Status of Freshwater Catfish (*Tandanus tandanus*) populations in Gunbower Creek 2009

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Status of Freshwater Catfish (*Tandanus tandanus*) populations in Gunbower Creek 2009. A report prepared for The North Central Catchment Management Authority by The Murray-Darling Freshwater Research Centre.

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Executive Summary

In May 2009 The North Central Catchment Management Authority (CMA) engaged The Murray-Darling Freshwater Research Centre (MDFRC) to establish the status of freshwater catfish *Tandanus tandanus* (*T. tandanus*) populations within selected lagoons associated with the Gunbower Creek. Seven sites were examined: Turner, Cockatoo, Phyland, Longmore, Gum, and Upper Gunbower Lagoons, as well as the 4km reach of the Gunbower Creek between Turner and Phyland Lagoons.

Habitat character of each lagoon was established following AUSRIVAS habitat assessment protocols and the fish assemblage from each lagoon was surveyed utilising large and small fyke nets during July and August 2009. Patterns in fish assemblage structure (species present and species abundance) and habitat characteristics among wetlands were related to the presence/absence of *T. tandanus*, to determine if fish assemblage structure, habitat character or a combination of fish assemblage/habitat characteristics influenced the structure of *T. tandanus* populations within sites surveyed during this investigation.

A total of 24 *T. tandanus* were captured from the seven wetland sites sampled; Turner Lagoon (n = 21), Phyland Lagoon (n=2) and Cockatoo Lagoon (n = 1). *T. tandanus* was not recorded in Upper Gunbower, Longmore or Gum Lagoons, or at Gunbower Creek survey sites. An additional 28,920 fish were captured from 8 native and 5 exotic species from the seven wetlands sampled.

The fish assemblages and habitat characteristics from wetlands where *T. tandanus* were encountered were more than 75% and 80% similar (respectively), with exception of Phyland Lagoon which exhibited a markedly different suite of habitat characteristics to other wetlands. As such, habitat character was not considered to significantly influence the distribution of *T. tandanus* at those sites examined: however, the structure of fish assemblages, particularly the relative abundance of redfin and carp, may have been of significant influence.

The status of the *T. tandanus* population in Turner Lagoon may be considered robust, as individuals from young of the year (0+) and a variety of year classes through to mature adults (based upon size-at age information) were represented within the population. Furthermore, the timing (winter) of sampling conducted here was considered to result in significantly fewer individual *T. tandanus* being encountered as might be expected from spring or summer sampling: As such, the status of the Turner Lagoon population may reflect other robust *T. tandanus* populations elsewhere in the Murray River system. Conversely, the status of *T. tandanus* populations within Cockatoo and Phyland Lagoons were not considered robust, even when considering the effects of sampling season.

As *T. tandanus* is listed as threatened under Victoria’s Flora and Fauna Guarantee Act (1988), are patchily distributed throughout Victoria, and a robust population was detected within Turner Lagoon, we recommend that the recent (past decades) hydrological regime of Turner Lagoon be determined and then a similar hydrological regime be maintained in order to sustain the *T. tandanus* population there. Consideration of this recommendation is especially important in regard to the proposed changes to the delivery of water throughout the Gunbower anabranch system via NVIRP. Furthermore, rehabilitation of fish passage (conducive to the requirements of small and large *T. tandanus*) between Turner Lagoon and the Gunbower Creek may stimulate the re-colonisation of adjacent wetlands within the Gunbower system by *T. tandanus*.

Contents

1. Introduciton

1.1. Systematics and morphology

Tandanus tandanus (Mitchell 1838) are a member of the Plotosidae family; the eel-tailed catfishes. All members of the family have a broad, slightly flattened head, four pairs of barbels around the mouth, a tapered body and an elongated, rounded tail (Figure 1) (Cadwallader and Backhouse 1983; Pusey *et al.* 2004). There are 32 species of Plotosids, half of which occur in the fresh waters of Australia and New Guinea, with the remainder occurring in the estuaries and coastal seas of the Indo-West Pacific Region (McDowall 1996, Pusey *et al.* 2004). *T. tandanus* is the only member of the Plotosidae family to naturally occur in the freshwater river systems of Victoria (Cadwallader and Backhouse 1983).

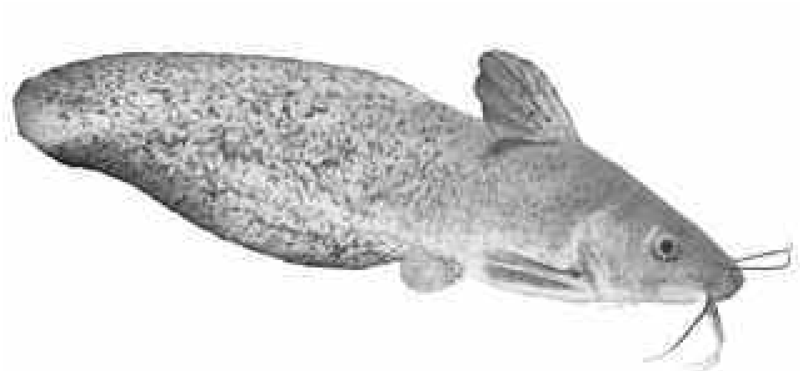

Figure 1. *Tandanus tandanus*

T. tandanus are commonly referred to as freshwater catfish, eel-tailed catfish and jewfish. They are a stout, robust fish with a large head relative to body size and a moderately sized eye. Their small downturned mouth is surrounded by thick fleshy lips and contains small vomerine teeth in a semicircular patch (Lake 1967; Cadwallader and Backhouse 1983; Pusey *et al.* 2004). The first dorsal fin starts just behind the head and the second dorsal fin is continuous with the tail and anal fin (140-150 rays). Pectoral fins are large and pointed (10 rays) and the pelvic fins are abdominal and rounded. The dorsal and pectoral fins have strong, sharp, serrated spines that can lock at right angles to the body (Cadwallader and Backhouse 1983). *T. tandanus* have smooth, tough skin with no scales and their colour varies from olive green to brown with a white underbelly. Smaller fish are usually mottled with dark brown, black or silver blotches. Sexual dimorphism is exhibited at about 1 year of age, when gender can be determined by the shape of the urinogenital papilla; that of the males being cylindrical and females being triangular (Lake 1967; Pusey *et al* 2004). *T. tandanus* mature by four years but may not reproduce until their fifth year (Davis 1977a). Males weigh 600-700 g and females 400-500 g at sexual maturity

(Davis 1977a). *T. tandanus* have been recorded up to 900mm and 7 kg, but are usually less than 2 kg (Roughly 1951; Lake 1967; McDowell 1980; Allen *et al* 2002). The lifespan of *T. tandanus* is unknown, however, fish of nine years have been recorded (Davis 1977).

1.2 Ecology

T. tandanus occurs in freshwater rivers, wetlands, lakes and billabongs, preferring slow flowing or sluggish waters (Cadwallader and Backhouse 1983; Lake 1967). They appear to have a strong association with submerged aquatic macrophytes and other types of structure such as undercut banks, root balls and large woody debris. (Pusey *et al* 2004). Adults are generally solitary but smaller fish are known to form loose schools (Pusey *et al.* 2004).

T. tandanus can tolerate water temperatures over 35^{o}C when slowly acclimatised but become stressed at temperatures greater than 38^{o}C; the upper limit of the species temperature tolerance, while 4^{o}C is considered the lower temperature limit (Lake 1967).

T. tandanus are carnivorous, feeding on zooplankton and insect larvae as juveniles, and yabbies, shrimp, snails, molluscs and small fish as adults (Roughly 1951; Lake 1967; Davis 1977b Lake 1967). *T. tandanus* reproduce during spring and summer when water temperatures are 19-25^{o}C (Lake 1967). Spawning is not considered to be induced by flooding (Lake 1967; Cadwallader and Backhouse 1983). Males construct a circular nest by stirring the substrate with their fins until a depression around 0.6-2.0m in diameter is formed (Lake 1967; Merrick and Midgley 1981). Males then collect pebbles, gravel or small sticks with their mouth and fill the depression (Roughly 1951; Lake 1967; Cadwallader and Backhouse 1983). A courtship ritual involves the male and female circling and weaving above the nest and the male nudging the female in the abdominal flank (Lake 1967; Merrick and Midgley 1981). This culminates in the female depositing up to 20,000 eggs (depending on size) into the nest (Lake 1967; Davis 1977).

Eggs are demersal, spherical, 2.3-3.3 mm in diameter (depending on the size of the female; Davis 1977a) and yellowish in colour (Lake 1967a; Davis 1977c) (Figure 2). The male guards the nest and fans the eggs until hatching occurs after about 7 days (Roughly 1951; Davis 1977c; Lake 1967). Larvae are about 7mm long upon hatching and do not develop barbels until approximately 7 days of age; at which time the larvae are about 12mm in length. Larvae metamorphose into the adult form at around 15 mm in length and three weeks of age (Lake 1967). Nests may be used in consecutive years but it is unknown if they are repeatedly used by the same individuals (Merrik and Midgley 1981).

Experiments have shown *T. tandanus* will abandon a nest if a drop in water level exposes it (Lake 1967). If fluctuations in water levels persist during the breeding period, reproduction will not occur and oocytes may be re-absorbed (Lake 1967).

Figure 1. *T. tandanus* eggs from a mature female. Image: R. Rehwinkel

1.3 Historical Distribution

Early records of European encounters with *T. tandanus* were by Oxley in the Macquarie River in 1818, Mitchell in the Barwon and Namoi Rivers in 1831-1832, and Mitchell in the Lachlan Valley in 1836 and in the Maranoa River in 1845-46 (Scott 2005). Prior to European settlement, *T. tandanus* were a widespread and abundant species found throughout the Murray Darling Basin and the coastal draining rivers of Eastern Australia from the wet tropics in northern Queensland down to central New South Wales (Roughly 1951; Davis 1977; Pusey *et al* 2004; Lintermans 2007). The species was said to 'swarm' in the Murray River (Roughly 1951) and was considered one of the most common fish in the Murray River system (Grant 1982). Anecdotal evidence suggests they were common in many rivers and associated wetlands in the Murray Darling Basin from the lowlands to the slopes of the upland zone (Trueman 2007).

1.4 Decline in Distribution

Within the Murray Darling Basin, most native fish species have undergone declines in their distribution and abundance (Lintermans 2007) and native fish populations are currently estimated to be at 10% of their pre-European levels (MDBC 2003). Perhaps more so than most species, *T. tandanus* have undergone a dramatic decline in their distribution and abundance in most areas of the Murray Darling Basin (Clunie and Koehn 2001). Declines in fish stocks within the Murray and Murrumbidgee Rivers were discussed in community forums from as early as 1947 (Roughly 1951), with declines observed over large spatial scales within relatively short time frames (Clunie and Koehn 2001; Lintermans 2007). In the Gunbower Island region, declines in lagoon and riverine populations were documented between 1930 and 1940 (Roberts and Sainty 1996; Trueman 2007). By 1947 *T. tandanus* were considered rare above the Torrumbarry Weir with only one individual being caught north of Torrumbarry in the 1949-1952 surveys by Langtry (1949 in Cadwallader 1977). By 1950, *T. tandanus* were considered rare upstream from Boundary Bend on the Murray River (Tueman 2007). River regulation is considered to have been a key factor implicated in the reduction of the distribution and abundance of the species at large spatial scales throughout Victoria (Clunie and Koehn 2001), although the exact mechanism for the species decline remain speculative.

Since 1857, approximately 3,600 regulating structures have been constructed in rivers of the Murray-Darling Basin (MDB), together with 50 intra/inter basin water transfer schemes (Arthington and Pusey 2003). Three key impacts of river regulation implicated in the decline of *T. tandanus* are; (i) changes to the timing, magnitude, and duration of flow regimes ('altered flow regimes'), (ii) changes to temperature regimes (particularly cold water pollution) and (iii) restriction of movement (Clunie and Koehn 2001). These changes are considered to have affected spawning migrations, pre-spawning interactions, recruitment and dispersal of *T. tandanus* (Clunie and Koehn 2001).

The increase in water extraction and construction of large storages from the 1950s reduced the area of floodplain wetlands which form key habitats for *T. tandanus* (Clunie and Koehn 2001). Anecdotal evidence suggests that lagoons and other wetland habitats were common places where large numbers of *T. tandanus* were observed before the 1930s (Trueman 2007). Reduction in the availability of these habitats (via river regulation) may have had a detrimental effect on *T. tandanus* populations, especially if these were important habitats in the recruitment ecology of the species.

In conjunction with river regulation, interactions with exotic fish species, particularly common carp (*Cyprinus carpio*) and redfin (*Perca fluvialitis*) are considered a significant factor in the reduction of *T. tandanus* throughout the MDB (Roughly 1951; Langtry 1949 in Cadwallader 1977). Trueman (2007) provided anecdotal accounts of lagoons throughout the Gunbower region within which *T. tandanus* were abundant prior to their colonisation by redfin, upon which *T. tandanus* rapidly became increasingly rare and then locally extinct. Redfin are a voracious predator of other fish, and were reported as being abundant in the Gunbower region by 1960 (Trueman 2007) thus the reduction of *T. tandanus,* coinciding with the rise of redfin may have been result of predation of juvenile *T. tandanus* by redfin resulting in population collapse via lack of recruitment (Clunie and Koehn 2001).

Common carp have also been implicated in the decline of *T. tandanus*. Carp were introduced into Australia in the 1860s but it was not until the 1960s when the Boolara strain was introduced into Victoria that they spread quickly throughout the Murray Darling Basin (Cadwallader and Backhouse 1983). Carp and *T. tandanus* occupy similar trophic niches, with some overlap in diets. As such, competition for resources may have occurred, to the detriment of *T. tandanus* (Clunie and Koehn 2001). There is also suggestion that the feeding mode of carp interferes with catfish reproduction, or that carp actively consume the eggs of *T. tandanus* while feeding upon the benthos in large schools (Clunie and Koehn 2001). The rapid regional contractions in abundance of *T. tandanus* throughout the period 1940 – 1960 in the Gunbower region and across most of the MDB from that time coincided with intensification of river regulation, irrigated agriculture and the rise of carp and redfin. Combined with constant fishing pressure during this period, population collapse was observed over a very short period.

The extensive decline in the abundance and distribution of *T. tandanus* throughout Victoria and inland NSW has resulted in the listing of *T. tandanus* as a threatened species under the Victorian Flora and Fauna Guarantee Act (1988) and the Murray-Darling Basin population of *T. tandanus* in NSW is declared endangered under the NSW Fisheries Management Act (1994). As such, *T. tandaus* are a protected species no longer able to be targeted or taken from the Murray River and its tributaries of NSW and the species is also protected within Victoria, apart from within the Wimmera River where the species has been translocated and is relatively abundant.

1.5 Gunbower Creek System

The Gunbower Creek is an anabranch system of the Murray River adjacent to the towns of Gunbower, Cohuna and Koondrook (Vic). At 112km in length, Gunbower Creek is a notable example of Murray River lowland river anabranch habitat in that it provides a mosaic of habitat types which are accessible by a variety of fish species at various life-history stages (Humphries et al.1999; Koehn and Harrington 2005). Gunbower Creek forms part of the Torrumbarry Irrigation region which covers 150,000 hectares of northern Victoria. Gunbower Creek and other natural water bodies are an integral part of the irrigation delivery system of the Torrumbarry Irrigation region.

Flow in Gunbower Creek is currently controlled by the release of water into the National Channel, upstream of Torrumbarry Weir on the Murray River. Water is further diverted to the Gunbower Creek, where it enters several lagoons via regulators. These lagoons are subsequently used to deliver water to Goulbourn-Murray Water (G-MW) customers for stock and domestic, agricultural and industrial use. Irrigation flows in the Gunbower Creek peak at 1650 ML/d during the period September – March. Following the peak irrigation season, water delivery declines and water levels in the Gunbower Creek and associated lagoons drop substantially via evaporation and seepage.

The state of Victoria is currently investigating the National Victorian Irrigation Renewal Project (NVIRP). The aim of NVIRP in the Goulburn Murray Irrigation District (G-MID) is to upgrade irrigation delivery infrastructure to improve irrigation efficiency. One option under consideration via NVIRP is to alter the current method of water delivery within the Gunbower Region by piping water directly from Gunbower Creek to customers, rather than channelling water through wetlands and lagoons as is the current method of delivery for numerous irrigators. This option may impose a significant change to the historical regulated hydrological regime of the Gunbower Creek and in particular those lagoons utilised for water delivery (NVIRP 2009). As such, the present research project aims to inform the North Central CMA of the status of *T. tandanus* in particular lagoons; including populations recently detected by Rehwinkel and Sharpe (2009), thus informing the environmental management of these and associated lagoons in light of potential changes to their hydrological regimes resulting from NVIRP.

1.6 Development of Appropriate Survey Techniques

The aim of this study was to identify the abundance and distribution of *T. tandanus* within selected lagoons and reaches of Gunbower Creek and to gather information on *T. tandanus* population demographics for each wetland where the species was detected. The review of the species' ecology and distribution (above), together with a review of methods applied by other investigations into the ecology this species (to follow), will inform an appropriate survey design here.

The MDFRC has conducted a number of research surveys specifically targeting *T. tandanus*, as well as other research surveys of collective fish assemblages at various locations throughout the Murray-Darling Basin in which *T. tandanus* have been encountered. In these studies, sampling techniques employed passive and active gear types. Passive gear includes large and small mesh fyke nets, panel (gill) nets of a variety of mesh sizes (i.e. 3" – 12" stretched mesh) and light traps, while electrofishing has been employed as an active survey technique at particular sites.

The project "Washpen Creek freshwater catfish survey (McCarthy *et al* 2008)" is at the time of writing an ongoing research project specifically targeting *T. tandanus*, with the aim of establishing a population size estimate (based upon a mark-recapture experiment) for the species within the Washpen Creek, near Euston NSW. That project is useful to inform the current project via a review of results obtained from comparative survey methods, with regard to development of appropriate sampling techniques and to indentify the influence of the timing (season) of sampling. In the Washpen Creek study, both passive fyke netting and active electrofishing were applied. For fyke nets, ten sites were randomly selected in the Washpen Creek within which 10 large fyke nets were deployed overnight at each site (total of 100 large fyke nets per sampling event). Electrofishing was applied at three sites for 400 seconds at each site (typical method for wetland habitats). For each method, sampling occurred during spring, summer and winter. A comparison of the total number of *T. tandanus* encountered result of fyke netting and electrofishing across seasons is given in Table 1 (fyke netting) and Table 2 (electrofishing).

This comparison indicated that fyke netting was the most effective technique for encountering the greatest number of *T. tandanus* in the Washpen Creek, for which an assessment of population structure is likely to be more accurate than that obtained by electrofishing, from which significantly fewer individual *T. tandanus* were encountered. Furthermore, this comparison indicates that the timing (season) of sampling with fyke nets resulted in significantly fewer individuals being encountered within the Washpen Creek during winter as compared to spring and summer.

Table 1. Number of nets set and *T. tandanus* encountered per sampling event in Washpen Creek between June 2008 and January 2009.

Wetland	Number of sites	Number of large nets	Season	Number of *T. Tandanus*
June 2008	10	100	Winter	73
August 2008	10	100	Winter	22
November 2008	10	100	Spring	75
January 2009	10	100	Summer	154

Table 2. Numbers of *T. tandanus* encountered using electrofishing per sampling event in Washpen Creek between August 2007 and June 2009.

Wetland	Duration	Season	Number of *T. tandanus*
August 2007	3*400 second shots	Spring	2
Febuary 2008	6*400 second shots	Summer	28
September 2008	6*400 second shots	Spring	13
June 2009	6*400 second shots	Winter	13

2. Methods: Gunbower Island

2.1 Site Selection

Sites selected included:

- Turner and Phyland Lagoons, within which Rehwinkel and Sharpe (2009) encountered *T. tandanus* in their survey of the Gunbower Island Fish community during 2008/09
- Longmore and Upper Gunbower Lagoons, due to their proximity to the former lagoons
- One 4km reach of the Gunbower Creek adjacent to Turner and Phyland Lagoons
- Cockatoo and Gum Lagoons, from which *T. tandanus* were anecdotally reported as being present by several people from the Gunbower Island community, during the June 2009 community forum conducted by the North Central CMA.

Cockatoo and Gum Lagoons were selected for study following the North Central CMA community engagement workshop held in Cohuna on the evening of July 21st 2009. This event was aimed at knowledge exchange between the North Central CMA and the wider public, to both relay information of existing CMA projects regarding Gunbower Island to the local community and to gain information from the public about the past and present distribution of fish species on Gunbower Island. From this event, the North Central CMA learned and relayed reports of freshwater catfish occupying Cockatoo and Gum Lagoons, thus those sites were incorporated into the current sampling regime. Each site location is shown in Figure 4.

2.2 Fish sampling

Based upon a review of methods applied in comparative studies, the following sampling protocol was developed for establishment of the status of *T. tandanus* populations in selected lagoons of the Gunbower Creek anabranch system.

At each wetland, 40 sites were sampled using one large fyke and one small fyke per site (40 large and 40 small fyke nets per wetland), spaced evenly according to the length of the wetland in order to reduce bias in sampling effort. Each wetland was sampled over two nights. Large fyke nets were deployed to encounter fish larger than about 150mm in length, while small fyke nets were utilised to encounter fish less than 150mm in length. Nets were set to include a diversity of structural habitat (open water, vegetation and woody material) in an attempt to sample all available habitat types. Large fyke nets (LFN) had a central wing (8 m x 0.65 m) attached to the first supporting hoop (Ø = 0.55 m) with a mesh entry of 32 cm, and stretched mesh size of 28 mm. Small fyke nets (SFN) had dual wings (each 2.5 m x 1.2 m), with a first supporting hoop (Ø = 0.4 m) fitted with a square entry (0.15 m x 0.15 m) covered by a plastic grid with rigid square openings (5 cm x 5 cm). Each SFN had a stretched mesh size of 2mm. Fyke nets were set in the afternoon and collected the following morning and the soak time for each net was calculated for subsequent development of catch per unit effort. The cod-end of fyke nets was suspended out of the water by the use of floats to avoid mortality of captured air-breathing vertebrates.

Each fish species encountered was identified following McDowall (1996) and Lintermans (2007). All fish captured in large fyke nets were measured (total length ± 1.0mm), and weighed (± 1.0g). All small bodied fish caught in small fyke nets were counted and batch weighed (± 1.0g). All native fish were released and non-native fish were euthanised following ACEC guidelines.

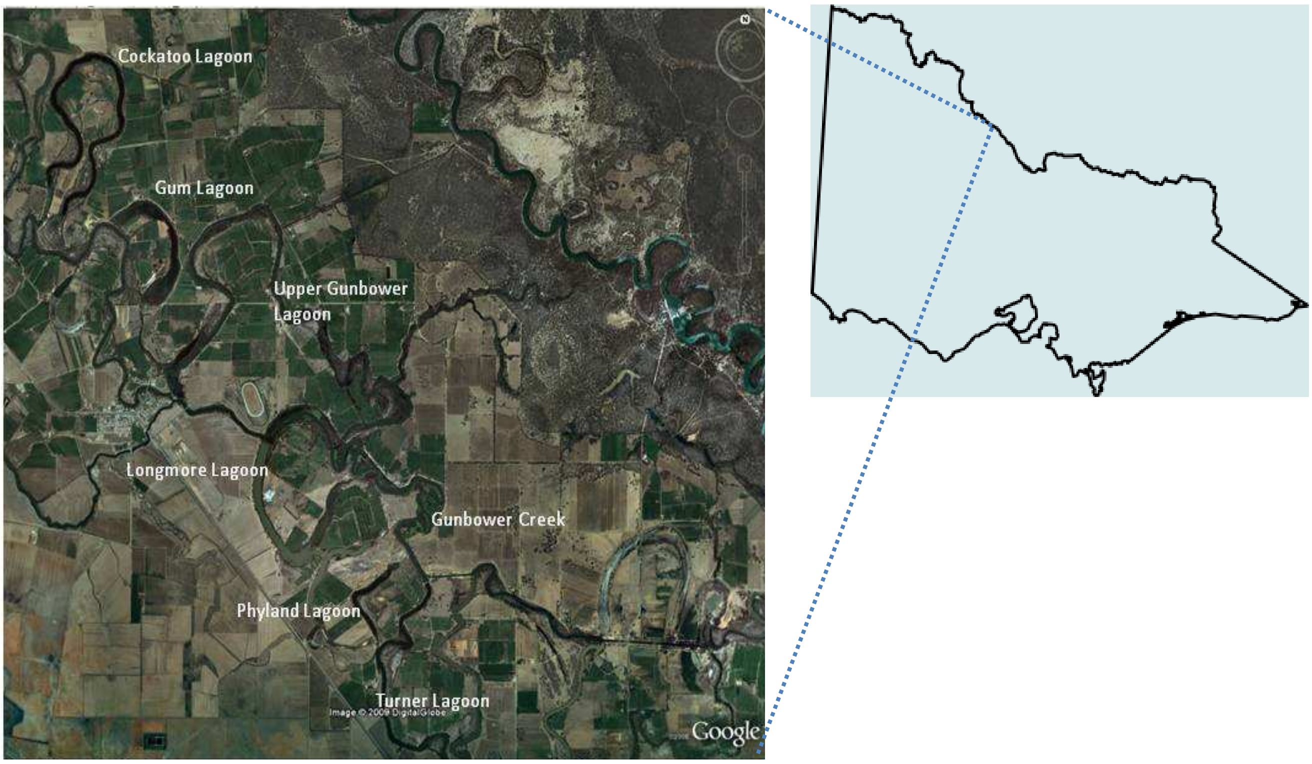

Figure 4. Locations of Lagoons and one reach of the Gunbower Creek surveyed on Gunbower Island.

2.3 Water Quality

At each of the forty netting locations, measurements of dissolved oxygen (mg/L^{-1}), temperature (^{o}C), electrical conductivity (µS cm^{-1}standardised to 25^{o}C), turbidity (NTU) and pH were determined *in situ* at a depth of 0.25m below the water surface and near the bottom of the water column using a Horiba U52-multiprobe. Coordinates were recorded using a hand-held GPS unit (datum WGS 84) and a digital photo of each site was recorded.

2.4 Habitat Assessment

Habitat assessments were conducted at six sites within each waterbody following AUSRIVAS physical habitat assessment protocols, providing a rapid yet comparable evaluation of habitat characteristics.

2.5 Data analysis

Fish

The relative abundance of each fish species was calculated, followed by development of length-frequency histograms for each species within each wetland. The catch per unit effort of each species within each wetland was standardised to the number of individuals from each species captured over 24hrs. All statistical analyses were conducted using PRIMER V6 (Clarke and Gorley, 2006). Fish abundance data (catch per unit effort) was double square root transformed and a Bray Curtis similarity applied. This transformation was applied to down-weight the influence of numerically abundant species. A Multi-Dimensional Scaling (MDS) ordination was generated from the resulting similarity matrix. A hierarchical cluster analysis supported with a SIMPROF test (with 999 permutations) was subsequently applied to the MDS ordination to assess the extent of similarity in the structure of fish assemblages between sites (wetlands). Similarity groupings were set at 75%.

Habitat characteristics

Habitat data was square root transformed and a Bray Curtis similarity applied. Non-metric Multidimensional Scaling was applied to the fifteen variables defining habitat characteristics (i.e. average depth, % emergent macrophytes, % submerged macrophytes, % riparian shading etc). An MDS ordination was generated from the subsequent similarity matrix. A hierarchical cluster analysis supported with a SIMPROF test (with 999 permutations) was subsequently applied to the MDS ordination to assess the extent of similarity in habitat indices between wetland sites.

Fish- Habitat associations

Fish-habitat associations were examined by fourth-root transformation of fish abundance data and application of a Bray-Curtis resemblance measure. Habitat data was normalised, and a BEST procedure applied to examine significant matches between the patterns of fish assemblage data and patterns of habitat data between wetlands (sites). The extent to which these patterns match reflects the degree to which the habitat data 'explains' the observed patterns in fish abundance data.

3. Results

3.1 Species Abundance

A total of 9 native and 5 exotic species of fish were encountered. A total of 24 *T. tandanus* were captured from three of the seven wetlands surveyed; Turner Lagoon (n=21) Phyland lagoon (n=2) and Cockatoo Lagoon (n=1) (Table 4). In Turner Lagoon these ranged in length from 46mm to 448mm, in Phyland Lagoon individuals were 437mm and 450mm in length and in Cockatoo Lagoon the only individual encountered was 380mm in length. The abundances of other fish species encountered within each wetland are given in Table 4. Length Frequency histograms for each large bodied species encountered (including *T. tandanus*) are provided in Appendix 1.

3.2 Fish Assemblages

MDS analysis of fish assemblage characteristics from each lagoon surveyed is presented in Figure 5. Cluster analysis of this data (SIMPROF) indicated that Cockatoo, Phyland and Turner Lagoons, together with Upper Gunbower Lagoon, displayed 75% similarity in fish assemblage structure (species present and relative abundance of species). *T. tandanus* were recorded at the former three wetlands but not the latter, and were an important indicator in the similarity observed. Murray cod were recorded only at the Gunbower Creek site, and the presence of this species was the most influential in the variation exhibited by this site. The presence and relative abundance of catfish, redfin, carp, Murray cod and flyspecked hardyhead (in that order) were most responsible for the variation in fish assemblage structure betweens sites. Cockatoo and Turner Lagoon were most dissimilar to other wetlands but exhibited between-site similarity (to each other) of 75% in fish assemblage structrue; however these wetlands (Cockatoo and Turner) were not closely located in the ordination (Figure 12). The similarity in the structure of fish communities at the later sites was explained by the presence of *T. tandanus* and the lower abundance of carp relative to other sites (Table 4).

Table 4. Total number of fish caught (by species) in each wetland. Gap = species not recorded.

Species	Cockatoo Lagoon	Gum Lagoon	Gunbower Creek	Longmore Lagoon	Phyland lagoon	Turner Lagoon	Upper Gunbower lagoon	Species Total
NATIVE								
Freshwater Catfish *Tandanus tandanus*	1				2	21		24
Fly-specked hardyhead *Craterocephalus stercusmuscarum fluvus*	54	56	169		3	16	11	309
Hypseleotris spp.	642	9906	1527	3004	2140	637	1784	19640
Golden perch *Macquaria ambigua*		5	1				4	10
Crimson-spotted rainbowfish *Melanotaenia Fluviatilis*			6			4		10
Murray Cod *Maccullochella peeli peeli*			3					3
Flat-headed gudgeon *Phylipnodon grandiceps*	56	19	259	311	244	1298	554	2739
Dwarf flat-headed Gudgeon *Phyipnodon macrostomus*	8	3	1	2		5	76	95
Australian Smelt *Retropinna semoni*	216	51	2993	312	106	1205	831	5714
EXOTIC								
Goldfish *Carassius auratus*	3	8	6	12	7	1	8	45
Common Carp *Cyprinus carpio*	1	33	19	26	14	9	23	125
Redfin *Perca fluviatilis*	16			26	2	3	7	54
Eastern gambusia *Gambusia holbrooki*	63	2			4	3	8	80
Oriental weatherloach *Misgurnus anguillicaudatus*	11	4	17		4	1	32	69
Wetland Total	**1071**	**10087**	**5002**	**3693**	**2526**	**3203**	**3338**	**28920**

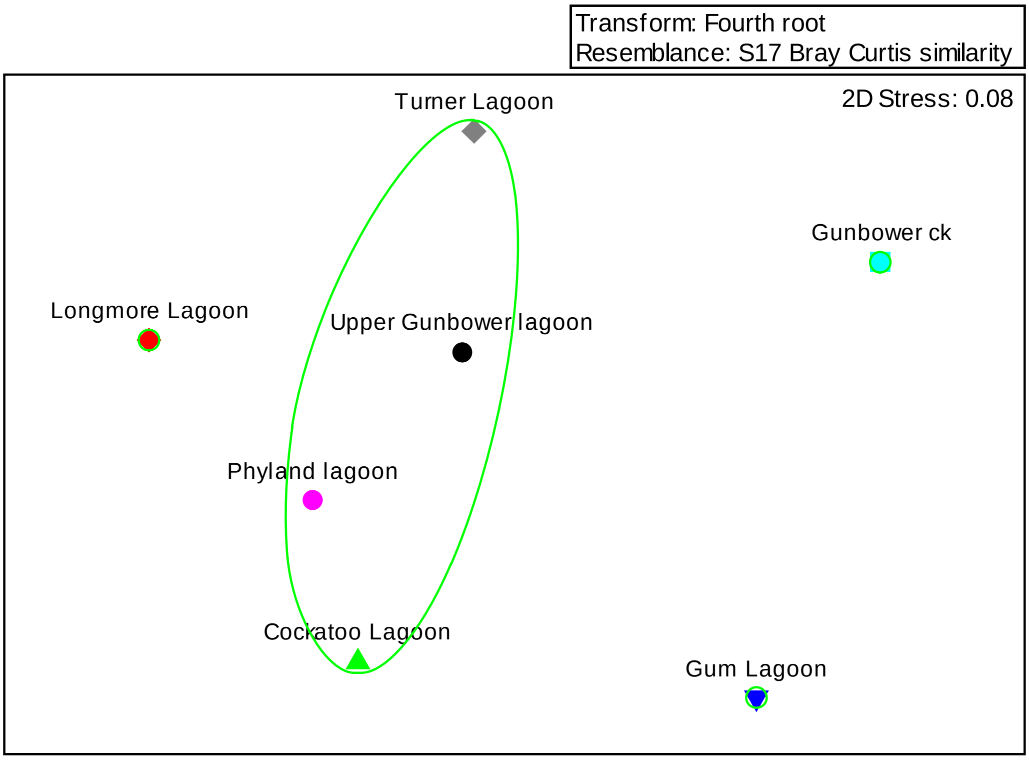

Figure 5. MDS of wetland fish assemblage structure based on species abundance data. Green ellipse represent groups of sites/trips with similarity greater than 80%.

3.3 Habitat

Habitat variables collected from 6 sites within each wetland were averaged and are presented in Tables 5-7 below. Mean values for each water quality parameter measured within each wetland are given in Table 8.

Table 5. Average Terrestrial riparian vegetation characteristics for each wetland.

Wetland	% Trees >10m	% Trees <10m	% Shrubs	% Grass	% Native terrestrial Veg	% Exotic Terrestrial Veg
Phyland Lagoon	21	0	8	67	53	47
Turner Lagoon	32	4	3	63	67	33
Gunbower Ck	18	8	18	40	80	20
Longmore Lagoon	31	5	2	50	75	25
Upper Gunbower Lagoon	57	13	10	18	68	32
Gum Lagoon	58	11	0	24	87	13
Cockatoo Lagoon	60	8	0	32	98	2

Table 6. Average percent shading of each wetland; average percent large woody debris within each wetland and average depth of each wetland.

Wetland	% channel shading	% Large Woody Debris	Average Depth (m)
Phyland Lagoon	5	28	0.68
Turner Lagoon	12	11	2.00
Gunbower Ck	13	10	2.67
Longmore Lagoon	5	30	0.97
Upper Gunbower Lagoon	12	16	2.00
Gum Lagoon	5	23	0.87
Cockatoo Lagoon	5	11	1.27

Table 7. Average percent macrophyte cover with percent native and non native macrophytes in each wetland.

Wetland	% Macrophyte cover	% Emergent	% Floating	% Submerged	% Native macrophyte	% Exotic Macrophyte
Phyland Lagoon	0	0	0	0	0	0
Turner Lagoon	8	1	0	6	23	77
Gunbower Ck	7	7	0	0	51	49
Longmore Lagoon	7	4	0	3	100	0
Upper Gunbower Lagoon	21	8	0	13	71	29
Gum Lagoon	23	18	4	1	90	10
Cockatoo Lagoon	85	13	7	65	84	16

MDS analysis (SIMPROF) of habitat characteristics from each site indicated that Turner Lagoon and Gunbower Creek were more than 85% similar in habitat character. Gum and Cockatoo Lagoons were also greater than 85% similar to each other, but not to the former group (Figure 16). Overall, each wetland site exhibited more than 75% similarity in their habitat characteristics with exception of Phyland Lagoon (in which catfish were present), which had a distinctly different combination of habitat variables (demonstrated by the large degree of separation between this site and all other sites in the MDS ordination (Figure 6)). A key habitat variable responsible for the segregation of Phyland Lagoon from other sites in the MDS ordination was the absence of submerged and emergent macrophytes in Phyland Lagoon at the time of sampling (Table 7).

When riparian vegetation was excluded from the analysis (because of its low variability in density between sites (Table 5)), BEST analysis highlighted three variables which provided the best match (R = 0.547) between habitat characteristics and the observed fish assemblage structure data:

1) Relative percentage cover of large woody debris (%LWD)

2) Average depth (m)

3) Percentage cover of emergent aquatic vegetation (% emergent)

With the exception of Phyland Lagoon, %LWD, Average depth (m) and % emergent macrophytes were considered to have the most influence upon fish assemblage structure and abundance from the suite of characteristics measured. This result suggests that variation among these three indicators may influence the structure of fish assemblages within wetlands examined here. However, this pattern was not consistent for the presence or absence of *T. tandanus*. Phyland lagoon displayed the shallowest average depth overall, lacked emergent aquatic macrophytes and was significantly different in habitat character to other sites from which *T. tandanus* were recorded. With exception of Phyland Lagoon, all other sites were 75% similar in aquatic macrophyte density and Cockatoo and Gum Lagoons, which had the highest relative density of aquatic macrophytes, exhibited more than 80% similarity.

Table 8. Mean water quality variables of each wetland with standard error and minimum and maximum values.

Wetland		Mean pH	Mean DO (Mg\L-^{1})	Mean Turbidity (NTU)	Mean Temperature (0°C)	Mean EC (ms\cm3)
Phyland Lagoon	Mean	7.11	11.57	229.0	13.66	145.75
	SE	0.04	0.27	3.0	0.28	0.41
	Min	6.56	9.56	205.0	10.75	143.00
	Max	7.73	15.00	311.0	17.60	147.00
Turner Lagoon	Mean	7.24	11.29	42.8	13.01	117.48
	SE	0.05	0.28	4.3	0.10	5.38
	Min	6.49	6.00	2.9	11.42	74.00
	Max	7.76	16.61	111.0	14.87	157.00
Gunbower Ck	Mean	7.15	10.77	35.4	12.43	63.45
	SE	0.04	0.09	3.3	0.07	0.15
	Min	6.46	10.04	16.2	11.59	62.00
	Max	7.49	12.68	102.0	13.08	68.00
Longmore Lagoon	Mean	7.56	10.09	217.9	14.01	165.33
	SE	0.03	0.10	20.6	0.20	29.76
	Min	7.33	9.11	149.0	11.41	131.00
	Max	7.96	11.45	756.0	16.44	1336.00
Upper Gunbower Lagoon	Mean	7.02	8.12	62.7	15.15	67.60
	SE	0.05	0.18	4.3	0.28	1.18
	Min	6.51	5.82	4.2	12.36	58.00
	Max	7.87	9.72	141.0	17.95	82.00
Gum Lagoon	Mean	6.97	9.10	223.8	15.04	87.60
	SE	0.07	0.22	82.9	0.20	0.71
	Min	6.34	6.52	71.4	12.16	84.00
	Max	7.68	11.33	3320.0	17.42	98.00
Cockatoo Lagoon	Mean	7.62	10.16	0.1	15.34	101.93
	SE	0.08	0.20	0.1	0.14	2.74
	Min	6.56	6.33	0.0	13.28	10.00
	Max	8.70	12.06	4.2	16.60	123.00

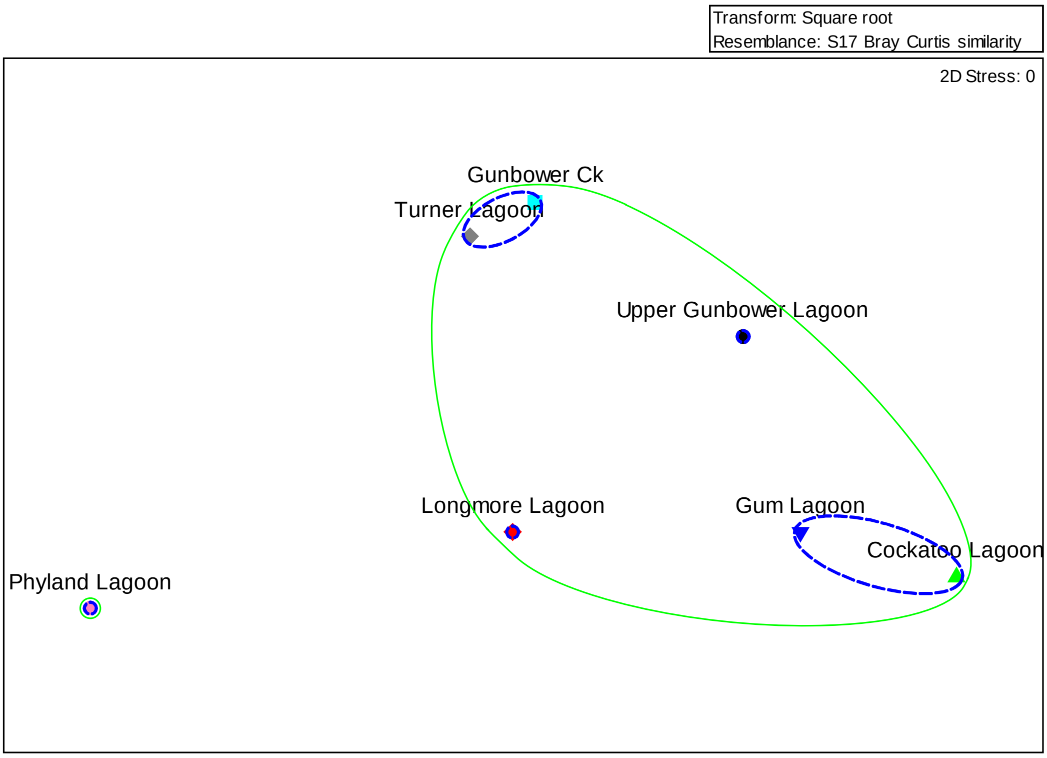

Figure 6. MDS of wetland habitat parameters (sites bounded by green ellipse = 75% similarity, blue ellipse = 85% similarity).

4. Discussion

T. tandanus were once widespread and abundant within the Murray River system, including the creeks, lagoons and wetlands of Gunbower Island (Lake 1967; Clunie and Koehn 2001; Lintermans 2007). During the 1940's the abundance of *T. tandanus* was reported to decline across the Gunbower region, coinciding with an abrupt increase in the abundance and distribution of the exotic redfin and common carp, as well as in conjunction with increasing regulation of the Murray River and the Gunbower Creek anabranch system (Roughly 1951; Clunie and Koehn 2001; Trueman 2007). By the 1990's, *T. tandanus* were rare and infrequently encountered in the wetlands, lagoons creeks and rivers of the Gunbower region. Anecdotally, the species has been infrequently captured by anglers at particular lagoons (Cockatoo, Turner and Gum Lagoons) and occasionally within the Gunbower Creek during the past three decades. The species was not recorded during any survey of the Gunbower Creek anabranch system or its associated wetlands and lagoons during any fisheries survey since at least the 1980's until it was detected as being present at Turner and Phyland Lagoons during 2009 (Rehwinkel and Sharpe 2009).

The current study aimed to determine the current distribution and establish the population structure of *T. tandanus* within six lagoons and one within channel reach of the Gunbower Creek. Following review of research and monitoring projects from which *T. tandanus* were encountered and more specifically targeted, a sampling regime specifically suited to the aims of the current investigation was established. Electrofishing was not considered as efficient at collecting *T. tandanus* as were fyke nets, which by combining the use of large and small mesh fyke nets, was considered most efficient to encounter the full suite of life-history stages of *T. tandanus* if present within wetlands. Electrofishing was therefore not utilised in this study, whereas it was determined that 40 large and 40 small fyke nets would be deployed at each site investigated here.

Of the seven wetlands surveyed, *T. tandanus* were recorded in three: Turner, Phyland and Cockatoo Lagoons. The structure of fish assemblages within those wetlands from which *T. tandanus* occurred exhibited several similarities, namely similar relative abundances of goldfish, Australian smelt, Murray-Darling rainbowfish and carp (in order of significance). Of note was the low abundance of redfin and carp from those wetlands in which *T. tandanus* were recorded. Redfin and carp have been implicated previously in the decline of *T. tandanus* in the Murray-Darling Basin (Roughly 1951; Clunie and Koehn 2001), with the decline of *T. tandanus* in the Gunbower region occurring at similar times to the increasing abundance of these species (Langtry in Cadwallader 1977). As such, the low relative abundance of redfin and carp may be an influence upon the occurrence of *T. tandanus* at the current study sites.

The population structure of *T. tandanus* in Turner Lagoon may be considered robust, with individuals from a variety of year classes occurring within the population (Appendix 1: Figure 12). Comparison with published length at maturity data indicates that sub-adults (SL, 200-300mm) and adults (SL, >300mm) are present in Turner Lagoon (Pusey *et al* 2004). Young of the year (age 0+) and multiple juvenile size classes, together with adult sized individuals are indicators of a robust *T. tandanus* population. Furthermore, as sampling was conducted in winter when *T. tandanus* have been shown to be less readily sampled using fyke nets (McCarthy 2009), it is possible that the relative abundance of the Turner Lagoon population is similar to other robust and relatively abundant populations of this species elsewhere in the MDB (i.e. Washpen Creek; McCarthy 2009). Conversely, the *T. tandanus* populations within Phyland and Cockatoo Lagoons appeared fragmented, with only one and two (adult) individuals captured from Cockatoo and Phyland Lagoons respectively. As such, despite the suppressed encounter rate expected from winter sampling, as compared to Turner Lagoon, these populations are not considered to be robust.

Habitat characteristics measured at each wetland were generally similar except for Phyland Lagoon which exhibited marked differences in physical habitat character, notably significantly lower average depth and a lack of aquatic macrophytes. However, Phyland Lagoon maintains physical connectivity to Turner Lagoon, thus providing colonisation potential for *T. tandanus* from Turner to Phyland Lagoon. Conversely the habitat characteristics present within Phyland Lagoon may not be conducive to support a robust population of *T. tandanus*, while the relative abundance of redfin and carp was similar between these wetlands.

When patterns of habitat character exhibited among wetlands were related to the structure of fish assemblages from each wetland, three habitat features were considered to be important in influencing fish assemblage structure: (i) the relative percentage cover of large woody debris (%LWD), (ii) average depth and (iii) percentage cover of emergent aquatic vegetation (% emergent). These indices were similar between Turner and Cockatoo Lagoons, from which *T. tandanus* were encountered, but not features common to Phyland lagoon. Subsequently, the contrast in population structure of *T. tandanus* between Turner and Cockatoo Lagoon's, despite exhibiting similar habitat characteristics, was considered to be influenced more by fish assemblage structure, namely the relatively high abundances of redfin and carp in Cockatoo Lagoon, rather than by habitat character.

Maintenance of the Turner Lagoon population of *T. tandanus*, which is currently the most robust discrete population of this species known to occur in the Gunbower anabranch system is considered of high importance. Clunie and Koehn (2001a) stated '…*protection of T. tandanus should include ensuring that management of particular areas where good populations occur is not changed dramatically without a sound understanding of what key ecological components are important…'*, thus continuation of the current (recent) hydraulic regime of Turner Lagoon may maintain the current status of *T. tandanus* there. Furthermore, restoring connectivity of Turner Lagoon to the Gunbower Creek and adjacent lagoons (with particular consideration to the passage requirements of *T. tandanus*) may promote re-colonisation of the

Gunbower Creek and lagoons adjacent to Turner Lagoon by this species, via dispersal from Turner Lagoon. As habitat characteristics were established as being generally similar among the wetlands examined here, the present lack of connectivity may be limiting the rehabilitation of the status of this species across Gunbower Island.

5. Conclusions

This study has demonstrated that a combination of fish assemblage structure (specifically the presence and abundance of redfin and carp) and habitat character are likely important factors influencing the distribution, abundance and population structure of *T. tandanus* at those sites examined on Gunbower Island.

The most robust population of *T. tandanus* encountered during this study was located in Turner Lagoon, where the abundance of redfin and carp were relatively low, and the relative densities of large woody debris and emergent aquatic macrophytes were high and average depth was relatively deep.

Unlike Turner Lagoon, the population structure of *T. tandanus* observed in Phyland and Cockatoo Lagoons appeared fragmented, while *T. tandanus* were not encountered in Upper-Gunbower Lagoon, Gum Lagoon, Longmore Lagoon or the Gunbower Creek, despite these all exhibiting similarities in habitat character to that observed in Turner Lagoon.

Phyland Lagoon exhibited a significantly different suite of habitat characteristics to other lagoons examined here; however its physical connection to Turner Lagoon and the robust *T. tandanus* population there suggests that continuing colonisation opportunities to Phyland Lagoon exist for *T. tandanus* from Turner Lagoon. The limited availability of suitable habitat within Phyland Lagoon may however be an important factor in the currently suppressed structure of the *T. tandanus* population there.

Cockatoo Lagoon, whilst exhibiting similar and potentially favourable habitat characteristics for *T. tandanus* to Turner Lagoon, did not possess a robust population of *T. tandanus*. We suggest that the structure of the Cockatoo Lagoon large-bodied fish assemblage, which was significantly different to that within Turner Lagoon (being numerically dominated by redfin), may be an important influence upon the current status of *T. tandanus* in Cockatoo Lagoon. Combined with a lack of colonisation potential from a robust source population of *T. tandanus* (such as Turner Lagoon) it is likely that without management intervention, the status of *T. tandanus* in Cockatoo Lagoon will not improve. Eradication of redfin from Cockatoo Lagoon, together with enhancement of connectivity to a robust source population of *T. tandanus* are recommended to rehabilitate the Cockatoo Lagoon population, thus the regional status of *T. tandanus* to more a robust level.

6. Recommendations

1. It is essential that the current status of the Turner Lagoon *T. tandanus* population be maintained for the regional status of *T. tandanus* in the Gunbower Region to be maintained or enhanced.

2. For the Turner Lagoon population of *T. tandanus* to be maintained at its current status, we recommend that no change be made to the historical (past decade) water management regime imposed upon Turner Lagoon. This recommendation is particularly relevant in light of potential operational changes in water delivery result of the NVIRP process in the Torrumbarry Irrigation Region. Furthermore, it is essential that the historical water management regime of Turner Lagoon be identified to enable mitigation of any adverse hydrological impacts upon this specific population.

3. With provision of sufficient colonisation opportunities via restored connectivity, the Turner Lagoon population of *T. tandanus* may act as a source for restoring the status of *T. tandanus* in similar habitats, including the Gunbower Creek, throughout the Gunbower Island region. This recommendation should be carefully examined in order to reduce any impact upon the Turner Lagoon *T. tandanus* population via colonisation of this lagoon by redfin and carp in light of enhanced connectivity to the Gunbower Creek.

4. Whilst the population of *T. tandanus* in Cockatoo Lagoon is currently suppressed, the character of habitat within this lagoon appears to be conductive for the establishment of a robust *T. tandanus* population should eradication of redfin and carp in Cockatoo Lagoon be achieved.

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Appendix 1. Length Frequency Histograms for each species

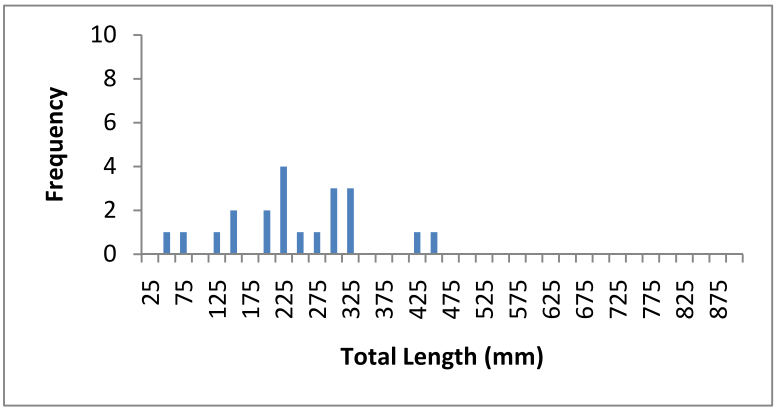

Figure 13. *T. tandanus* length frequency distribution in Turner Lagoon.

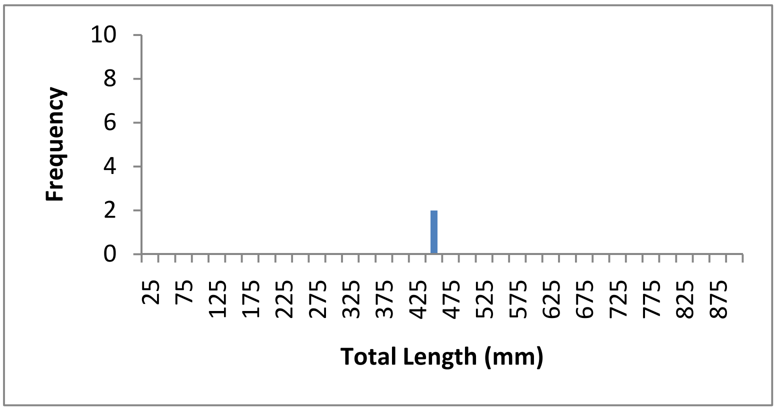

Figure 14. *T. tandanus* length frequency distribution in Phyland Lagoon.

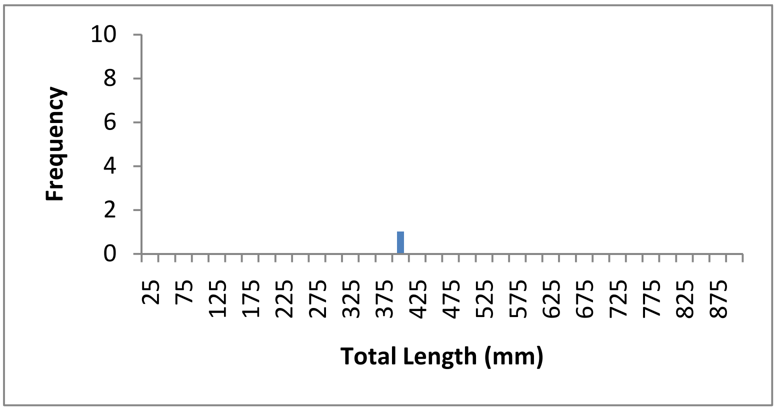

Figure 15. *T. tandanus* length frequency distribution in Cockatoo Lagoon.

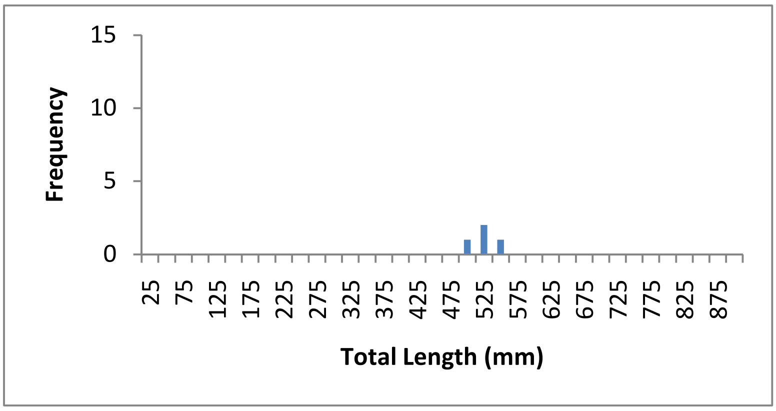

Figure 17. *M. ambigua* length frequency distribution in Upper Gunbower Lagoon.

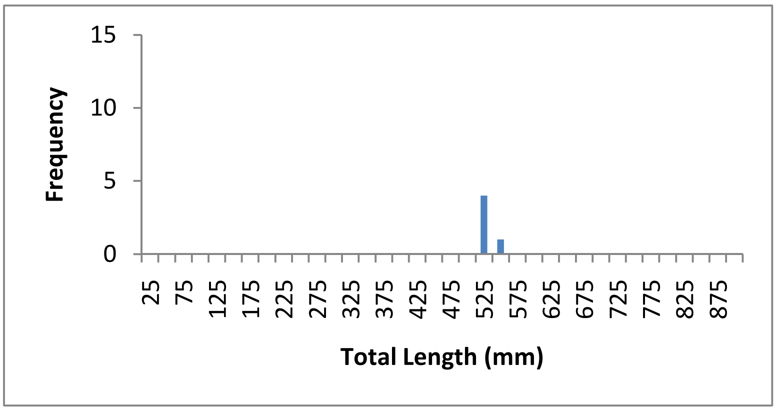

Figure 18. *M. ambigua* length frequency distribution in Upper Gum Lagoon.

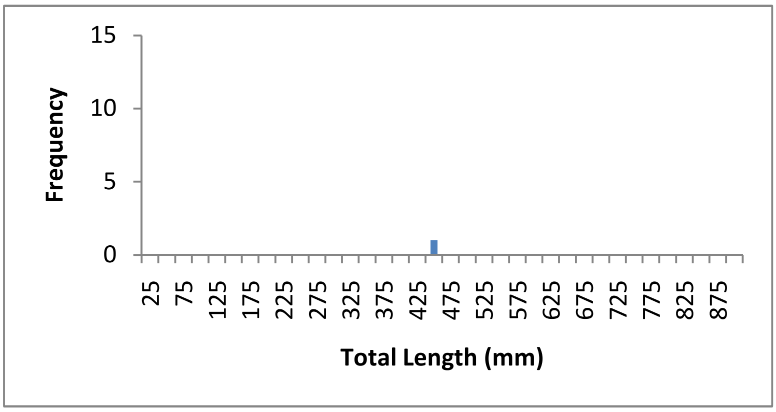

Figure 19. *M. ambigua* length frequency distribution in Upper Gunbower Creek.

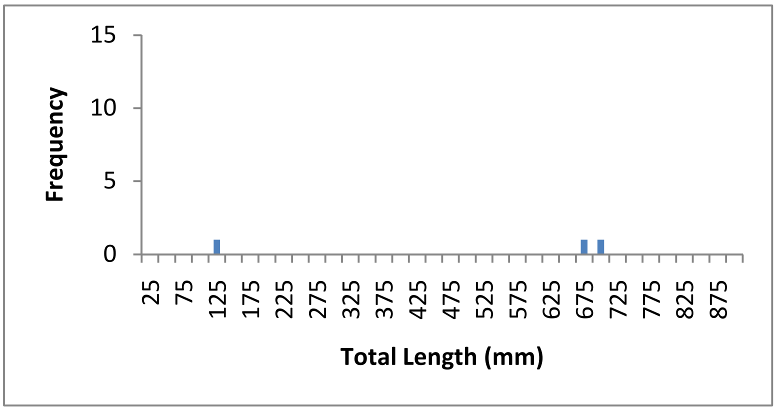

Figure 20. *M. peelli peelli* length frequency distribution in Gunbower Creek.

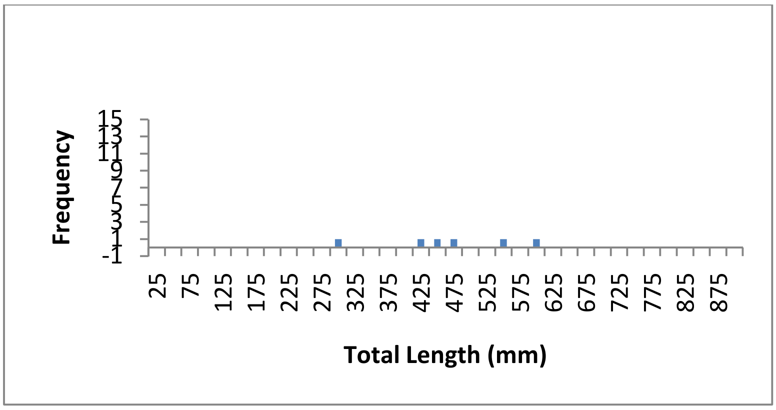

Figure 21. *C. carpio* length frequency distribution in Turner Lagoon.

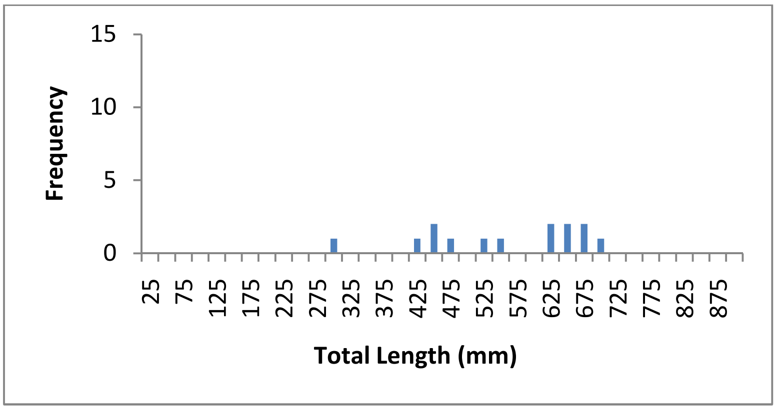

Figure 22. *C. carpio* length frequency distribution in Phyland Lagoon.

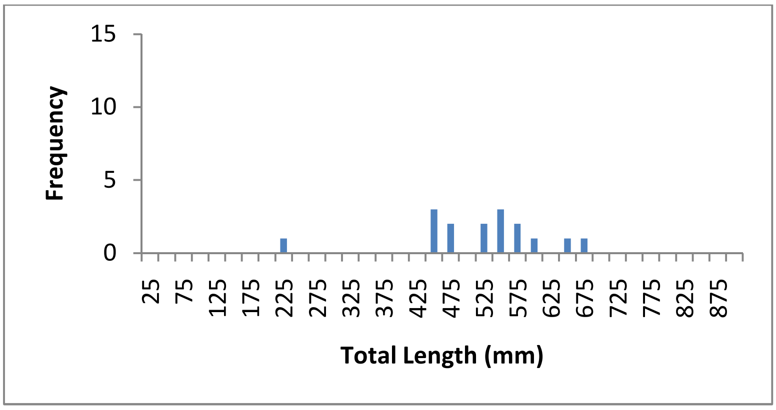

Figure 23. *C. carpio* length frequency distribution in Gunbower Creek.

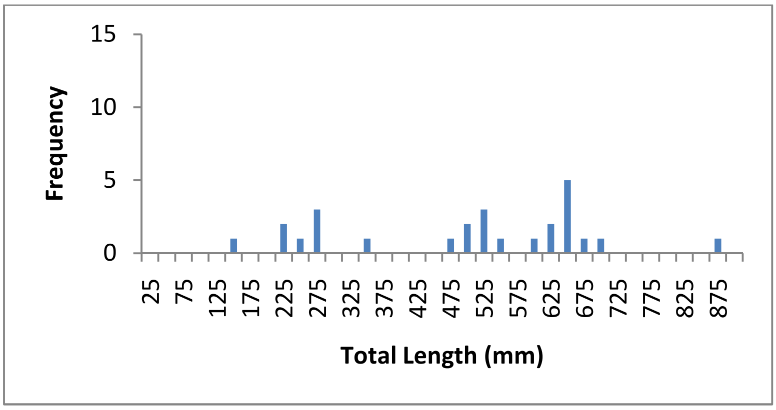

Figure 24. *C. carpio* length frequency distribution in Longmore Lagoon.

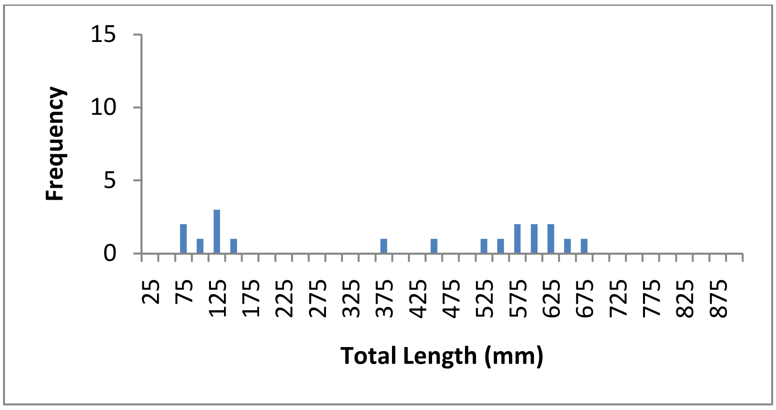

Figure 25. *C. carpio* length frequency distribution in Upper Gunbower Lagoon.

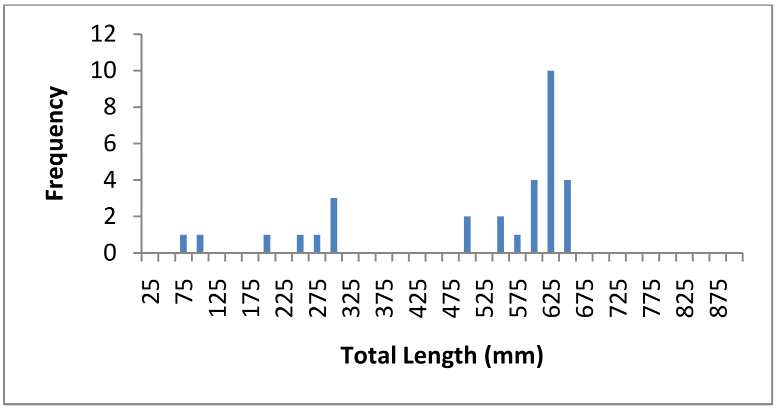

Figure 26. *C. carpio* length frequency distribution in Upper Gum Lagoon.

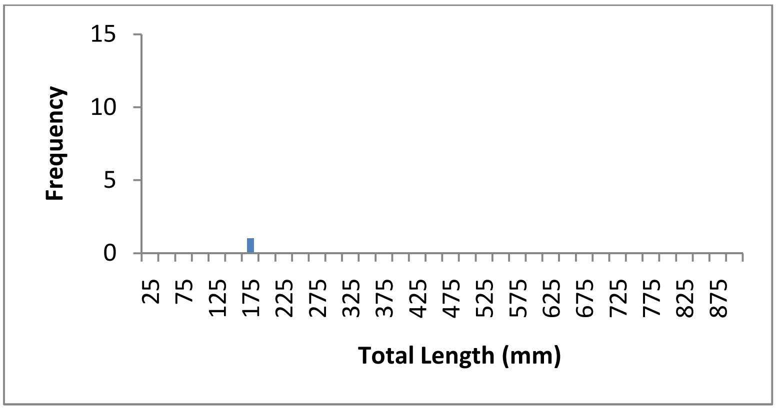

Figure 27. *C. carpio* length frequency distribution in Cockatoo Lagoon.

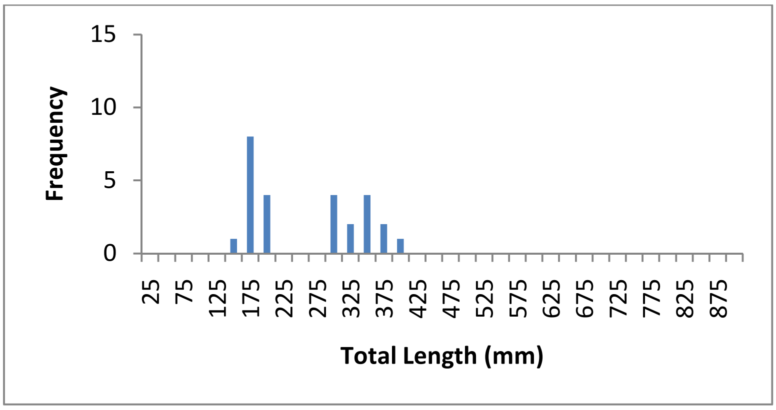

Figure 28. *P. fluvialitis* length frequency distribution in Longmore Lagoon.

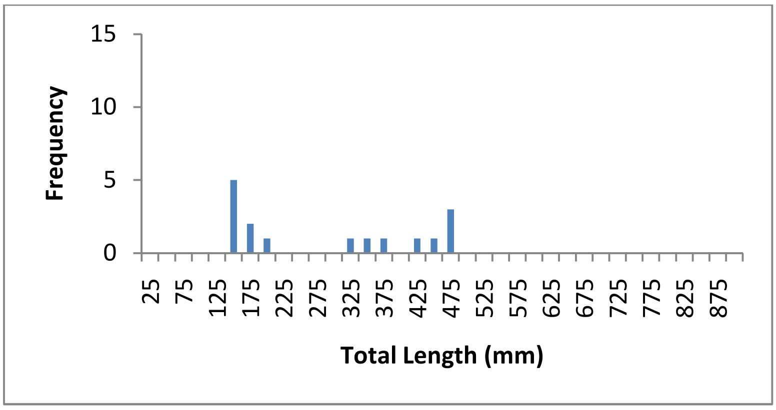

Figure 29. *P. fluvialitis* length frequency distribution in Cockatoo Lagoon.

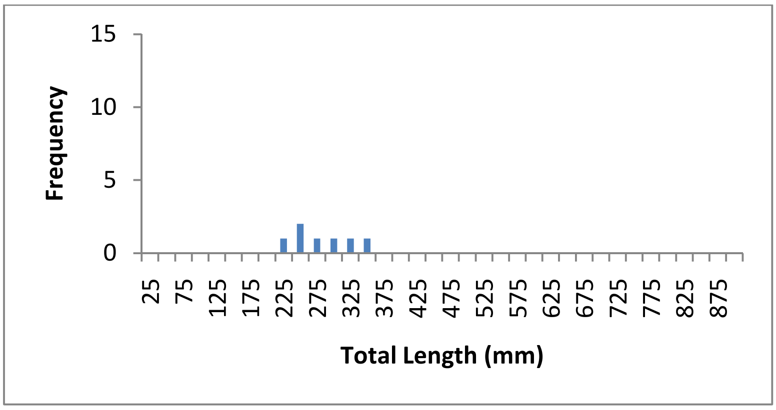

Figure 30. *P. fluvialitis* length frequency distribution in Upper Gunbower Lagoon.

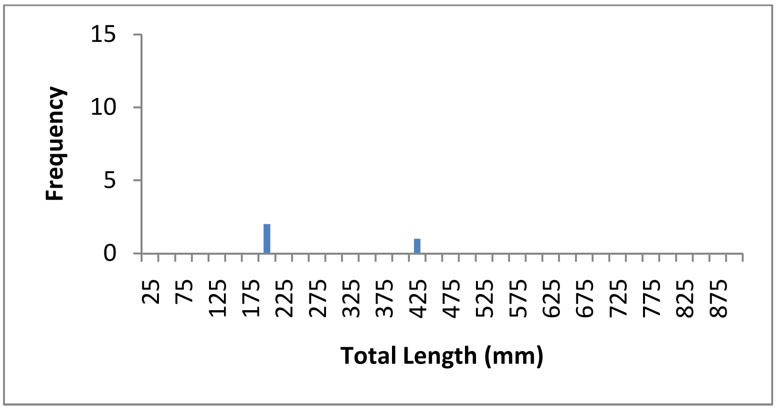

Figure 31. *P. fluvialitis* length frequency distribution in Turner Lagoon.

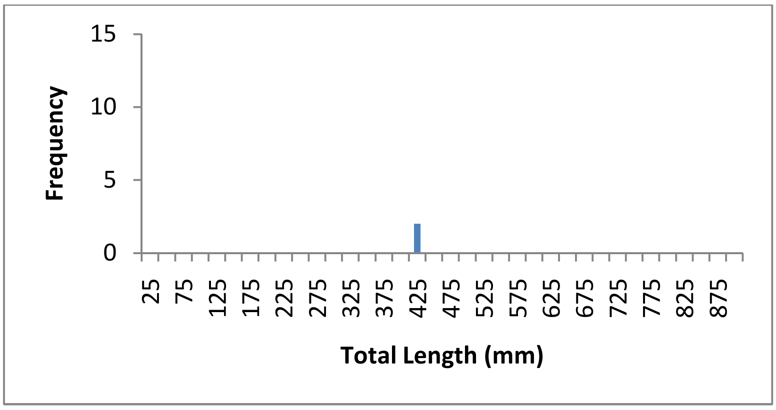

Figure 32. *P. fluvialitis* length frequency distribution in Phyland Lagoon.

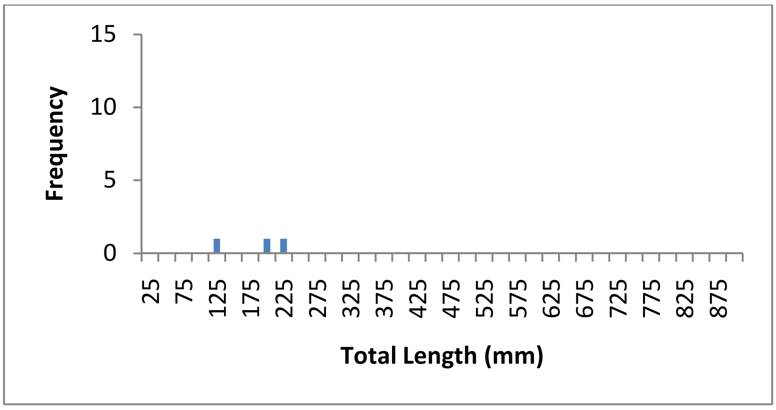

Figure 33. *C. auratus* length frequency distribution in Gunbower Creek.

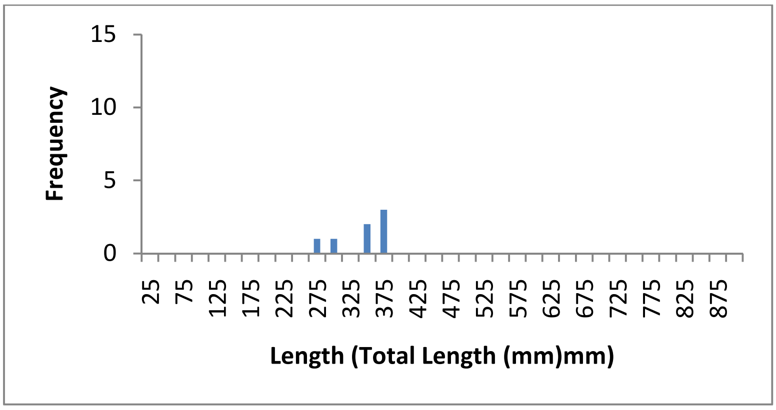

Figure 34. *C. auratus* length frequency distribution in Phyland Lagoon.

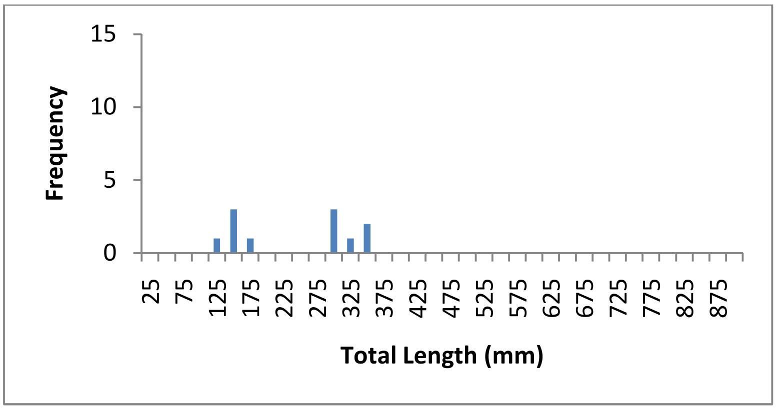

Figure 35. *C. auratus* length frequency distribution in Longmore Lagoon.

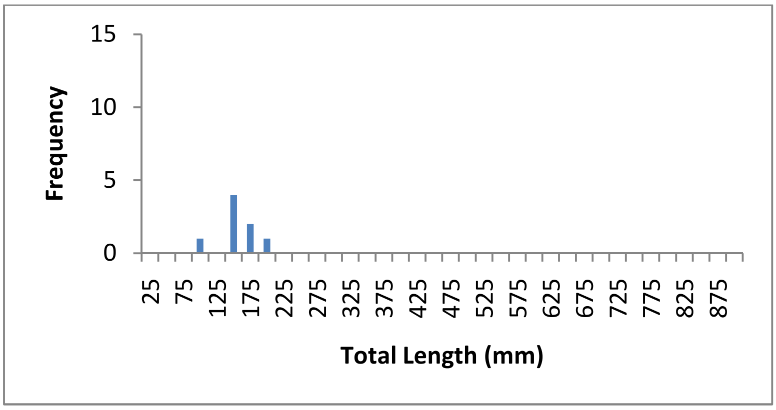

Figure 36. *C. auratus* length frequency distribution in Upper Gunbower Lagoon.

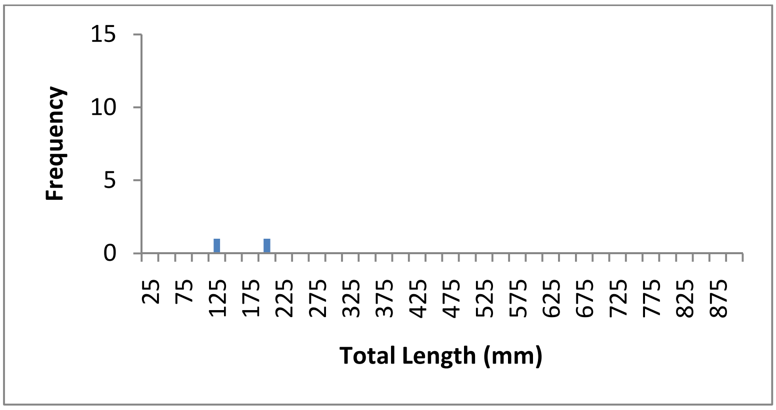

Figure 37. *C. auratus* length frequency distribution in Cockatoo Lagoon.

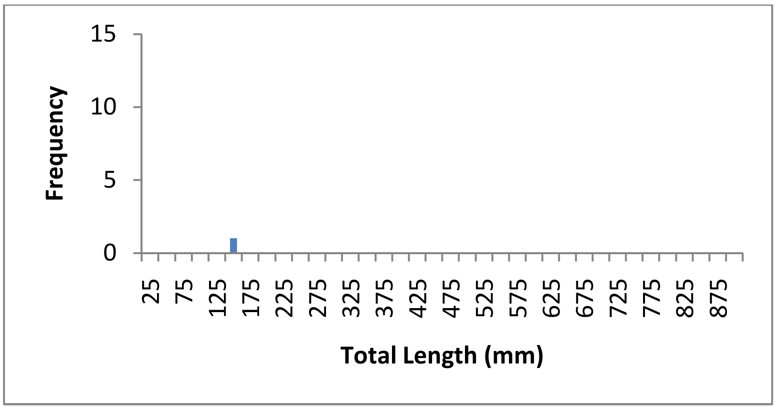

Figure 38. *C. auratus* length frequency distribution in Turner Lagoon.