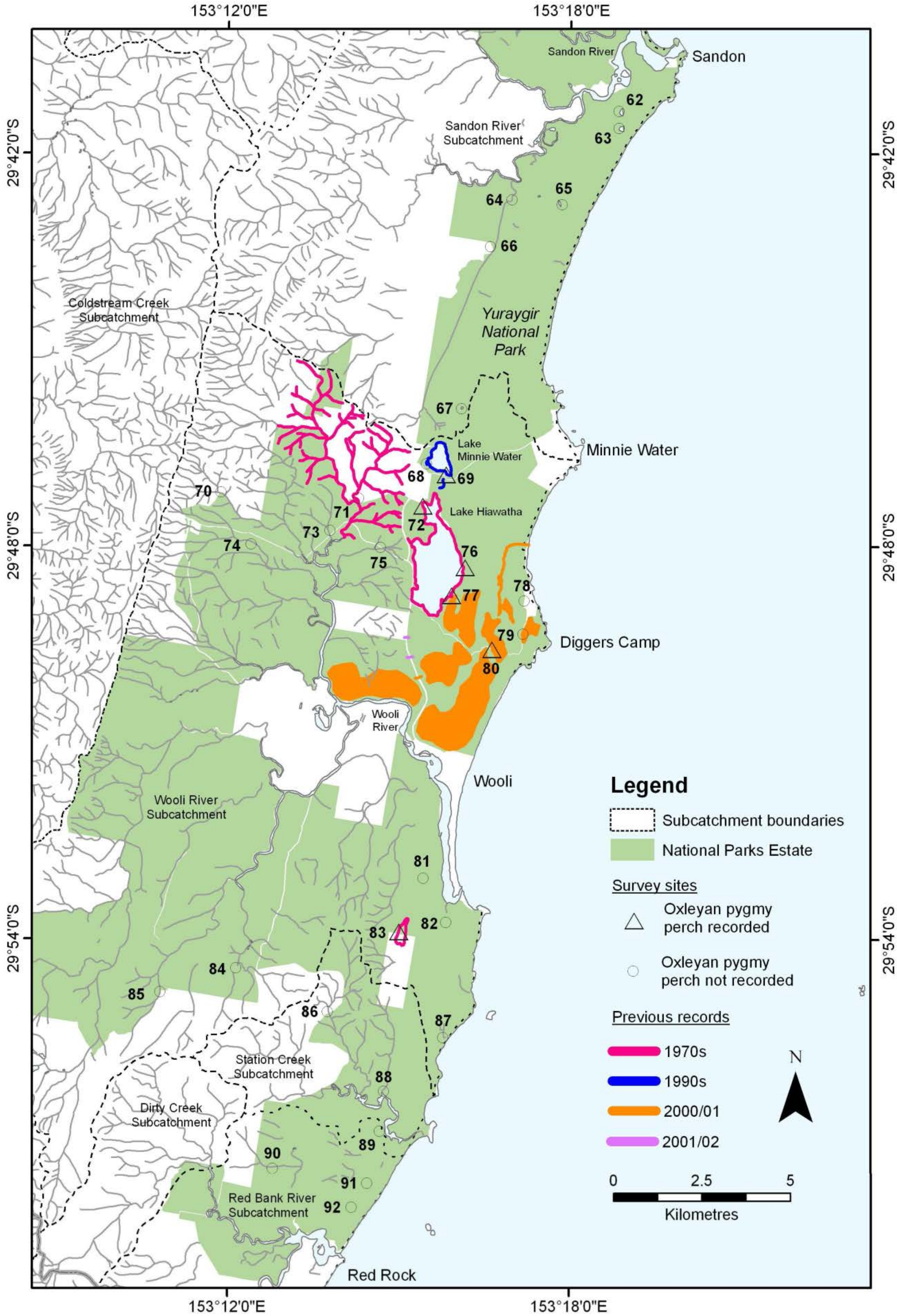


Figure 18 Distribution of Oxleyan pygmy perch recorded in this study south of the Sandon River, Yuraygir National Park, together with all other known localities. Survey sites are numbered in a north to south and west to east direction.



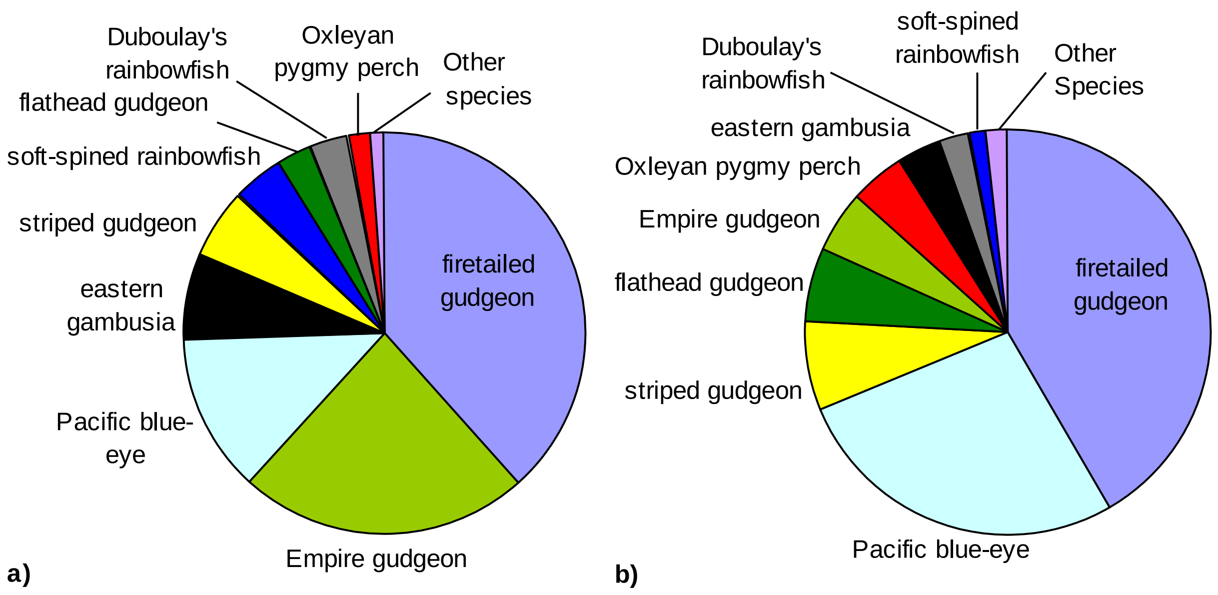
In the north of Bundjalung National Park, the Oxleyan pygmy perch is known to occur throughout the Evans Creek subcatchment but was not recorded from the two sites sampled during this study (Figure 16). The species has never been recorded from the Clarence Coastal subcatchment (Figure 16). This is probably due to a general lack of permanent freshwater wallum habitats. Further south within Yuraygir National Park, the species was not detected throughout most of the Angourie/Redcliffe subcatchment and remains to be documented from the adjacent Sandon River subcatchment (Figure 17, 18). This trend may also be partially attributed to a lack of suitable drought refuge habitat, which was made worse by the extreme drought conditions experienced during the study. Indeed, it was particularly difficult to find permanent freshwater systems within the northern half of the reserve.

Fourteen of the 20 water bodies found to support Oxleyan pygmy perch represent new locality records for the species (Figure 16, 17). Of the remaining six water bodies, four had recently been documented to support the species. These include Bullocky Creek (site 4), Jerusalem Creek (site12) (Figure 16), Lake Minnie Water (site 69) and an unnamed swamp south-east of Lake Hiawatha (site 80) (Figure 18). Another recent record from Yorkies Gully, a feeder creek of the Esk River in Bundjalung National was also investigated (Site 31) (Figure 16). Sampling was done further downstream of the location of the original record in an attempt to ascertain if the species inhabited the lower reaches of the creek and the Esk River but it was not captured.

Oxleyan pygmy perch were found in two of the three waterbodies in which it was documented during the 1970s. Its capture from three sites in Lake Hiawatha (sites 72, 76, 77) (Figure 18) is quite significant given that despite a number of previous surveys, the species had not been recorded there since 1977 (Knight 2000a). This study has therefore resolved the uncertainty surrounding the status of the species within this lake. However, since 1976, it has not been found in the nearby Bookram Creek, despite sampling in three of the creeks tributaries (sites 71, 73, 75) and two other connected drainages (Matenga Creek, site 70 and Corkscrew Creek, site 74) (Figure 18). The status of the species within Bookram Creek therefore remains unclear. The species may be locally extinct or may simply be in low numbers and/or have a patchy distribution within the creek making it difficult to detect. An intensive survey of Bookram Creek may clarify this situation. Oxleyan pygmy perch was recorded from Tick Gate Swamp (site 83) (Figure 18) for the first time since 1977. The species has also been more recently captured from a swampy drainage approximately four kilometres further south of Tick Gate Swamp (Keller and Brown 2008). It is yet to be recorded in Yuraygir National Park south of the Wooli subcatchment. An historical record exists for the species south of the reserve but recent surveying suggests that it no longer persists there (see Survey 1). Thus, it appears that Oxleyan pygmy perch are currently restricted to drainage systems of the Richmond and Clarence River catchments within and adjacent to the north coast conservation system. Within this area it is widely distributed throughout and surrounding Broadwater (Knight 2000a) and Bundjalung National Parks and is more patchily distributed in Yuraygir National Park and some bordering habitats.

The Oxleyan pygmy perch was the sixth most widely distributed (Table 11) but the ninth most abundant species sampled, comprising only 2% of the total catch of 11,140 fish (Figure 19a). Firetailed gudgeon, empire gudgeon and striped gudgeon were the most widely distributed and among the most abundant species sampled. This finding is typical for the north coast of NSW (Survey 1; Grant 1987; Allen 1989; Schiller *et al*. 1997). The soft-spined rainbowfish and eastern gambusia were caught in higher numbers than the Oxleyan pygmy perch but were detected in a similar number of waterbodies and subcatchments. The former species was, however, more commonly captured in the Wooli River subcatchment whereas eastern gambusia was well distributed throughout the Esk River subcatchment. These two species are typical inhabitants of the coastal wallum ecosystems of mid-eastern Australia (Arthington 1996; Knight 2000a; Pusey *et al*. 2004). Although not widely distributed, the Pacific blue-eye was captured in large numbers from two waterbodies including Lake Minnie Water (sites 68, 69) and Lake Hiawatha (sites 72, 76, 77) and hence comprised 13% of the total catch. Similar trends were evident for the flathead gudgeon and Duboulay's rainbowfish, although the numbers caught were not as high. The remaining seven species were not commonly captured throughout the study area. The catch composition for each site sampled is provided in Appendix 7.

Figure 19 Contribution of each species to the total catches for a) all sample sites and b) sites that had Oxleyan pygmy perch. N = 11140 for a), n = 4922 for b).



Oxleyan pygmy perch was the sixth most abundant species sampled from the 22 sites supporting the species (Figure 19b). In total, 4,922 fish were captured from these sites, including 220 Oxleyan pygmy perch. The species was associated with various assemblages of the other fifteen fish species sampled, although it typically only co-occurred with between two to four species within a site (Table 12). The exceptions to this included Lake Minnie Water (site 69) with 11 species recorded, Lake Hiawatha (sites 72, 76, 77) with 12 to 13 species, and an un-named pond in Bundjalung National Park (site 11) from which the Oxleyan pygmy perch was the only fish caught. The eastern gambusia was also commonly detected, being recorded from 36% of the sites that had Oxleyan pygmy perch (Table 12).

The Pacific blue-eye, flathead gudgeon, Duboulay's rainbowfish, common jollytail, freshwater catfish (*Tandanus tandanus*), short and longfinned eel, Australian bass, olive perchlet, and dwarf flathead gudgeon were not frequently recorded from habitats supporting Oxleyan pygmy perch (Table 12). Most of these have not been recorded from other Oxleyan pygmy perch localities in NSW (Knight 2000a), but some are known to co-exist with the species in Queensland (Arthington 1996). All of these species were recorded to inhabit the two Wooli dune lakes: Lake Minnie Water and Lake Hiawatha (Figure 20). In addition, of all the water bodies sampled, Australian bass (Figure 21) common jollytail (Figure 22), and freshwater catfish were only sampled from these two lakes. Australian bass is a large, catadromous, carnivore endemic to Australia's south- eastern coastal drainages that requires access to estuaries to breed (Harris 1986). As the two Wooli dune lakes contain fresh waters with no estuarine connections, it is unlikely that Australian bass could sustain a viable reproducing population in the lakes. Hence, it is likely to have been stocked.

This is supported by analysis of trace elements of the otoliths removed from fish sampled from Lake Minnie Water, which revealed no evidence of a typical species migration pattern from estuarine to freshwaters (D. Crook, DSE, pers. comm.). The common jollytail populations are believed to be the northern most landlocked populations in Australia and are the only populations known to inhabit the dune lakes of mid-eastern Australia. The olive perchlet and freshwater catfish are each known from only one other east coast dune lake; Lake Wabby in Queensland and Lake Ainsworth north of Ballina in NSW, respectively (Arthington *et al.* 1986; NSW DPI Aqua- See Database). Lake Hiawatha also represents the natural southern distributional limit for the olive perchlet on Australia's east coast (Morris *et al.* 2001).

Table 12 Species of fish recorded from the sites where Oxleyan pygmy perch were sampled.

Species	2	3	4	9	11	12	18	20	23	27	28	35	36	41	42	53	69	72	76	77	80	83	Total
Oxleyan pygmy perch	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	22
Firetailed gudgeon	+		+	+		+	+	+	+	+	+	+	+		+	+	+	+	+	+	+		18
Striped gudgeon	+		+	+		+						+		+	+			+	+		+		10
Empire gudgeon	+		+	+		+						+			+			+	+		+		9
Soft-spined rainbowfish		+	+			+				+			+		+			+		+		+	9
Eastern gambusia				+			+		+		+	+	+			+	+						8
Pacific blue-eye																	+	+	+	+			4
Flathead gudgeon																	+	+	+	+			4
Duboulay's rainbowfish																	+	+	+	+			4
Common jollytail																	+	+	+	+			4
Freshwater catfish																	+	+	+	+			4
Longfinned eel																	+	+	+	+			4
Australian bass																	+		+				2
Olive perchlet																	+	+		+			3
Dwarf flathead gudgeon																			+	+			2
Shortfinned eel																			+				1
Unidentified eel																				+			1
Total	4	2	5	5	1	5	3	2	3	3	3	5	4	2	5	3	11	12	13	12	4	2	

The two Wooli dune lakes had the highest recorded species richness of all the 69 water bodies sampled, with a total of 15 species captured from Lake Hiawatha and 11 from Lake Minnie Water. This may be partially attributed to the use of an electrofishing boat within the two systems, a technique generally more effective at catching larger fish species such as Australian bass than other sampling techniques used. Nevertheless, most of the species sampled in the two Wooli dune lakes are also susceptible to capture by backpack electrofishing, seine netting and/or trapping, and hence had the potential to be detected in other sites throughout the study area. When the species lists from this study are combined with records from the Australian Museum and published lists by Timms (1969, 1982), Arthington (1996) and Gerkin (2001), a total of 15 native, one translocated, one stocked and one alien species have been recorded from Lake Hiawatha and 11 native, one stocked and one alien species from Lake Minnie Water (Appendix 8). This study has contributed new records for Australian bass and longfinned eel from both lakes, and for the common jollytail, flathead gudgeon, freshwater catfish and eastern gambusia from Lake Minnie Water. The native species richness of these two systems is remarkably high for dune lakes. Due to their general isolation, low productivity and harsh environmental conditions the fish communities of the dune lakes of central eastern Australia are generally depauperate with typically only one to two species present (Bayley *et al.* 1975; Arthington *et al.* 1986; Knight 2000b). One exception is Lake Wabby on Fraser Island, which is known to support 12 fish species (Arthington *et al.* 1986; ANGFA Southeast Queensland Regional Group 1986). The Wooli lakes therefore have relatively high species richness for mid-eastern Australian dune lakes, with Lake Hiawatha having the highest known richness of all the approximately 200 dune lakes present in the region. In addition, the species richness of the two lakes is equivalent to or higher than the richness of native fish recently recorded for a number of south-eastern Australian rivers such as the Brogo, Lower Murray-Darling and Murrumbidgee Rivers (Gehrke and Harris 2000; Gilligan 2005a, 2005b).

Figure 20 The Wooli dune lakes: Lake Minnie Water (top left) and Lake Hiawatha.

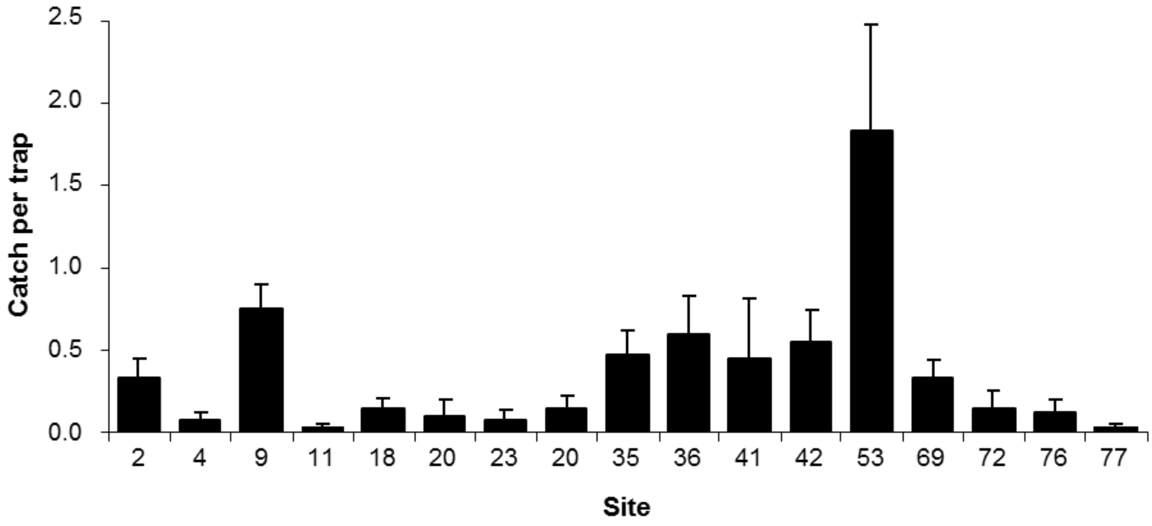
Figure 21 Australian bass (Percalates novemaculeata); a predatory species stocked into the Wooli dune lakes (Fork length: 475mm).

Figure 22 The common jollytail (Galaxias maculatus); a unique inhabitant of the Wooli dune lakes (total length: 65mm). Photo: Tarmo Raadik.

Relative abundance and population structure of Oxleyan pygmy perch

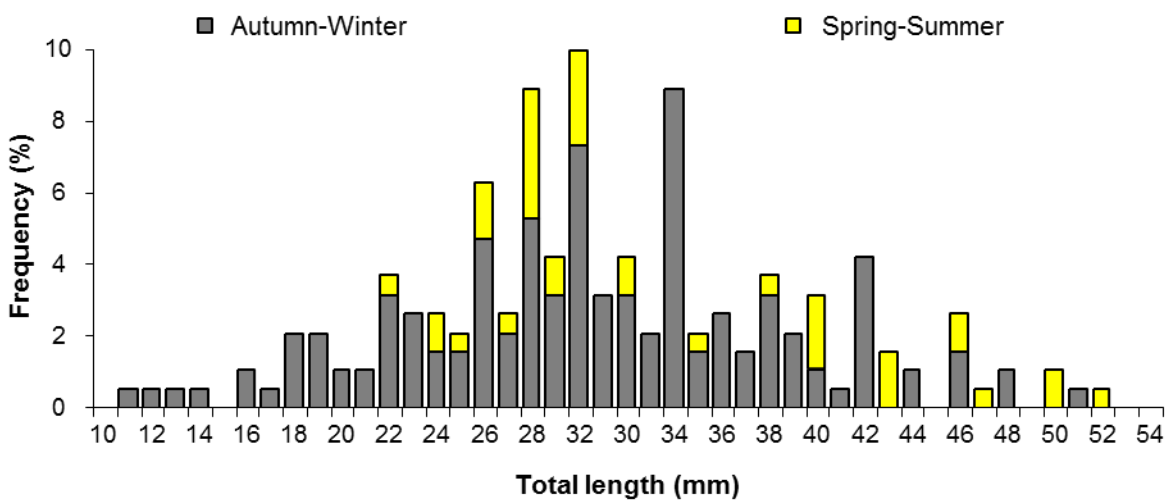
A total of 19 of the 22 sites supporting the species contained enough water to allow the deployment of traps. Trapping resulted in the capture of the species from 17 sites. The catch per trap was relatively high at site 53 with an average of 1.8 pygmy perch caught in each trap deployed (Figure 23). The catch per trap ranged between 0.5 and 0.8 for sites 9, 35, 36, 41 and 42, while values of 0.3 or less were recorded for the remaining sites. Differences in the relative abundance of Oxleyan pygmy perch may be attributed to a range of factors such as variation in habitat characteristics, competition with other species, threatening processes, and stochastic events (Gorman and Karr 1978; Evans *et al*. 1987; Wootton 1992; Arthington 1996; Knight 2000a). For example, the high relative abundances recorded at site 53 may possibly be the result of the severe drought in 2002 forcing fish to congregate in one of the last remaining deep pools in the creek. Drought may have also increased mortality rates in drainage systems under environmental stress (Magoulick and Kobza 2003), thereby contributing to the low numbers of fish captured from most of the sites. Indeed, these waterbodies appeared to be rapidly drying out. The two sites in which trapping failed to detect the species (site 12, 27) also appeared to drying out due to the effects of the drought with only one individual captured from each site with the backpack electrofisher.

Figure 23 **Catch per trap (± standard error) for Oxleyan pygmy perch.**



Temporal differences in the size structure of Oxleyan pygmy perch sampled during the survey are shown in Figure 24. The smallest individuals sampled were captured in the autumn and winter months. These fish are likely to be small juveniles (Knight and Trnski 2011) recruiting into the population from the previous spring/summer spawning season. Males and females reach sexual maturity at approximately 24 to 29 mm (Knight *et al*. 2007a); hence larger juveniles were also present in samples collected in spring and summer. Based on the presence of both mature and juvenile fish, recruiting populations were sampled from half of the sites that had Oxleyan pygmy perch. Insufficient numbers were collected from the remaining sites to draw sound conclusions. Overall, the size structure is similar to that of populations previously studied, with the most abundant size classes comprised of fish at or slightly larger than the size of maturity (Survey 1; Arthington 1996; Knight 2000a). Relationships between total length and standard length and total length and body weight are provided in Appendix 4.

Figure 24 **Length frequency distribution of Oxleyan pygmy perch collected during the autumn- winter and spring-summer seasons of 2002 and 2004.**



Assessment of habitats supporting Oxleyan pygmy perch

Table 13 provides an overview of the habitat characteristics and human effects associated with sites supporting Oxleyan pygmy perch, while Table 14 summarises the water quality parameters measured at these sites and at all sites sampled. The tabulated data reveal that populations were found in lakes, swamps, creeks and several water bodies created or modified by sand mining. All water bodies were located within wallum environments with a surrounding vegetation community consisting of broad-leaved paperbark, heath banksia, wallum banksia and various other heath species. The species was typically captured in sandy, shallow habitats averaging approximately 0.6 metres in depth with no visible signs of flow. Thick stands of emergent vegetation including the giant sedge, small bog rush and spike rush were common and provided instream cover along with beds of frogsmouth, water ribbon (*Triglochin procerum*) and water lilies (*Nymphaea* spp.). Where aquatic vegetation was less abundant, as in site 2, Bullocky Creek (site 4), Jerusalem Creek (site 12) and Mara Creek (site 41), Oxleyan pygmy perch were caught near steep or undercut banks fringed with overhanging vegetation such as coral fern, the sedge *Baloskion tetraphyllus* and saw- sedge. Plant litter, algae, aquatic moss and fallen timber also provided habitat for the species. The waters were always acidic (pH < 7) and fresh with low conductivity (< 850 µS. cm^{-2}; <1‰ salinity). Dissolved oxygen levels were never less than 2.50 mg. L^{-1} and temperature ranged between approximately 11 and 23°C. All water bodies containing the species were clear to darkly stained with organic acids, and were generally not turbid. These characteristics are common features of many of the water bodies supporting Oxleyan pygmy perch (Table 2; Survey 1).

Table 13 Habitat characteristics and human effects associated with sites supporting Oxleyan pygmy perch. Values for aquatic vegetation (% cover) include for the whole site and for the location of capture of pygmy perch (in parentheses). UC bank = steep/undercut bank fringed with overhanging vegetation. Human effects: D = Disturbance, A = Access, T = Threats, I = Introduced fish species, S = Land use status. Refer to Table 4 for scoring of human effects. * denotes introduced species previously recorded.

Site	Waterbody type	Depth (m)	Flow ($m\ s^{-1}$)	Substratum	Aquatic cover	Aquatic veg (% cover)	Human effects				
							D	A	T	I	S
2	Creek	0.3	<0.1	Sand	Sedges, UC banks, timber, plant litter	5 (0)	5	5	5	5	5
3	Creek	0.2	<0.1	Sand	Sedges, macrophytes, rocks, plant litter	70 (70)	4	4	4	5	5
4	Creek	0.5	<0.1	Sand, mud	Sedge, UC bank, timber, plant litter	5 (0)	5	5	5	5	5
9	Swamp	0.5	N/A	Sand	Sedges, macrophytes, plant litter	90 (90)	5	2	4	1	5
11	Swamp	0.3	N/A	Sand	Sedges, plant litter	80 (80)	5	5	5	5	5
12	Creek	0.3	<0.1	Sand	Sedges, UC bank, macrophytes, timber, plant litter	5 (0)	4	2	3	5	5
18	Dredge pond	0.7	N/A	Sand	Sedges, macrophytes, plant litter	10 (85)	3	4	4	1	5
20	Mining drain	0.6	<0.1	Sand	Sedges, UC bank, aquatic moss	90 (90)	3	5	5	5	5
23	Dredge pond	0.7	N/A	Sand	Sedges, plant litter	5 (100)	3	4	4	1	5
27	Swamp	0.6	N/A	Sand	Sedges, macrophytes, plant litter	85 (85)	3	5	5	5	5
28	Swamp	0.8	N/A	Sand, mud	Sedges, plant litter	70 (70)	3	5	5	3	5
35	Dredge pond	0.5	N/A	Sand	Sedges, macrophytes, plant litter	50 (85)	3	4	4	1	5
36	Swamp	0.3	N/A	Sand	Sedges, plant litter	50 (80)	5	5	5	3	5
41	Creek	1.0	<0.1	Sand	Sedges, UC bank, aquatic moss, plant litter	10 (10)	5	5	5	5	5
42	Creek	0.9	<0.1	Sand	Sedges, UC bank, aquatic moss, plant litter	40 (40)	5	5	5	5	5
53	Creek	0.6	<0.1	Sand	Sedges, timber, plant litter	70 (85)	2	4	2	1	5/2
69	Dune Lake	1.0	N/A	Sand, mud	Sedges, plant litter	90 (90)	5	4	4	3	5
72	Dune Lake	1.0	N/A	Sand	Sedges, plant litter	70 (70)	5	4	5	5*	5
76	Dune lake	1.0	N/A	Sand	Sedges, timber, plant litter	70 (80)	4	4	4	3	5
77	Dune Lake	0.7	N/A	Sand, mud	Sedges	80 (80)	5	4	5	5*	5
80	Swamp	0.2	N/A	Sand, mud	Sedges	90 (90)	5	2	4	5	5
83	Swamp	0.1	N/A	Sand	Sedges, timber, plant litter	90 (90)	3	4	4	5	5/3

Table 14 **Summary of water quality parameters of all sites sampled and of sites supporting Oxleyan pygmy perch. Water colour abbreviations: Cl = clear, Lt = light tannin, Mt = medium tannin, Dt = dark tannin, Tr = translucent/cloudy, Hs = heavy suspended solids.**

Parameter	All Sample sites (n = 73)			Pygmy perch sites (n = 22)		
	Range	Mean	SE	Range	Mean	SE
Temperature (°C)	10.1-23.3	16.28	0.358	10.9-23.3	16.92	0.645
Dissolved oxygen (mg L^{-1})	0.04-9.6	5.55	0.272	2.5-9.6	6.51	0.490
pH	3.52-8.06	5.233	0.1224	3.52-6.90	5.153	0.2566
Conductivity (µS cm^{-2})	110-22900	810.1	337.38	111-830	228.5	33.01
Turbidity (NTU)	0-160	18.9	3.52	0-80	14.0	4.46
Water colour	Cl-Dt; Tr	---	---	Cl-Dt; Tr	---	---

Sampling within two waterbodies provides insight into the environmental tolerances of the species. An environmental gradient was present in Mara Creek south of Yamba, which was sampled in its lower (site 40), middle and upper reaches (site 41) (Figure 17). Mara Creek drains back barrier sand dunes and contains little dissolved oxygen until the waters are aerated as they flow over tree roots and coffee rock towards the creeks middle reaches (Table 15). The creek flows intermittently into the Pacific Ocean and receives saltwater input through spring tides and possibly storm surges. A salt wedge dissipates upstream and waters within the middle reaches and headwaters are fresh. At the time of sampling, the mouth was not open to the ocean and the stagnant waters in the lower reaches were anoxic. Despite intensive sampling in all three reaches, Oxleyan pygmy perch were only captured within the middle section where waters were fresh and dissolved oxygen levels were 2.76 mg. L^{-1} (29.6% air saturation). These oxygen concentrations are still considered relatively low for freshwater systems (Moyle and Cech 2000) and are at a level that generally causes fish stress (Wootton 1992; Lefrancois *et al*. 2005). Given that the species has been recorded in waters with similar low dissolved oxygen concentrations (as low as 2.15 mg. L^{-1} and 20.2% air saturation; Appendix 9), these data suggest that it can tolerate hypoxic but not anoxic conditions.

Table 15 **Water quality parameters recorded in Mara Creek, Yuraygir National Park.**

Water Quality	Site 40	Site 41	
	Lower Reaches	Middle Reaches	Headwaters
Temperature (°C)	16.8	18.6	17.4
Dissolved oxygen (mg L^{-1})	0.04	2.76	1.07
% Air saturation	0.4	29.6	11.2
pH	5.87	3.71	3.74
Conductivity (µS cm^{-2})	22900	162	184
Turbidity (NTU)	52	8	7
Water colour	Dark	Dark	Dark

While it is plausible that estuarine salinities (22,900 µS.cm^{-2} = ~ 14‰ salinity; seawater is approximately 35‰) in conjunction with the low oxygen levels may have excluded Oxleyan pygmy perch from the lower reaches of Mara Creek (Table 15), there is some evidence to suggest that the species can tolerate at least slightly saline waters. Like Mara Creek, Bullocky Creek, which is located in the north of Bundjalung National Park (Figure 16), also drains through wallum scrub towards the ocean and receives saltwater input during spring tides. In 2002, the species was found in the middle reaches of this system where conductivity was 8,950 µS.cm^{-2} near the surface and 12,700 µS.cm^{-1} near the bottom (~ 4.5 and 7‰ salinity, respectively) (Harrison *et al.* 2002). During the current study, the capture of Oxleyan pygmy perch further upstream in the freshwaters of Bullocky Creek (site 4) suggests that the species continues to persist throughout this system and that the 2002 surveys did not simply catch vagrant individuals originating from another nearby permanently fresh water body. Similarly, south of Bullocky Creek, the species has been recorded from the estuarine reaches (WBM Oceanics Australia 2000) and the upper freshwater reaches (site 12) of Jerusalem Creek (Figure 16). These data show that the Oxleyan pygmy perch is capable of tolerating waters of higher conductivity than previously thought and can inhabit slightly brackish habitats.

Most sites supporting Oxleyan pygmy perch were in a relatively pristine condition with little or no obvious signs of disturbance; were relatively inaccessible to the general public; and generally free from threats (Table 13). This may be attributed to the fact that all but two sites were situated within National Park estate. Tick Gate Swamp (site 83) crosses the boundary of Yuraygir National Park onto private property (Figure 18), which at the time of sampling was being heavily logged. Further north, a tributary of Haleys Creek (site 53) drains out of the reserve onto agricultural land (Figure 17), resulting in a range of human disturbances and threats to Oxleyan pygmy perch occurring outside the park boundary. Fish passage has also been disrupted outside of the park by a management trail that runs perpendicular to the creek. Although a culvert pipe has been added to reduce vehicle damage to the creek and to allow continual drainage, the pipe's elevated position above the creek bed impeded upstream fish passage. This is regarded as a significant threat as the upstream population is likely to be continually depleted as fish, which move downstream either voluntarily or by high flow events are unable to swim back upstream into the more undisturbed environment. This is a likely scenario, particularly given that the displacement of small-bodied fishes including Oxleyan pygmy perch downstream and below barriers to fish passage has been well documented (Semple 1991; Arthington 1996; Knight 2000a; see also Survey 1). While not immediately threatened by anthropogenic impacts, site 9, Jerusalem Creek (site 12) and site 80 are easily accessible by public road, and hence are potentially susceptible to human disturbance. Road run-off may also increase sediment loads, nutrient levels and introduce toxic substances.

Six water bodies within Bundjalung National Park are also located in areas disturbed by past sand mining practices (sites 18, 20, 23, 27, 28, 35) (Figure 16). When surveyed, these waterbodies, some of which are remnant dredge ponds and drains, appeared to be functioning wallum ecosystems containing acidic, tannin stained freshwaters, areas of thick emergent vegetation and aquatic assemblages of insects, fish, crustaceans and turtles. These organisms form the basic food webs typical of dune lakes in mid-eastern Australia (Bayly *et al*. 1975; Arthington *et al*. 1990). Four of these waterbodies contained eastern gambusia, as did sites 9 and 36, Lake Minnie Water (site 69) and the disturbed Haleys Creek tributary. This species had also been previously recorded from Lake Hiawatha (Appendix 8) but was not captured during the present study (sites 72, 76, 77). The eastern gambusia proliferates in disturbed environments (Arthington *et al*. 1983; Arthington and Lloyd 1989; NPWS 2003). Hence, their wide distribution within the Esk River subcatchment (Table 11) may be correlated with extensive sand mining in the recent past. It is implicated in the decline of Oxleyan pygmy perch (NSW DPI 2005) and is therefore considered a threat to the populations inhabiting these sites.

Similarly, Australian bass stocked into Lake Minnie Water and Lake Hiawatha may also be impacting on the Oxleyan pygmy perch. The Australian bass is recognised as an important recreational angling species in NSW and is regularly stocked into rivers and impoundments to improve the fishery (Harris and Rowland 1996). Of seven bass caught in Lake Minnie Water, five were estimated to be 10 years and two to be 12 years of age (J. Knight, unpublished data). Assuming the bass were stocked as fingerlings, these ages imply two separate stocking events, one in 1991/92 and one in 1993/94. The species is known to have been introduced into other dune lakes in NSW for recreational fishing purposes including Observation Lake within the Weapons Range in the north of Bundjalung National Park (R. Amos, RAAF, pers. comm.). Sampling of Observation Lake during this study (site 7) and by Timms (1982; referred to as Cooks Lagoon) and Harrison *et al.* (2002) has resulted in the capture of only one gudgeon species. In contrast, the Oxleyan pygmy perch and a range of other small, native freshwater fish commonly occurred throughout similar waterbodies in the immediate vicinity. Hence, Australian bass may have heavily predated on the small-bodied fish species inhabiting Observation Lake, and may be having a similar impact on the fish in the Wooli dune lakes. Indeed, analysis of the stomach contents of the Australian bass sampled from Lake Minnie Water bass revealed they had been preying upon small native fish and crustaceans (Figure 25). These items are known to form a major component of diet of bass in their natural habitat (Harris 1985).

Figure 25 **Range of dietary items found in the stomachs of Australian bass sampled from Lake Minnie Water. Top left: atyid shrimp (*Caridina* sp.); top right: firetailed gudgeon (*Hypseleotris galii*); centre left: claw of freshwater crayfish (*Cherax* sp.); centre right: freshwater prawn (*Macrobrachium australiense*); bottom: Duboulay's rainbowfish (*Melanotaenia duboulayi*).**

General Discussion and Recommendations

This report presents the results of the most extensive and intensive surveys for the Oxleyan pygmy perch undertaken in NSW. Over a four year period between 2001 and 2004, a total of 213 coastal waterbodies were investigated along a 550 kilometre stretch of coastline from the Queensland border south to and including Myall Lakes National Park. Of these, 159 were sampled for fish, resulting in the capture of Oxleyan pygmy perch from 27 waterbodies. The species was detected in 21 new and six previously documented localities, but was not found in three of five waterbodies historically reported to support the species. Coupled with the population and habitat assessments, these data provide a detailed account of the distribution and abundance patterns of the species, insights into the factors influencing these patterns, and of the current conservation status of extant populations. In turn, the information provides the basis for recommendations regarding conservation-based management initiatives and further research.

Distribution of the Oxleyan pygmy perch

Prior to the commencement of the recovery planning process in 2000, little was known of the overall distribution and conservation status of the Oxleyan pygmy perch in NSW (Knight and Butler 2004). The species had been recorded from only nine localities over a 70 year period (Figure 26). A need for baseline data stimulated an extensive survey of over 300 sites in the state's north-east. The species is now known to inhabit 86 waterbodies within 67 permanently connected, unfragmented (i.e. contiguous) drainage systems (Knight *et al*. 2012; NSW DPI Aqua-See database; Geolink, 2013, 2015; Matt Birch, Aquatic Science and Management, unpublished data). These systems occur within eight subcatchments of the Richmond and Clarence River systems and are restricted to approximately 100 kilometres of coastal habitat encompassed by Broadwater, Bundjalung and Yuraygir National Park and bordering habitats (Table 16). The habitats are typically situated within eight kilometres of the coast at elevations of less than 30 metres above sea level. Approximately 80% of the locality records occur in close proximity to one another on contiguous lowland, coastal floodplains. Populations also inhabit several adjacent subcatchments isolated from these floodplains by high (≤ 70 m) barrier sand dunes. To assist in the protection and conservation of the Oxleyan pygmy perch, it is recommended that waterbodies supporting the species are listed as Critical Habitat under the NSW *Fisheries Management Act 1994*.

Figure 26 Time-line of initial discovery of lakes, swamps, creeks and smaller tributary streams supporting Oxleyan pygmy perch in NSW. Grey bars: number of new record localities in a given year that are known to currently support the species. White bars: number of previously recorded localities that no longer support the species. Black line: cumulative number of new N. oxleyana locality records over time.

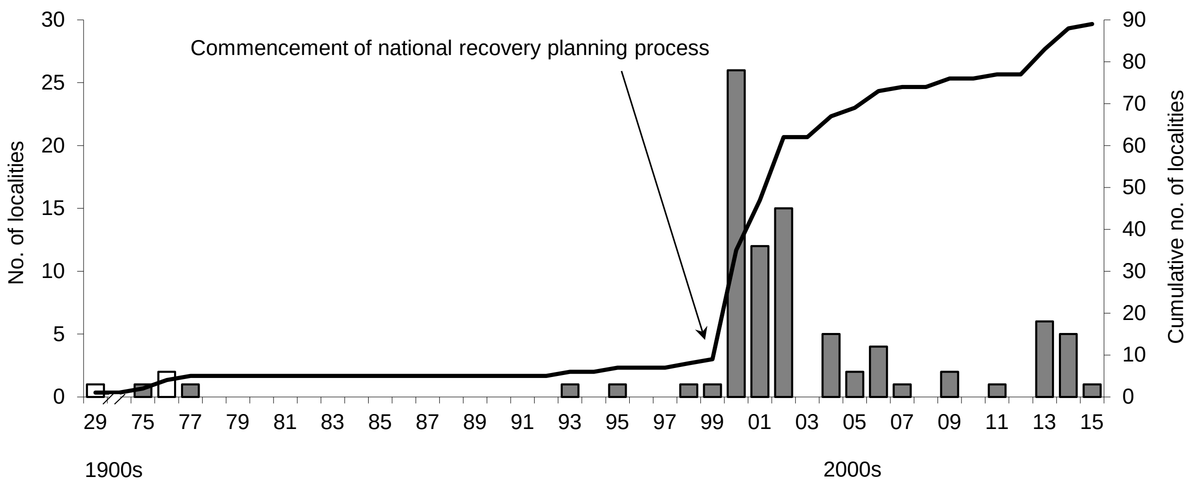


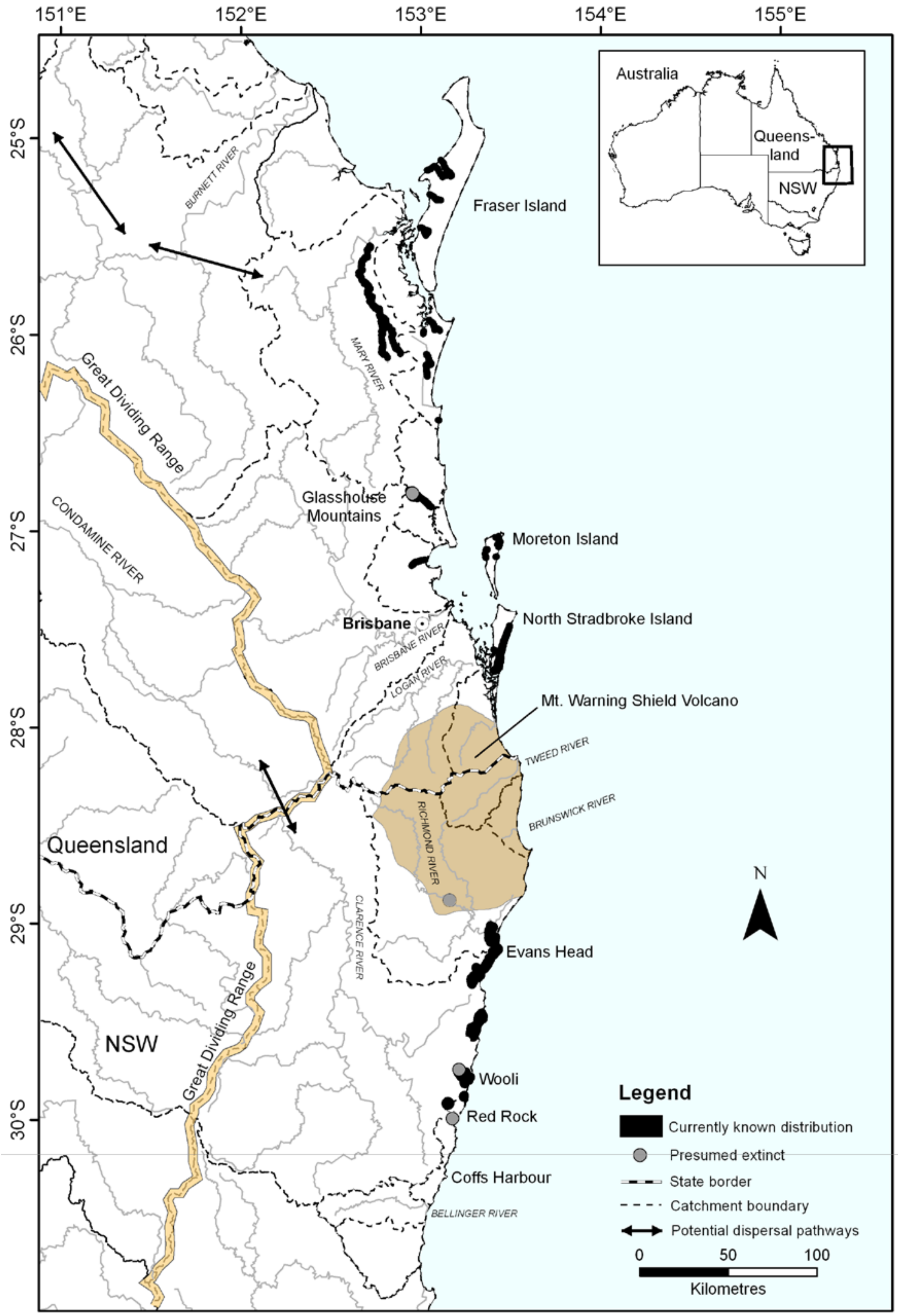
Table 16 **Numbers of waterbodies documented to support Oxleyan pygmy perch populations since 2000 within the national parks and adjacent habitats, river catchments and subcatchments of NSW.**

National Parks and adjacent habitats	Catchment	Subcatchment	Lakes, swamps, creeks & smaller tributary streams	Discete drainage systems
Broadwater	Richmond	Coraki Area	17	10
		Broadwater Area	8	7
		Evans River	19	12
Bundjalung	Richmond	Evans River	1	1
		'unclassified'	5	5
	Clarence	Esk River	24	22
Yuraygir	Clarence	Angourie/Redcliffe	1	1
		Wooloweyah Lake	3	3
		Wooli River	8	6

On a broader scale, the overall geographic distribution of the Oxleyan pygmy perch encompasses approximately 534 kilometres of coastline from Coongul Creek on Fraser Island, Queensland (25º 16'S, 153º 09'E) south to an un-named tributary of the Wooli River, NSW (29º 56'S, 153º 09'E) (Figure 27; Keller and Brown, 2008; Knight and Arthington, 2008). The species is rarer and has a more fragmented distribution in south-east Queensland. Small populations inhabit six isolated, mainland drainages, and 15 discrete drainages distributed across Fraser, Moreton and North Stradbroke islands (Knight and Arthington, 2008; D. Richardson, WBM Oceanics, pers. comm.). The Queensland and NSW populations no longer appear to intermix as they are separated by approximately 250 kilometres of coastline (Figure 27). There is also strong evidence of a southern range contraction in the last 30 years and this species is no longer found in several localities where it was collected between 1929 and 1976 (Beerwah Forest, Queensland, and Bookram Creek, Cassons Creek and near Coraki, NSW) (Figure 27). Since 2000, several localities near Evans Head have also been cleared for development and the subsequent status of affected populations is unknown (Appendix 10).

The prevalence of the Oxleyan pygmy perch on the NSW coastal floodplains has been attributed to intermittent connection among water bodies during high rainfall events or large floods emanating from the Richmond and Clarence Rivers. These conditions may facilitate dispersal, thereby allowing the species to colonise new systems and/or to recolonise previously disturbed areas within a subcatchment (Knight 2000a, 2008; Knight *et al*. 2009). Flood dispersal could explain the species capture from remnant sand mining dredge ponds during this study and by Knight (2000a). It is reasonable to assume that in months or years with high rainfall, swollen wallum drainages and inundated floodplains would provide ample habitat and food resources for the Oxleyan pygmy perch (Welcomme 1985; Junk *et al*. 1989), particularly in vegetated meso- and microhabitats protected from the destructive force of the main flow (Knight and Arthington 2008). These conditions may allow subpopulations, enlarged via increased recruitment success (Knight *et al*. 2007a), to migrate within drainages and across the floodplain to colonise permanent and ephemeral habitats (Knight 2000a; Balcombe *et al*. 2005). Alternatively, as observed by Knight (2000a) in the Richmond River coastal floodplain subcatchments, the distribution and abundance of the Oxleyan pygmy perch may be substantially reduced in dry months or years, through the desiccation of ephemeral habitats. A similar scenario has been documented for the Balston's pygmy perch *Nannatherina balstoni* Regan inhabiting the peat flats of south-western Australia (Morgan *et al*. 1995).

Figure 27 Currently known distribution of the Oxleyan pygmy perch (black shading) and locations where the species has been historically recorded but is now presumed extinct (grey circles). Geological events attributed to shaping the species' distribution including the Mount Warning shield volcano (taken from Graham 2004a) and ancient dispersal pathways (refer to Appendix 11) are also depicted.



Contemporary movement and mixing, and hence gene flow, is also apparent among interconnected swampy seepages and lakes on Moreton Island (Hughes *et al*. 1999). However, high levels of genetic structuring have been found among other mainland and insular populations studied in Queensland, inferring that they diverged from each other as a result of extremely limited dispersal (Hughes *et al*. 1999; Knight *et al*. 2009). These populations are therefore likely to be vulnerable to localised catastrophic events, with re-colonisation unlikely to occur (Hughes *et al.* 1999). Likewise, whilst dispersal may occur within some of the NSW subcatchments, distinct genetic differentiation and hence restricted gene flow is evident among these subcatchments (Knight *et al*. 2009). This isolation should be taken into account when managing the species. Future efforts to increase genetic diversity may be warranted for remnant populations suffering the effects of small population size. In such cases, the introduction of individuals from other populations can increase genetic variation and fitness affecting a ‘genetic rescue’ (Tallmon *et al*. 2004; but see also Hedrick 2005). However, predicting the outcome of such strategies in fish is problematic (McClelland and Naish 2007). In the absence of additional information from nuclear loci and comparative measurements of fitness in Oxleyan pygmy perch populations, a precautionary measure would be to maintain as many genetically differentiated populations as possible and to avoid translocation between catchments.

Management of extant populations of the Oxleyan pygmy perch and the processes threatening their survival requires not only knowledge of contemporary distributions but also an understanding of historical patterns of biogeography inferred from studies of population genetic structuring and landscape evolution patterns in which the species evolved (Keenan 1994; Unmack 2001; Ponniah and Hughes 2006; Page and Hughes 2007). Despite the current fragmentation of the Queensland and NSW populations, recent historic connectivity appears to have existed (Knight *et al*. 2009). Indeed, opportunities for northward and southward gene flow may have existed as recently as 8,000 years BP, at the end of the last glacial period, when lower sea levels facilitated shared confluences between adjacent drainages in northern NSW, and those in south-eastern Queensland (Lambeck and Nakada 1990; Hughes *et al*. 1999; Page and Hughes 2007; Knight *et al*. 2009). Genetic data also suggest a range expansion around 18,000 years BP (Knight *et al*. 2009) consistent with lower sea levels during the last glacial maximum (Neal and Stock 1986).

The underlying causes of the current geographic gap between Queensland and NSW populations are unclear as there are no records of the occurrence of the species in this area. It is possible that the Oxleyan pygmy perch either never dispersed into those catchments within the distribution gap or was once present there but have since became locally extinct via natural or human causes. Human-induced habitat destruction, degradation and fragmentation within the Tweed and Brunswick River catchments (Figure 27) may have caused the localised species extinction in this area. Indeed, a high number of disturbed potential habitats for the species were documented north of Broadwater National Park. Similarly, a recent audit of NSW river systems found that most of the subcatchments in this area were under high environmental stress (DLWC 1999). The south-east corner of Queensland has suffered equivalent levels of degradation with numerous areas that once formed appropriate habitat for the species now drained, cleared and developed (Graham 2004a). The Tweed and Brunswick River catchments also lack the large floodplains amenable to dispersal and recolonisation such as those in the Richmond and Clarence catchments, thereby increasing the probability of extinction (Unmack 2001). The species absence from this area also coincides with the presence of the Mount Warning shield volcano (Figure 27), which formed 23.5 to 20.5 mya and like many shield volcanos was responsible for the formation and super-imposition of radial drainage in the vicinity and major drainage disruption in adjacent catchments (Ollier 1995; Graham 2004a). It particularly altered the Brunswick and Tweed Rivers but its influence spread over a wider area from the Logan River southward to most of the Richmond River. Miocene volcanism also restricted drainage to the Clarence River, confining it largely to the south-eastern part of the Clarence-Moreton Basin (Haworth and Ollier 1992). These processes may have fragmented the distribution of the Oxleyan pygmy perch through extinction or impeded dispersal into these catchments.

A correlation also exists between the occurrence of the species and areas in northern NSW and southern Queensland inundated by marine transgressions during more recent interglacial periods. While its distribution coincides with large sand plains formed when sea levels were five or six metres higher than present approximately 120,000 to 130,000 years ago, the species is conspicuously absent from areas inundated 6,500 to 4,000 years ago, when sea levels were approximately one to one and a half metres higher than present (Lambeck and Nakada 1990; Graham 2004b). As discussed earlier, lower sea levels as recently as 8,000 years ago may have allowed Oxleyan pygmy perch to disperse between adjacent drainage systems that were joined at the time (Hughes *et al*. 1999; Knight *et al*. 2009). During this period however, the radial drainages associated with Mount Warning may have remained isolated thereby impeding colonisation of this area. A combination of past volcanism, recent marine transgressions and/or anthropogenic impacts is also plausible, as are climatic conditions such as droughts, which may have caused the localised extinction of populations with limited dispersal opportunities (Unmack 2001; Magoulick and Kobza 2003; Matthews and Marsh-Matthews 2003). Further analysis of more ancient landscape evolution patterns in which the species evolved is provided in Appendix 11.

The gross impacts of activities such as urban development were obvious throughout the study area. Populations appear to have been extirpated at the degraded historical localities at Coraki and Cassons Creek, reinforcing the belief that this species is sensitive to habitat disturbance and modification (Arthington 1996; Pusey *et al*. 2004; NSW DPI 2005). Likewise, the species distribution comes to an abrupt halt to the west of the north coast conservation system. Habitats modified to grow sugar cane such as those surrounding Wooloweyah Lagoon and to the west of Broadwater National Park are prime examples. Hence, human activities appear to have had a significant influence on the species presence/absence patterns.

Smaller spatial and temporal scale impacts may have also significantly influenced the species distribution. For example, the low nutrient waters of wallum lakes, creeks and swamps may be easily degraded by excess nutrients, toxic substances and silt entering via urban, agricultural and industrial runoff, and by recreational and camping activities (Arthington *et al.* 1990; Outridge *et al.* 1989; Leggett 1990; Arthington 1991; Arthington and Kennard 1991; Arthington 1996; van Senden *et al.* 1996). Riparian and littoral vegetation clearing can also disrupt nutrient cycles, reduce suitable habitat for Oxleyan pygmy perch and other aquatic animals, and reduce the contribution of plants and terrestrial insects to the food chains of which Oxleyan pygmy perch may form a part (Blyth and Jackson 1985; Arthington *et al.* 1990; van Senden *et al.* 1996). Furthermore, vegetation clearing may also lead to the rapid erosion of sandy substrates followed by the siltation and infilling of pools and the smothering of macrophytes, a preferred habitat of the species (Timms 1977a, 1982; Wager 1992; Arthington 1996; Knight 2000a). Concomitantly, suspended sediments may also smother eggs and sensitive larvae (Kock *et al*. 2006) and impair the visual acuity and foraging success of fish such as Oxleyan pygmy perch that hunt by sight (Bruton 1985, cited in Arthington 1996). These threatening processes may have led to reductions in the size and eventual extirpation of populations.

Research into the tolerances of the Oxleyan pygmy perch to changes in habitat and water quality would provide useful insights into the factors influencing its distribution and abundance patterns. Knowledge of the species tolerance to turbidity levels, for example, would assist in understanding the direct impacts of suspended sediments on populations and sensitive life history stages. Similarly, the species is regularly captured in waters with a pH less than 4 and has been kept in aquaria at concentrations greater than 7 (J. Knight, unpublished data). The low pH is derived from organic acids from the surrounding vegetation but the species ability to tolerate sulphuric acids associated with acid sulphate soils is unknown. Indeed, historical records and field surveys demonstrate that the species has a potentially broader niche than it typically occupies. Its capture within a variety of habitats raises questions regarding the factors influencing its current, strong association with wallum environments. Fieldwork has also revealed that Oxleyan pygmy perch can tolerate relatively low dissolved oxygen concentrations and slightly saline conditions. Given the importance of salinity in influencing the localised distribution and dispersal patterns of freshwater fish (Wootton 1992), experimental research into this area has already been completed (J. Knight, unpublished data). The species was found to be intolerant to salinity concentrations of 13.5‰ or higher. However, fish held in waters of 11‰ salinity for two weeks displayed feeding and other behaviours similar to those of control fish in fresh water. Eggs and larvae also tolerated 11‰ for 96 hours, but egg incubation time increased, hatch rate decreased and larval mortality increased as concentrations increased beyond this level. These data strengthen current knowledge regarding species-habitat associations, provide information on environmental factors influencing dispersal opportunities, and assist in identifying environmental indicators for the species presence. The information may also assist in the management of remaining habitats and in the environmental assessment of proposed developments, as would research into other aspects of the species ecological tolerances. A better understanding of variables influencing the size and dynamics of populations may also be gained (see below). An updated summary of the water quality parameters of NSW sites supporting Oxleyan pygmy perch is provided in Appendix 9.

Conservation status of extant NSW populations

The majority of populations sampled were relatively secure within national park estate. Although most populations were relatively small, there was evidence of breeding and recruitment success suggesting self-sustaining populations were present throughout the study area. Subtle variations in habitat quality, drought conditions and the seasonality of breeding and recruitment may have influenced the size and structure of populations sampled (Pusey *et al*. 2004; Knight 2008). Further interpretation of patterns of variation in abundance is hindered by poor understanding of driving variables, such as ecological and environmental tolerances, interactions with introduced species and the influence of stochastic, deterministic and threatening processes on populations (NSW DPI 2005). As such, these knowledge gaps may be considered a significant threat as they impede the effective management of the species (Pusey *et al*. 2004).

Despite the protection provided by the reserve system, a number of anthropogenic impacts and potential threats to Oxleyan pygmy perch populations were observed throughout the study areas. Populated creeks draining out of reserves became heavily degraded within agricultural land. Disruption to fish passage through the elevated positioning of culvert pipes was also observed. Heavy logging, with the associated threats of reduced riparian vegetation and increased siltation, was apparent at one locality partially situated within private property. Potential human effects and water pollution associated with public access also threatened several populations. Stocked populations of the predatory Australian bass were also detected within the Wooli dune lakes. In addition, 45% of all water bodies sampled throughout the entire study area contained the alien eastern gambusia, as did 44% of water bodies supporting Oxleyan pygmy perch. As such, approximately 45% of habitats reported to support Oxleyan pygmy perch in NSW are contaminated with this noxious pest fish (J. Knight, unpublished data). Knight (2000a) identified additional threats to populations in and around Broadwater National including the periodic channelisation of streams, disruption to the connectivity of drainage systems by management trails, and proposed urban development.

The conservation and recovery of Oxleyan pygmy perch is heavily reliant upon the effective management of threatening processes. Mitigation actions may include modification of culvert pipes and management trails disrupting fish passage in accordance with government policy and guidelines (Fairfull and Carter 1999), rehabilitation of degraded habitats, and negotiations with landowners and local councils regarding the conservation of populations outside protected areas. Measures to restore fish passage should take into consideration the possible encroachment of eastern gambusia into upstream areas. As the interactions between eastern gambusia and Oxleyan pygmy perch are not well understood (Morris *et al*. 2001; NSW DPI 2005), studies are recommended to clarify the degree of threat posed by this pest species. Co-occurring eastern gambusia populations should also be regularly monitored and eradicated where possible. Similarly, research is required to elucidate the effects that Australian bass may be having on Oxleyan pygmy perch and associated aquatic fauna, and to assist in determining the feasibility of eradicating this stocked species. Fostering community ownership and support through public education programs and other initiatives may also assist in reducing threats to Oxleyan pygmy perch caused by human activities. For example, public education may assist in preventing further introductions of Australian bass into the Wooli lakes. Steps have already been taken by NSW DPI to address some of these threats (Knight *et al*. 2012).

Oxleyan pygmy perch appeared to be relatively well established throughout an area in Bundjalung National Park previously disturbed by past sand mining practice. This has also been observed in Broadwater National Park (Knight 2000a). When surveyed, these waterbodies, some of which are remnant dredge ponds and drains, appeared to be functioning wallum ecosystems containing acidic, tannin stained freshwaters, areas of thick emergent vegetation and a food web typical of dune lakes of mid-eastern Australia (Bayly *et al*. 1975; Arthington *et al*. 1990). Flood dispersal may have contributed to the establishment of these systems. Nevertheless, it is apparent that while mining may have been detrimental to Oxleyan pygmy perch until the industry was phased out, its legacy of deep artificial water bodies have since provided drought refuge habitat for the species. Indeed, numerous shallow habitats were observed to be under considerable environmental stress and were rapidly drying up. For example, several water bodies recorded to support the species near Evans Head by Knight (2000a) were found to be desiccated during the present study (Appendix 10). The severity of the drought was intrinsically linked to global warming (Karoly *et al*. 2003), which has recently been recognised a significant threat to freshwater fishes (Matthews and Marsh- Matthews; 2003; Pusey *et al*. 2004).

A less obvious conservation concern, which in part may be related to increased aridity, is the threat posed by fire. It is well known that fire can negatively affect fish populations. Impacts include increases in pH, removal of riparian vegetation (resulting in altered temperature regimes and reductions in allochthonous inputs), altered nutrient cycling, reductions in structural fish habitat, and increased siltation and biological oxygen demand (Chessman 1986; Minshall *et al*. 1989; Bozek and Young 1994; Gerla and Galloway 1998). It remains unclear whether bushfires and hazard reduction burns have influenced the distribution of the Oxleyan pygmy perch. When GIS layers of spatio-temporal fire patterns were overlaid on species distribution maps for Broadwater and Bundjalung National Park there was no apparent correlation between the absence of the species and fire (J. Knight, unpublished data). However, sampling of a stream (site 59 in Survey 1) prior to and subsequent to an intense bushfire in 2001/02 revealed an 89% reduction on overall fish abundance and a 99% reduction in the abundance of Oxleyan pygmy perch (J. Knight, unpublished data). Several fire management activities may also be considered a form of habitat degradation. While fighting fires, fire-fighting foams used in close proximity to water bodies may cause toxic chemicals to enter and pollute pygmy perch habitat. In addition, these water bodies may be used as water sources, thereby reducing water levels in critical habitats (Knight 2000a). The abstraction of water may also directly remove fish from the water body. Consequently, these potential threats have been taken into consideration in the development of fire management strategies for national park estate (Holder 2005). Similar management initiatives are required for areas occupied by the species outside of conservation areas.

The re-establishment of populations is one of many actions that may be adopted within a recovery plan to assist in returning a threatened species to a position of viability in nature (Environment Australia 2000). The undisturbed, potential habitats may be considered suitable water bodies for a targeted stocking program, particularly those located within the species distribution gap between Queensland and Broadwater National Park. Stock enhancement aimed at increasing recruitment and therefore population size is another potential management option. However, Knight (2008) found that population densities appear to be governed less by demographic processes and more by independent environmental uncertainty. Hence, management initiatives focused on maintaining and rehabilitating habitats, dispersal corridors and environmental conditions supporting Oxleyan pygmy perch are likely to be more beneficial to the conservation of this species.

Monitoring the status of NSW populations is considered an important step in the conservation and recovery of the species. This study and work by Knight (2000a) and others have provided a benchmark upon which temporal and spatial changes in the distribution, abundance and habitats of Oxleyan pygmy perch can be assessed. This may provide valuable insights into the factors influencing distribution and abundances patterns and well as provide information necessary for adaptive management. To date, monitoring in NSW has found populations persisting where previously recorded (NSW DPI Freshwater Fish Research Database).

Other species and habitats of conservation significance

Three other species of conservation concern were recorded during the study. Morris *et al*. (2001) identified the common jollytail, soft-spined rainbowfish and the shortfinned eel as potentially threatened species due to apparent reductions in their distribution and abundance in NSW. For example, the shortfinned eel was considered extremely rare, given that Gehrke and Harris (2000) reported catching only one specimen during extensive surveys of north-eastern NSW. The findings of the current study supports this notion with the species only recorded from six of the 159 water bodies sampled. Morris *et al*. (2001) also noted that data were lacking on the conservation status of the common jollytail and soft-spined rainbowfish and that research was required to establish the extent of their current distribution, abundance and the causes of any observed declines. The current project provides baseline data on the status of these species within the study area.

Landlocked populations of the common jollytail in Lakes Minnie Water and Hiawatha are unique to the dune lakes of mid-eastern Australia and are thought to be the northern most landlocked populations in Australia. Concomitantly, they are morphologically distinct to other populations of the species (B. McDowall, NIWA, pers. comm.). Given the concern regarding the species and the uniqueness of the fish inhabiting the Wooli dune lakes, these populations should be considered of special conservation significance. Similarly, due to the unique fish assemblages and high species richness of Lakes Hiawatha and Minnie Water, it is recommended that the lakes be recognised as having high conservation significance requiring special management considerations. Appropriate signage at the lakes informing local communities and tourists of the unique origins of Australia’s dune lakes, the novel fish assemblages and high species richness of the Wooli lakes, and the threats posed by human activities such as introducing the predatory Australian bass may assist in fostering community ownership and support.

The soft-spined rainbowfish was recorded from 41 water bodies in this study and have been documented to frequently co-occur with populations of Oxleyan pygmy perch throughout south- eastern Queensland and north-eastern NSW (Knight 2000a; Pusey *et al*. 2004). Like the Oxleyan pygmy perch, this species is considered sensitive to habitat degradation, water pollution and negative interactions with eastern gambusia. Although the soft-spined rainbowfish has a patchy distribution in NSW, the species still appears to be more prevalent than the Oxleyan pygmy perch. While much of its habitat north and south of the north coast conservation system has been degraded it remains relatively well distributed throughout this system and in adjacent habitats.

Finally, in Queensland the Oxleyan pygmy perch co-exists with populations of the honey blue-eye (*Pseudomugil mellis*). This species is listed as vulnerable under the EPBC Act and Queensland *Nature Conservation Act 1992* as it is confined to wallum environments and has suffered declines similar to the Oxleyan pygmy perch (Arthington and Marshall 1993). Many of the previously unsurveyed drainage systems within the study area appeared to be similar to those inhabited by the honey blue-eye in Queensland, and distributional data on the southern and northern limits of numerous freshwater fishes suggests that the species could potentially occur as far south as the Clarence River catchment (Bishop 1999). The species was however not recorded in this study and no confirmed records exist of its occurrence in NSW.

Summary of recommendations

It is recommended that:

- All known habitat supporting Oxleyan pygmy perch are listed as Critical Habitat under the provisions of the NSW *Fisheries Management Act 1994*.
- Actions are undertaken to improve fish passage at key sites in accordance with government policy and guidelines. Management decisions should however take into the consideration the possible encroachment of eastern gambusia into upstream areas.
- Negotiations with landholders and local councils are initiated/continued regarding the conservation of the populations occurring outside protected areas. Community awareness should also be raised regarding the endangered status of Oxleyan pygmy perch and the ways in which the species can be conserved.
- Initiatives to mitigate the potential impacts of fire management practices are adopted throughout the distributional range of the Oxleyan pygmy perch.
- Research is undertaken into the variables driving population fluctuations and persistence, such as ecological and environmental tolerances, interactions with introduced species and the influence of stochastic, deterministic and threatening processes.
- Interactions between the alien eastern gambusia and Oxleyan pygmy perch are studied to clarify the degree of threat posed by this pest species. Co-occurring gambusia populations should be regularly monitored and eradicated where possible.
- A targeted study of Lakes Hiawatha and Minnie Water is undertaken to elucidate the effects that Australian bass may be having on the Oxleyan pygmy perch and associated aquatic fauna, and to assist in determining the feasibility of eradicating this stocked species from the lakes.
- The monitoring program is continued to assess the ongoing conservation status of the species and to provide information necessary for adaptive management.

- Special management consideration is given to the unique fish assemblages and species richness of Lakes Hiawatha and Minnie Water, and to the unique landlocked populations of the common jollytail. Appropriate signage is also recommended to raise awareness of the lake's novel fish assemblages, high species richness, and threats posed by human activities (including stocking of Australian bass).

- An intensive survey of Bookram Creek in Yuraygir National Park is undertaken to assist in determining whether Oxleyan pygmy perch still inhabit this system (see Survey 2).

- Surveys of the undisturbed potential habitats surrounding the north coast conservation system are repeated to conclusively validate the non-occurrence of Oxleyan pygmy perch in these areas (see Survey 1).

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Appendices

Appendix 1

Details of the sites surveyed in the first survey round between the Queensland/NSW border and Myall Lakes National Park. Sites are listed by subcatchments classified by DLWC (1999). Area name includes either National Park (NP), Nature Reserve (NR) or nearest town. * indicates sites assessed but not sampled. ** indicates dry sites not assessed or sampled. Trib. = tributary. Datum = GDA94.

Appendix 1 table 1 **Northern zone survey sites located between the Queensland/NSW border and the northern boundary of Broadwater National Park.**

Catchment/subcatchment	Site No.	Water body &/area name	Latitude	Longitude
Tweed River				
Cudgen Lake	1	Cudgen	-28.29022	153.55600
	2	Cudgen	-28.29137	153.55533
	3	Cudgen	-28.30907	153.55190
	4**	Boganger	-28.34167	153.56667
Mooball Creek	5	Pottsville	-28.38960	153.55105
	6**	Pottsville	-28.40000	153.55667
Lower Burringbar River	7	Wooyung	-28.46028	153.55247
Brunswick River				
Lower Marshall Creek	8	Billinudgel NR	-28.48267	153.53977
	9	Billinudgel NR	-28.48525	153.54990
Belongil Creek	10	Tyagarah	-28.60192	153.56088
	11	Tyagarah NR	-28.60258	153.57268
	12	Tyagarah NR	-28.60772	153.56555
	13	Belongil Swamp, Tyagarah NR	-28.61203	153.56383
	14	Belongil Creek, Bryon Bay	-28.64702	153.62907
Tallow Creek	15*	Bryon Bay	-28.64833	153.60197
	16	Bryon Bay	-28.65027	153.62365
Richmond River				
Lennox Area	17	Newrybar Swamp, Lennox Head	-28.74787	153.59262
	18	Newrybar Swamp, Lennox Head	-28.75537	153.58688
	19	Newrybar Swamp, Lennox Head	-28.75773	153.57982
	20	Newrybar Swamp, Lennox Head	-28.77035	153.58500
	21	Roberts Creek, Ballina	-28.82360	153.54465
Coraki Area	22	Walshs Creek, Tatham	-28.89445	153.17735
	23*	Richmond River, Tatham	-28.89862	153.14990
	24	Tatham	-28.90408	153.15357
Broadwater Area	25	Bingal Creek, Wardell	-28.93815	153.44733
	26	Wardell	-28.93947	153.44272
	27	Wardell	-28.97313	153.43613
	28	Broadwater	-29.00310	153.47195

Appendix 1 table 2 **Central zone survey sites located to the west of and surrounding Broadwater, Bundjalung and Yuraygir National Park.**

Catchment/subcatchment	Sites No.	Water body &/or area name	Latitude	Longitude
Richmond River				
Coraki Area	29	Richmond River trib, Rileys Hill	-29.02057	153.3956
	30	Richmond River trib, Rileys Hill	-29.0212	153.39195
	34	McDonalds Creek trib, Woodburn	-29.05128	153.39643
	35	McDonalds Creek, Woodburn	-29.05317	153.3925
	36*	McDonalds Creek trib, Woodburn	-29.0633	153.38899
Broadwater Area	31	Eversons Creek, Broadwater	-29.02316	153.45525
	32	Montis Gully, Heathvale	-29.02604	153.42477
	33	Heathvale	-29.03104	153.42885
Evans River	37**	Woodburn	-29.07227	153.37915
	38**	Evans Head	-29.12157	153.38805
	39	Evans River trib, Evans Head	-29.12311	153.39662
	40	Evans River trib, South Evans Head	-29.12449	153.43852
	41	Evans River trib, South Evans Head	-29.12677	153.44219
	43	Evans River trib, South Evans Head	-29.12837	153.43565
	45**	Rocky Mouth Creek trib, Donaldson	-29.13336	153.32387
	47**	Evans	-29.15541	153.30564
‘unclassified’	44	South Evans Head	-29.13191	153.44737
Double Duke Area	42	Blackbutt Lagoon, Darke	-29.1268	153.0906
	46*	Donaldson	-29.15383	153.17887
	49	Barrawanga	-29.1707	153.10125
	54	Barrawanga	-29.19223	153.09893
	55	Jackybulbin Creek, Double Duke	-29.19853	153.17305
Clarence River				
Esk River	48	Evans	-29.16684	153.38734
	50	Tabbimoble NR, Double Duke	-29.18231	153.28585
	51	Evans	-29.18884	153.34412
	52	Evans	-29.18987	153.36223
	53	Evans	-29.18607	153.36519
	56**	Esk	-29.19864	153.34017
	57**	Esk	-29.20232	153.31805
	58	Esk	-29.20242	153.35848
	59	Esk	-29.20452	153.36574
	60**	Double Duke	-29.23086	153.26842
	61**	Double Duke	-29.23882	153.28349
	62**	Tabbimoble Creek, Tabbimoble	-29.28047	153.24357
	63**	Woombah	-29.34506	153.2594
	65*	Woombah	-29.35742	153.32645

Catchment/subcatchment	Sites No.	Water body &/or area name	Latitude	Longitude
Clarence Coastal	64**	Mororo Creek, Woombah	-29.35289	153.22737
Clarence River (continued)				
Clarence Coastal (continued)	66	Woombah	-29.35803	153.24068
	67*	Palmers Island	-29.39434	153.29349
	68	Yamba	-29.43917	153.35685
	69	Yamba	-29.45171	153.35925
Wooloweyah Lagoon	70	Wooloweyah Lagoon trib, Yamba	-29.46089	153.35410
	71*	Yamba	-29.46207	153.35675
	72	Gulmarrad	-29.52917	153.24833
	73	Gulmarrad	-29.53630	153.25745
	74	Gulmarrad	-29.54617	153.25973
	75	Haleys Creek trib, Gulmarrad	-29.55944	153.29082
	76	Haleys Creek, Gulmarrad	-29.56257	153.29509
Shark Creek	77**	Shark Creek trib, Tyndale	-29.57756	153.24608
	78	Oak Flat Creek, Tyndale	-29.59024	153.28181
	79	Shark Creek trib, Tyndale	-29.59060	153.21643
	80	Coldstream	-29.65364	153.20258
Coldstream Creek	81	Champions Creek, Coldstream	-29.65676	153.17920
Sandon River	82	Candole	-29.67474	153.25501
	83	Candole Creek trib, Candole	-29.67627	153.27155
	84**	Candole	-29.68971	153.24923
	85	Sandon River trib, Candole	-29.69792	153.25981
	86	Sandon River, Candole	-29.71770	153.24408
	87	Scope	-29.74427	153.24906
Wooli River	88**	Bookram Creek trib, Candole	-29.77542	153.25125
	89**	Minnie Water	-29.78051	153.29215
	90	Wanderer Creek, Wooli Wooli	-29.83510	153.20327
	91*	Wooli Wooli	-29.83997	153.22128
	92**	Wooli Wooli River trib, Wooli Wooli	-29.86099	153.24546
	93**	Wooli Wooli River trib, Wooli Wooli	-29.89094	153.14960
	96**	Wooli Wooli	-29.90689	153.24956
	97**	Barcoongeree River trib, Wooli Wooli	-29.90877	153.20851
	98**	Barcoongeree River trib, Wooli Wooli	-29.92439	153.17233
Mid Orara River	94	Dundoo Creek, Qwyarigo	-29.89861	153.04643
	95	Halfway Creek, Dundoo	-29.90166	153.06506

Appendix 1 table 3 Southern zone survey sites located between the southern boundaries of Yuraygir National Park and Myall Lakes National Park

Catchment/subcatchment	Site No.	Water body &/or area name	Latitude	Longitude
Bellinger				
Red Bank River	99**	Red Rock	-29.99666	153.22169
	100	Corindi River trib, Red Rock	-30.00460	153.20104
	104**	Corindi Beach	-30.01862	153.20522
Corindi River	101	Cassons Creek, Corindi Beach	-30.00713	153.18355
	102	Red Bank Creek, Corindi Beach	-30.00722	153.18118
	103	Cassons Creek, Corindi Beach	-30.00887	153.18130
	105	Corindi River trib, Corindi Beach	-30.03598	153.15972
Arrawarra Creek	106	Arrawarra	-30.04492	153.19233
Pine-Bundageree Creek	107	Scrub Creek, Bongil Bongil NP	-30.41132	153.06462
	108	Bundageree Creek, Bongil Bongil NP	-30.44100	153.05598
Nambucca River				
Coastal Nambucca	109	Macksville	-30.73848	152.97085
Macleay River				
Coastal Macleay	110	Hat Head NP	-31.00698	153.02955
	111	McGuires Crossing, Hat Head NP	-31.12015	153.00275
	112*	Hat Head NP	-31.15097	152.98407
Hastings River				
Limeburners Creek	113	Goolawah Lagoon, Crescent Head	-31.21982	152.96007
	114	Limeburners Creek NR	-31.32575	152.96050
	115	Limeburners Creek NR	-31.35492	152.93973
'unclassified'	116	Crowdy Bay NP	-31.73493	152.78875
	117	Crowdy Bay NP	-31.74268	152.75280
	118	Crowdy Bay NP	-31.77545	152.74725
	119	Crowdy Bay NP	-31.78005	152.75183
Manning River				
Manning Estuary	120	Crowdy Bay NP	-31.79318	152.71238
	121	Crowdy Bay NP	-31.81245	152.70987
	122	Harrington Lagoon, Crowdy Bay NP	-31.86213	152.70550
Karuah River				
Wallis	123*	Saltwater Gully, Wallabi Point	-32.00363	152.56223
	124	Tuncurry	-32.14475	152.42740
	125**	Tuncurry	-32.15000	152.43083
	126	Booti Booti NP	-32.25327	152.53433
	127	Myall Lake NP	-32.40043	152.47590
Myall	128	Eurundaree Lagoon, Myall Lake NP	-32.51388	152.33457

Appendix 2

Sites surveyed in the second survey round in Bundjalung and Yuraygir National Park.

Appendix 2 table 1 Survey sites in Bundjalung National Park. Sites are listed by subcatchments classified by DLWC (1999). H and R indicate historically and recently recorded Oxleyan pygmy perch localities. * indicates sites visited but not sampled. Datum = GDA94.

Catchment/subcatchment	Site No.	Water body name	Latitude	Longitude
Richmond River				
Evans Creek	1	Oyster Creek	-29.14032	153.41593
	5	'un-named'	-29.17375	153.40384
'unclassified'	2	'un-named'	-29.14426	153.44473
	3	Culvert Creek 1	-29.16374	153.4161
	4	Bullocky Creek R	-29.17353	153.41998
	6	'un-named'	-29.19065	153.40771
Clarence River				
Esk River	7	Observation Lake	-29.1972	153.38031
	8	Target Lake	-29.19996	153.40013
	9	'un-named'	-29.23	153.37114
	10	'un-named'	-29.23294	153.2879
	11	'un-named'	-29.24173	153.32136
	12	Jerusalem Creek R	-29.24487	153.36088
	13	Esk River tributary	-29.24725	153.30475
	14	'un-named'	-29.24784	153.35553
	15	Esk River	-29.25832	153.31678
	16	'un-named'	-29.26143	153.2812
	17*	'un-named'	-29.26519	153.32969
	18	Wendoree Lagoon	-29.26538	153.34521
	19	'un-named'	-29.2721	153.28019
	20	'un-named'	-29.27414	153.34429
	21	'un-named'	-29.27795	153.3451
	22	'un-named'	-29.28169	153.28576
	23	'un-named'	-29.29075	153.33189
	24	'un-named'	-29.29359	153.33001
	25	'un-named'	-29.29684	153.33098
	26	Teatree Swamp - north lake	-29.29733	153.29381
	27	'un-named'	-29.30135	153.30103
	28	Teatree Swamp - south lake	-29.30352	153.29315
	29*	'un-named'	-29.30365	153.30505
	30	'un-named'	-29.30394	153.32607
	31	Yorkies Gully R	-29.30428	153.30677
	32*	'un-named'	-29.30856	153.29835
	33	'un-named'	-29.31345	153.33943

Catchment/subcatchment	Site No.	Water body name	Latitude	Longitude
Clarence River (continued)				
Esk River (continued)	34*	‘un-named’	-29.31784	153.31192
	35	Little Marsh - north lake	-29.32209	153.29786
	36	Little Marsh - south lake	-29.32535	153.29633
	37*	‘un-named’	-29.34559	153.3024
	38*	‘un-named’	-29.34817	153.31578
Clarence Coastal	39	Woolpack Gully	-29.36275	153.29472

Appendix 2 table 2 **Survey sites in Yuraygir National Park. Sites are listed by subcatchments classified by DLWC (1999). H and R indicate historically and recently recorded Oxleyan pygmy perch localities. * indicates sites visited but not sampled. Datum = GDA94.**

Catchment/subcatchment	Site No.	Water body name	Latitude	Longitude
Clarence River				
Angourie/Redcliffe	40	Mara Creek - lower reach	-29.48854	153.35791
	41	Mara Creek - upper reach	-29.49054	153.34860
	44*	'un-named'	-29.51793	153.35708
	45	'un-named'	-29.51986	153.35399
	46*	'un-named'	-29.52416	153.35349
	48	Lake Arragan tributary	-29.53295	153.33547
	49	Lake Arragan tributary	-29.53523	153.33492
	50	'un-named'	-29.53590	153.34951
	54	Lake Arragan tributary	-29.55430	153.33104
	55	Lake Arragan tributary	-29.56902	153.32705
	57	Cakora Lagoon tributary	-29.61688	153.31802
Wooloweyah Lake	42	Wooloweyah Lagoon tributary	-29.49865	153.33481
	43*	Wooloweyah Lagoon tributary	-29.50703	153.32882
	47*	Wooloweyah Lagoon tributary	-29.52565	153.32453
	51	Deadmans Gully	-29.53745	153.30180
	52	Haleys Creek tributary	-29.54295	153.30039
	53	Haleys Creek tributary	-29.54957	153.29912
Sandon River	56	Borches Waterhole	-29.61656	153.28824
	58	'un-named'	-29.62861	153.32231
	59*	Candole Creek headwater swamp	-29.64355	153.27631
	60	Toumbaal Creek	-29.65050	153.30891
	61	Candole Creek	-29.65235	153.27687
	62*	'un-named'	-29.68924	153.31400
	63*	'un-named'	-29.69360	153.31406
	64	Scope Creek	-29.71182	153.28276
	65*	'un-named'	-29.71303	153.29746
	66	Scope Creek headwater swamp	-29.72376	153.27657
	67	'un-named'	-29.76507	153.26815
Wooli River	68	Lake Minnie Water R	-29.77906	153.25797
	69	Lake Minnie Water R	-29.78187	153.26366
	70	Matenga Creek	-29.78628	153.19790
	71	Bookram Creek tributary H	-29.78791	153.23815
	72	Lake Hiawatha H	-29.78986	153.25690
	73	Bookram Creek tributary H	-29.79608	153.22976
	74	Corkscrew Creek	-29.79960	153.20667
	75	Bookram Creek tributary H	-29.80037	153.24449
	76	Lake Hiawatha H	-29.80551	153.26931

Catchment/subcatchment	Site No.	Water body name	Latitude	Longitude
Clarence River (continued)				
Wooli River (continued)	77	Lake Hiawatha H	-29.81263	153.26529
	78*	‘un-named’	-29.81396	153.28657
	79	‘un-named’	-29.82242	153.28625
	80	‘un-named’ R	-29.82640	153.27710
	81	Corduroy Crossing	-29.88457	153.25719
	82	Wooli River tributary	-29.89587	153.26389
	83	Tick Gate Swamp H	-29.89831	153.25011
	84	Barcoongere River tributary	-29.90748	153.20247
	85	Barcoongere River	-29.91363	153.18025
	87	‘un-named’	-29.92518	153.26308
Bellinger				
Station Creek	86	Cabbage Tree Creek	-29.91858	153.22929
	88*	Station Creek tributary	-29.93891	153.24580
Red Bank River	89*	‘un-named’	-29.94903	153.24462
	90*	Corindi River tributary	-29.95856	153.21324
	91	Blue Lagoon	-29.96239	153.24084
	92*	Southern Lake	-29.96844	153.23637

Appendix 3

Catch composition of each site sampled in the first survey round (Survey 1)

Appendix 3 table 1 Catch composition of each site sampled in survey 1.

Site	Firetailed gudgeon	Striped gudgeon	Eastern gambusia	Empire gudgeon	Soft-spined rainbowfish	Oxleyan pygmy perch	Duboulay's rainbowfish	Flathead gudgeon	Olive perchlet	Longfinned eel	Shortfinned eel	Unidentified eel	Pacific blue-eye	Sea mullet
1	5	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	0	0	0	0	0	0	0	0	0	2	0	0
3	44	0	0	0	148	0	0	0	0	0	0	0	0	0
5	129	0	7	6	0	0	0	0	0	0	0	0	0	0
7	0	1	0	5	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	43	2	15	15	0	0	0	0	0	0	0	0	0	0
10	235	0	84	0	0	0	0	0	0	0	0	0	0	0
11	5	0	23	0	0	0	0	0	0	0	0	1	0	0
12	389	1	67	0	21	0	0	0	0	0	0	0	0	0
13	213	1	210	1	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	34	1	0	0	18	0	0	0	0	0	0	0	0	0
18	5	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1	0	0	0	1	0	0	0	0	0	0	0	0	0
20	81	7	2	0	24	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	104	0	1	0	0	0	0	0	0	0	0	0	0	0
24	679	0	90	10	0	0	0	0	5	0	0	0	0	0
25	0	2	0	0	0	0	0	0	0	0	0	0	0	0
26	12	10	0	38	0	0	0	0	0	0	0	0	0	0
27	25	2	159	2	0	0	0	0	0	0	0	0	0	0
28	0	2	36	3	0	0	0	0	0	0	0	0	0	0
29	1	0	0	0	0	2	0	0	0	0	0	0	0	0
30	1	2	86	0	0	1	0	0	0	0	0	0	0	0
31	0	3	74	4	0	0	0	0	0	0	0	1	0	0
32	0	20	5	12	1	0	0	0	0	0	0	0	0	0
33	1	18	0	1	1	0	0	0	0	0	0	0	0	0
34	2	19	0	0	0	4	0	0	0	0	0	0	0	0
35	0	0	1	1	0	0	0	0	0	0	0	0	0	0
39	0	25	0	1	9	0	0	2	0	1	1	0	0	0
40	0	2	0	3	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0

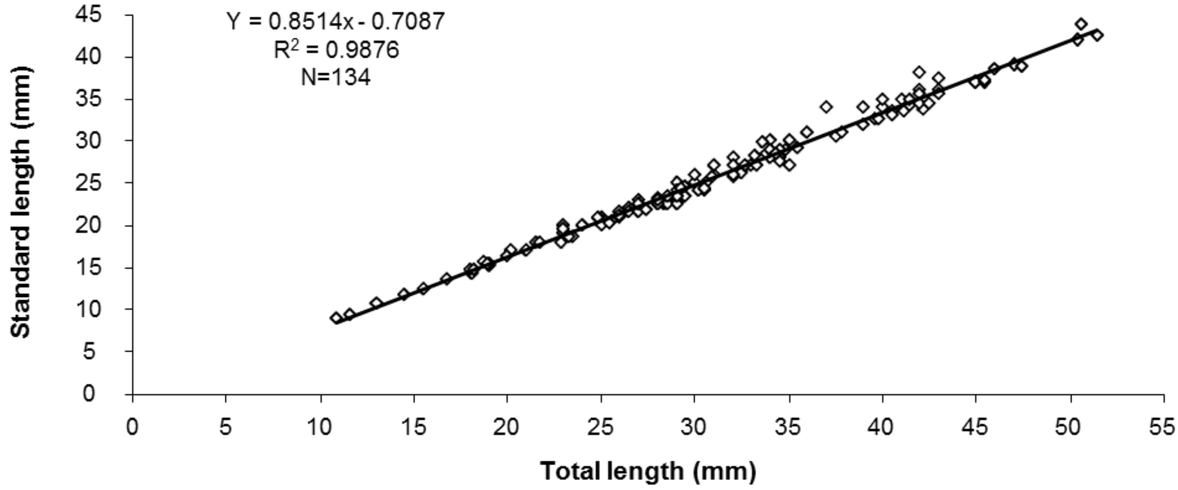
Site	Firetailed gudgeon	Striped gudgeon	Eastern gambusia	Empire gudgeon	Soft-spined rainbowfish	Oxleyan pygmy perch	Duboulay's rainbowfish	Flathead gudgeon	Olive perchlet	Longfinned eel	Shortfinned eel	Unidentified eel	Pacific blue-eye	Sea mullet
42	37	5	186	20	0	0	0	5	1	0	0	0	0	0
43	0	14	0	12	49	50	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	7	0	0	0	3	0	0	0	0	0	0	0	0	0
49	11	1	2	9	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	29	11	2	0	0	2	0	0	0	0	0	0	0	0
52	39	1	30	0	9	2	0	0	0	0	0	0	0	0
53	42	7	5	1	15	0	0	0	0	0	0	0	0	0
54	89	1	39	1	0	0	0	13	0	0	0	0	0	0
55	16	8	8	11	0	0	0	0	1	0	0	0	0	0
58	20	0	20	0	0	20	0	0	0	0	0	0	0	0
59	281	25	0	86	10	99	0	0	0	0	0	0	0	0
66	324	2	532	5	0	0	0	0	0	0	0	0	0	0
68	0	4	5	0	0	0	0	0	0	2	0	0	2	2
69	233	43	150	127	0	0	0	0	0	0	0	0	0	0
70	0	4	0	4	0	0	0	0	0	0	0	0	0	0
72	7	0	13	0	0	0	0	0	0	0	0	0	0	0
73	1	0	10	0	0	0	0	0	0	0	0	0	0	0
74	11	0	16	0	0	0	0	0	0	0	0	0	0	0
75	2	0	50	0	0	0	0	0	0	0	0	0	0	0
76	15	4	2	43	1	0	0	0	0	0	0	0	0	0
78	5	3	0	1	22	0	0	0	0	0	0	0	0	0
79	32	0	0	68	187	0	0	0	0	0	0	0	0	0
80	5	9	0	0	8	0	0	0	0	0	0	0	0	0
81	80	10	4	21	10	0	0	0	0	0	0	0	0	0
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	25	20	0	197	18	0	0	0	0	0	0	0	0	0
85	29	34	0	123	0	0	0	0	0	0	0	0	0	0
86	0	6	0	8	0	0	0	0	0	0	0	1	0	0
87	0	1	177	18	0	0	0	0	0	0	0	0	0	0
90	27	3	0	71	17	0	0	0	0	0	0	0	0	0
94	145	10	33	246	0	0	0	0	0	0	0	0	0	0
95	78	3	158	13	0	0	0	3	0	0	0	2	0	0
100	228	1	614	1	0	0	0	0	0	0	0	0	0	0
101	279	32	16	188	135	0	0	0	0	0	0	0	0	0
102	223	10	289	72	0	0	0	0	0	0	0	0	0	0
103	66	21	27	211	0	0	0	0	0	0	0	0	0	0

Site	Firetailed gudgeon	Striped gudgeon	Eastern gambusia	Empire gudgeon	Soft-spined rainbowfish	Oxleyan pygmy perch	Duboulay's rainbowfish	Flathead gudgeon	Olive perchlet	Longfinned eel	Shortfinned eel	Unidentified eel	Pacific blue-eye	Sea mullet
105	1	0	1	1	0	0	0	0	0	0	0	0	0	0
106	30	14	23	701	0	0	0	0	0	0	0	0	0	2
107	0	0	0	1	0	0	0	0	0	0	0	0	0	0
108	0	0	0	5	0	0	0	4	0	0	0	0	0	0
109	24	6	3	68	0	0	0	0	0	0	0	0	0	0
110	5	0	4	0	0	0	0	0	0	0	0	0	0	0
111	13	2	6	14	0	0	0	0	0	0	0	0	0	0
113	42	0	37	0	0	0	0	0	0	0	0	0	0	0
114	70	0	13	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0	0	0	0
116	4	0	2	0	0	0	0	0	0	0	0	0	0	0
117	27	4	2	13	0	0	0	0	0	0	0	0	0	0
118	63	0	53	0	0	0	0	0	0	0	0	0	0	0
119	0	6	0	0	0	0	0	0	0	0	0	0	0	0
120	3	10	0	4	0	0	0	0	0	0	1	0	0	0
121	5	15	0	22	0	0	0	0	0	0	0	0	0	0
122	22	0	4	0	0	0	0	0	0	0	0	0	0	0
124	0	0	0	0	0	0	0	0	0	0	0	0	0	0
126	0	0	0	0	0	0	0	0	0	0	0	0	0	0
127	0	7	0	1	0	0	0	1	0	0	0	0	0	0
128	8	1	3	0	0	0	0	0	0	0	0	0	0	0

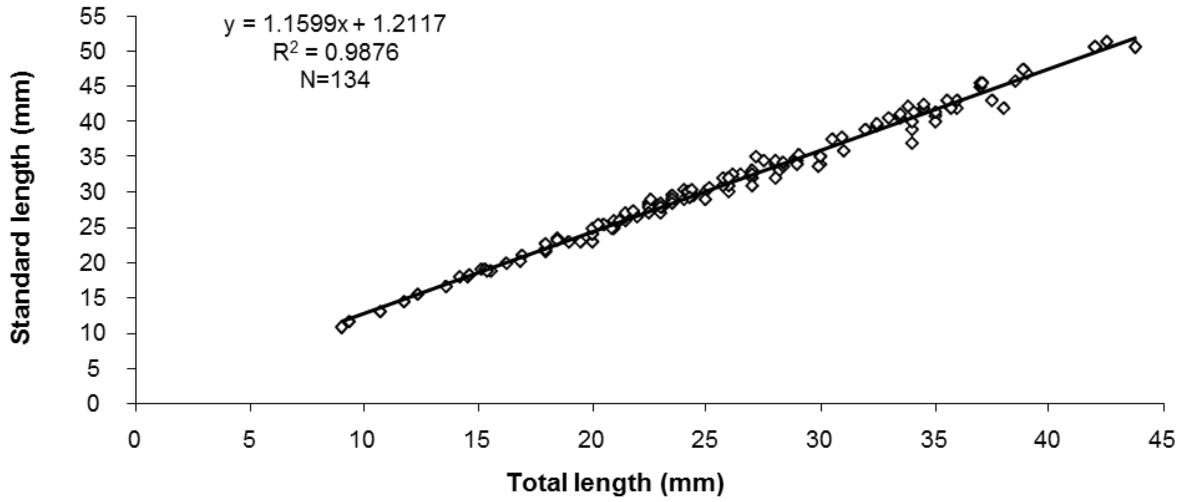
Appendix 4

Relationships between total length and standard length and total length and wet weight for Oxleyan pygmy perch.

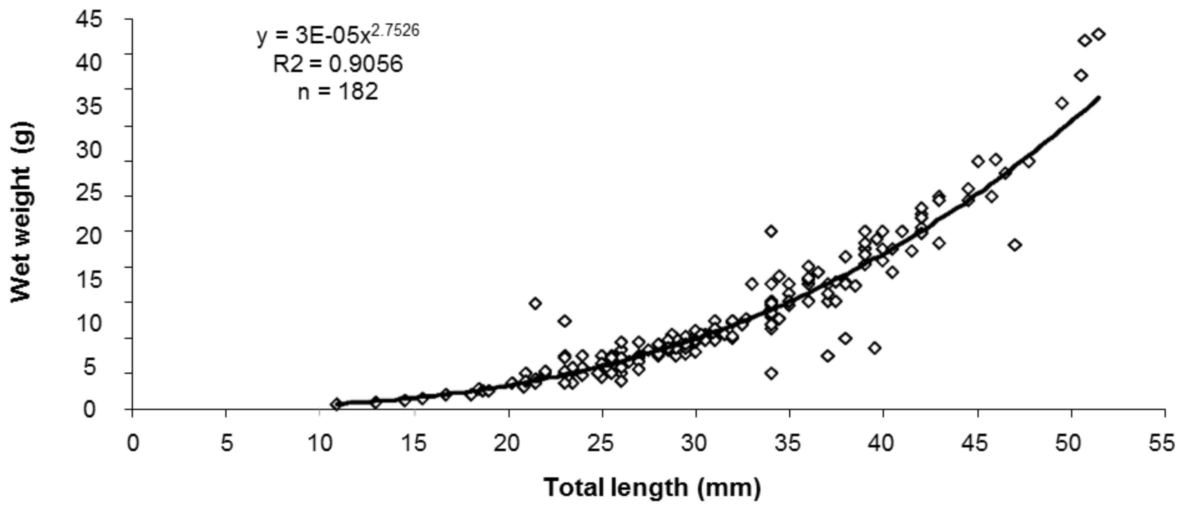
Appendix 4 table 1 Relationship between total length and standard length for Oxleyan pygmy perch.



Appendix 4 table 2 Relationship between standard length and total length for Oxleyan pygmy perch.



Appendix 4 table 3 Relationship between total length and wet weight for Oxleyan pygmy perch.



Appendix 5

List of undisturbed potential habitats.

Appendix 5 table 1 **List of undisturbed potential habitats. Sites are listed by subcatchments classified by DLWC (1999). Area name includes either National Park (NP), Nature Reserve (NR), nearest town or county (in remote areas). Counties are specified in italics. Trib. = tributary. Datum = GDA94.**

Catchment/subcatchment	Site	Water body &/or area name	Latitude	Longitude
Northern Zone				
Brunswick River				
Belongil Creek	11	Tyagarah NR	-28.60258	153.57268
Tallow Creek	16	Bryon Bay	-28.65027	153.62365
Richmond River				
Lennox Area	17	Newrybar Swamp, Lennox Head	-28.74787	153.59262
	18	Newrybar Swamp, Lennox Head	-28.75537	153.58688
	19	Newrybar Swamp, Lennox Head	-28.75773	153.57982
	20	Newrybar Swamp, Lennox Head	-28.77035	153.58500
Central Zone				
Richmond River				
Evans River	40	Evans River trib, South Evans Head	-29.12449	153.43852
	41	Evans River trib, South Evans Head	-29.12677	153.44219
Double Duke Area	46	Donaldson	-29.15383	153.17887
Clarence River				
Esk River	50	Tabbimoble NR, Double Duke	-29.18231	153.28585
Wooloweyah Lagoon	70	Wooloweyah Lagoon trib, Yamba	-29.46089	153.35410
	76	Haleys Creek, Gulmarrad	-29.56257	153.29509
Shark Creek	80	Coldstream	-29.65364	153.20258
Sandon River	83	Candole Creek trib, Candole	-29.67627	153.27155
Southern Zone				
Macleay River				
Coastal Macleay	110	Hat Head NP	-31.00698	153.02955
	111	McGuires Crossing, Hat Head NP	-31.12015	153.00275
Hastings River				
Limeburners Creek	113	Goolawah Lagoon, Cresent Head	-31.21982	152.96007
'unclassified'	118	Crowdy Bay NP	-31.77545	152.74725
Manning River				
Manning Estuary	120	Crowdy Bay NP	-31.79318	152.71238
Karuah River				
Wallis	126	Booti Booti NP	-32.25327	152.53433
	127	Myall Lake NP	-32.40043	152.47590
Myall	128	Eurundaree Lagoon, Myall Lake NP	-32.51388	152.33457

Appendix 6

Fish species recorded from the wallum water bodies of Bundjalung and Yuraygir National Park. Fish species recorded from the wallum water bodies of Bundjalung and Yuraygir National Park. A = anecdotal report. Data sourced from Timms (1969, 1982), Arthington (1996), Gerkin (2001), Harrison *et al*. (2002), Australian museum records, NSW DPI Aqua-See database, and R. Amos, RAAF, pers. comm. Systematic information based on McDowall (1996), Jerry *et al.* (2001) and Allen *et al.* (2002).

Family	Scientific Name	Common Name	Bundjalung NP	Yuraygir NP
Ambassidae	*Ambassis agassizii*	Olive perchlet		+
Anguillidae	*Anguilla australis*	Shortfinned eel		+
	Anguilla spp.	Long- or shortfinned eel	+	+
Atherinidae	*Craterocephalus marjoriae*	Marjorie's hardyhead		+
Eleotridae	*Gobiomorphus australis*	Striped gudgeon	+	+
	Hypseleotris compressa	Empire gudgeon	+	+
	Hypseleotris galii	Firetail gudgeon	+	+
	Philypnodon grandiceps	Flathead gudgeon	+	+
	Philypnodon macrostomus	Dwarf Flathead gudgeon	+	+
Galaxiidae	*Galaxias maculatus*	Common jollytail		+
Melanotaeniidae	*Melanotaenia duboulayi*	Doboulay's rainbowfish	+	+
	Rhadinocentrus ornatus	Soft-spined rainbowfish	+	+
Mugilidae	*Mugil cephalus*	Sea mullet		+
Percichthyidae	*Percalates novemaculeata*	Australian bass	A	+
	Nannoperca oxleyana	Oxleyan pygmy perch	+	+
Plotosidae	*Tandanus tandanus*	Freshwater catfish		+
Poeciliidae	*Gambusia holbrooki*	Eastern gambusia	+	+
Pseudomugilidae	*Pseudomugil signifer*	Pacific blue-eye	+	+
	Retropinna semoni	Australian smelt		+

Appendix 7

Catch composition of each site sampled in the second survey round (Survey 2).

Appendix 7 table 1 Catch composition of each site sampled in survey 2.

Site	Firetailed gudgeon	Empire gudgeon	Pacific blue-eye	Eastern gambusia	Striped gudgeon	Soft-spined rainbowfish	Flathead gudgeon	Duboulay's rainbowfish	Oxleyan pygmy perch	Common Jollytail	Longfinned eel	Freshwater catfish	Australian bass	Olive perchlet	Dwarf flathead gudgeon	Shortfinned eel	Unidentified eel
1	0	750	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	17	4	0	0	17	0	0	0	10	0	0	0	0	0	0	0	0
3	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
4	22	9	0	0	29	2	0	0	3	0	0	0	0	0	0	0	0
5	16	156	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	204	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	138	23	0	82	12	0	4	33	0	0	0	0	0	0	0	0	0
9	94	4	0	17	4	0	0	0	31	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
12	34	178	0	0	134	20	0	0	1	0	0	0	0	0	0	0	0
13	8	34	0	0	10	3	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	254	0	0	4	0	0	0	0	0	0	0	0	0	4	0	0
16	2	2	0	5	3	0	0	0	0	0	0	0	0	0	0	0	0
18	614	0	0	33	0	0	0	0	6	0	0	0	0	0	0	0	0
19	93	0	0	52	0	125	0	0	0	0	0	0	0	0	0	0	0
20	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	142	0	0	101	0	49	0	0	0	0	0	0	0	1	0	0	0
23	493	0	0	97	0	0	0	0	3	0	0	0	0	0	0	0	0
24	57	0	0	39	0	0	0	0	0	0	0	0	0	0	0	0	0
25	35	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	118	0	0	0	0	0	0	0	0	0	0	0	0	0
27	50	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
28	17	0	0	1	0	0	0	0	6	0	0	0	0	0	0	0	0
30	237	0	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
33	15	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0
35	368	8	0	13	16	0	0	0	23	0	0	0	0	0	0	0	0
36	41	0	0	3	0	14	0	0	10	0	0	0	0	0	0	0	0
39	0	1	0	0	17	0	0	0	0	0	1	0	0	0	0	0	0
40	24	7	0	0	8	5	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	72	0	0	0	12	0	0	0	0	0	0	0	0

Site	Firetailed gudgeon	Empire gudgeon	Pacific blue-eye	Eastern gambusia	Striped gudgeon	Soft-spined rainbowfish	Flathead gudgeon	Duboulay's rainbowfish	Oxleyan pygmy perch	Common Jollytail	Longfinned eel	Freshwater catfish	Australian bass	Olive perchlet	Dwarf flathead gudgeon	Shortfinned eel	Unidentified eel
42	11	34	0	0	86	1	0	0	11	0	0	0	0	0	0	0	0
45	24	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	2	5	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
51	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	73	17	0	127	8	0	0	0	0	0	0	0	0	0	0	0	0
53	8	0	0	1	0	0	0	0	56	0	0	0	0	0	0	0	0
54	13	59	0	6	18	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	5	3	2	0	1	0	0	0	0	0	0	0	0	0	0
56	64	100	0	0	5	0	0	2	0	0	0	0	0	0	0	0	0
57	6	1	5	0	4	0	0	0	0	0	2	0	0	0	0	4	0
58	0	7	0	6	0	0	0	0	0	0	0	0	0	0	0	1	0
60	4	416	0	0	59	0	0	0	0	0	1	0	0	0	0	0	0
61	53	200	0	0	21	9	0	77	0	0	0	0	0	0	0	0	0
64	12	33	0	4	26	0	0	0	0	0	3	0	0	0	0	0	4
66	26	156	0	1	10	0	0	0	0	0	2	0	0	0	0	0	1
67	69	10	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
68	272	0	85	0	0	0	49	88	0	1	3	4	0	0	1	0	0
69	145	0	117	3	0	0	117	107	13	3	5	3	7	1	0	0	0
70	19	4	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
71	76	58	0	0	26	12	0	0	0	0	0	0	0	0	0	0	0
72	4	1	557	0	2	4	45	8	7	12	2	3	0	5	0	0	0
73	5	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0
74	97	8	0	0	8	18	0	0	0	0	0	0	0	0	0	0	0
75	8	0	0	0	1	6	0	0	0	0	0	0	0	0	0	0	0
76	80	8	62	0	1	0	7	2	10	21	2	2	3	0	1	1	0
77	21	0	587	0	0	15	107	6	1	4	4	5	0	2	1	0	1
79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	32	4	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0
81	1	18	0	0	7	1	0	0	0	0	0	0	0	0	0	0	0
82	420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	1	0	0	10	0	0	0	0	0	0	0	0
84	5	1	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0
85	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	7	8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	0	1	98	0	0	0	0	0	0	0	0	0	0	0
91	0	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 8

Fish species recorded from Lake Hiawatha and Lake Minnie Water.

Appendix 8 table 1 **Fish species recorded from Lake Hiawatha and Lake Minnie Water. Data sourced from Racek (1954-57, cited in Timms 1969), Timms (1982), Arthington (1996), Gerkin (2001), and Australian Museum Records. * = new records collected during the present study. I = introduced species; T = translocated species; S = stocked species.**

Family	Scientific Name	Common Name	Hiawatha	Minnie Water
Percichthyidae	*Nannoperca oxleyana*	Oxleyan pygmy perch	+	+
	Percalates novemaculeata	Australian bass (S)	+*	+*
Eleotridae	*Hypseleotris galii*	Firetail gudgeon	+	+
	Hypseleotris compressa	Empire gudgeon	+	+
	Gobiomorphus australis	Striped gudgeon	+	
	Philypnodon grandiceps	Flathead gudgeon	+	+*
	Philypnodon macrostomus	Dwarf Flathead gudgeon	+	+
Melanotaeniidae	*Rhadinocentrus ornatus*	Soft-spined rainbowfish	+	
	Melanotaenia duboulayi	Doboulay's rainbowfish	+	+
Pseudomugilidae	*Pseudomugil signifer*	Pacific blue-eye	+	+
Anguillidae	*Anguilla reinhardtii*	Longfinned eel	+*	+*
	Anguilla australis	Shortfinned eel	+	+
	Anguilla spp.	Long- or shortfinned eel		+
Galaxiidae	*Galaxias maculatus*	Common jollytail	+	
Ambassidae	*Ambassis agassizii*	Olive perchlet	+	+
Plotosidae	*Tandanus tandanus*	Freshwater catfish	+	+*
Poeciliidae	*Gambusia holbrooki*	Eastern gambusia (I)	+	+*
Retropinnidae	*Retropinna semoni*	Australian smelt	+	
Mugilidae	*Mugil cephalus*	Sea mullet (T)	+	

Appendix 9

Water quality parameters recorded at NSW sites supporting Oxleyan pygmy perch.

Appendix 9 table 1 **Water quality parameters recorded at NSW sites supporting Oxleyan pygmy perch. Water colour abbreviations: Cl = clear, Lt = light tannin, Mt = medium tannin, Dt = dark tannin, Tr = translucent/cloudy, Hs = heavy suspended solids. n = 92.**

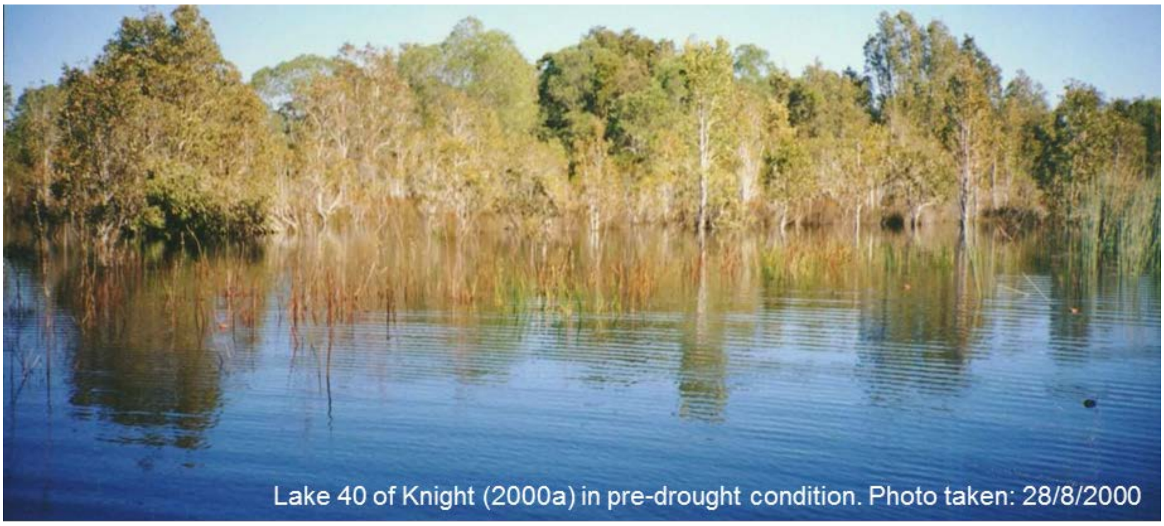
Water Quality Parameter	Range	Mean	SE
Temperature (°C)	10.9 - 29.7	17.21	0.473
Dissolved oxygen (mg L^{-1})	2.15 - 10.02	6.354	0.1829
% Air saturation	20.2 – 107.6	66.7	2.05
pH	3.32 - 6.96	4.451	0.0976
Conductivity (µS cm^{-2})	90 - 12700	349.2	141.11
Turbidity (NTU)	0 - 80	13.6	3.62
Water colour	Cl - Dt; Tr	N/A	N/A

Appendix 10

Destruction and desiccation of known Oxleyan pygmy perch habitat.

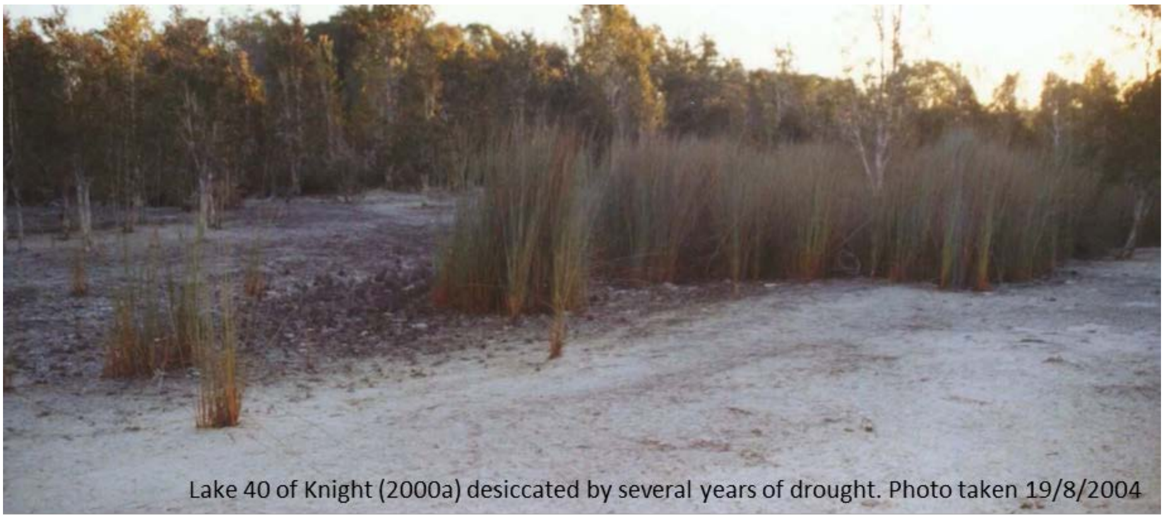
Appendix 10 figure 1 Destruction of known Oxleyan pygmy perch habitat.

Appendix 10 figure 2 Desiccation of known Oxleyan pygmy perch habitat near Evens Head



Lake 40 of Knight (2000a) in pre-drought condition. Photo taken: 28/8/2000

Appendix 10 figure 3 Desiccation of known Oxleyan pygmy perch habitat near Evens Head



Lake 40 of Knight (2000a) desiccated by several years of drought. Photo taken 19/8/2004

Appendix 11

Further analysis of landscape evolution patterns in which the Oxleyan pygmy perch evolved

It is currently hypothesised that most of Australia's freshwater fish fauna including members of the Percichthyidae family evolved from marine ancestors trapped in an ancient retreating inland sea (Jerry *et al*. 2001; Allen *et al*. 2002, 2005). This sea entered Australia during Cretaceous times over 120 million years ago (mya) and fluctuated in relation to global sea level changes and geological events for nearly 25 million years. Approximately 90 mya, ocean rifting resulted in the uplifting of the Great Dividing Range, thereby separating the inland Murray-Darling Basin from the east coast drainages (Ollier 1995). Despite this apparent barrier to fish dispersal, high faunal similarity currently exists between the inland basin and drainages east of the Great Dividing Range. In particular, nine species co-occur in both the Murray-Darling Basin and the Clarence River, while the former basin shares eleven species with the Fitzroy drainage in central Queensland (Unmack 2001). There are a number of genera including *Nannoperca* whose distributions also straddle the divide (Allen *et al*. 2002). These trends have been attributed to either the geological process of stream capture or simply areas of lesser elevation in the Great Dividing Range, which under certain climatic or geological conditions such as flooding and volcanism may have allowed fish to cross the mountain range (Musyl and Keenan 1992; Rowland 1993; McGlashan and Hughes 2001; Unmack 2001).

Based on geomorphologic and electrophoretic research, it is conceivable that speciation within the genus *Nannoperca* may have resulted from the separation of the inland and east coast drainages. The current geographic range of the Oxleyan pygmy perch falls entirely within the expansive Clarence-Moreton Basin, which was once drained primarily by the Clarence River (Haworth and Ollier 1992). This river initially flowed westward into the Condamine River of the Murray-Darling Basin, but uplifting of the Great Dividing Range split these two rivers approximately 65-25mya and caused the Clarence to flow eastward towards the coast (Haworth and Ollier 1992) (Figure 27). It is possible that species divergence may have occurred within the genus *Nannoperca* subsequent to it separation by this vicariant event. Indeed, *Nannoperca* is considered one of the most derived genera within the Percichthyidae (Johnson 1984; Jerry *et al*. 2001) with divergence between the Oxleyan pygmy perch and extant relative species from the Murray-Darling Basin thought to have occurred as far back as tens of millions of years (M. Hammer, University of Adelaide, South Australia, pers. comm.).

Alternatively, the Oxleyan pygmy perch, a congener, or an ancestor may have more recently crossed the divide either by the geological process of stream capture or at areas of lesser elevation in the Great Dividing Range. For example, the low point between the Fitzroy and Burnett drainages (Unmack, 2001) may have facilitated the dispersal of fish into this area and then southward into the adjacent Mary River catchment where present day populations of Oxleyan pygmy perch exist. Likewise, the headwaters of the Clarence River are one of the few places with elevations low enough to allow fish to cross the divide from the Murray Darling Basin to the east coast (Figure 27; Unmack, 2001). However, recent genetic research suggests the possibility that dispersal may have occurred in the opposite direction, with coastal populations of southern purple spotted gudgeon *Mogurnda adspersa* (Eleotridae), eel-tailed catfish *Tandanus tandanus* (Plotosidae), golden perch *Macquaria ambigua* (Percichthyidae) and Macquarie perch *Macquaria australasica* (Percichthyidae) all apparently ancestral to populations in the Murray-Darling Basin (Faulks *et al*. 2008, 2009; Jerry 2008). These findings contradict the 'inland sea hypothesis' and given the evolution of the Clarence River, lead to the possibility that the genus *Nannoperca* may have also evolved in a similar way.

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