ARTICLE

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Destocking waterways: Evidence that stocked Murray Cod (*Maccullochella peelii*) were extracted at pumped irrigation diversions within 24 hours of release

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Summary **Millions of native fish are entrained into irrigation pumps in Australian rivers every year. It is often assumed these fish are wild, but stocked fish may also be affected. During fish entrainment surveys at two pump intakes on the Macquarie River, New South Wales, a noticeable increase of entrained juvenile Murray Cod (*Maccullochella peelii*) was observed. DNA parentage analysis confirmed that a large proportion of these fish were linked to nearby fish restocking events. At both pump intakes, genetic analysis confirmed that at least 70% and 17% of the individuals sampled were stocked fish. This equated to up to 3% of the fish that were stocked – most of which were entrained less than 24 h after their release. Given the large number of unscreened irrigation pumps in this reach of river, and more broadly throughout the Murray–Darling Basin, fish losses at pump intakes have the potential to remove large numbers of stocked fish from the river where they are released to support native fish recovery and boost recreational fishing opportunities. The use of fish-protection screens at pump intakes may be a suitable solution to reduce the number of fish entrained and thus increase the survival of recently stocked fish in the rivers.**

Key words: *entrainment, fish protection screens, hatchery-bred fish, Murray–Darling Basin, pump diversion, stocking.*

Introduction

Fish extraction from rivers at unscreened water diversions and pump intakes is an acknowledged issue worldwide and is affecting the long-term viability of fish populations (Moyle & Israel 2005; Turnpenny & O'Keeffe 2005; King & O'Connor 2007; Simpson & Ostrand 2012; Boys *et al*. 2021). Once entrained, fish can rarely return to the river and if not, are permanently lost from breeding populations (Baumgartner *et al*. 2009; Gregory *et al*. 2018).

A recent review estimated a mean of ~3.5 native fish per megalitre (ML) of

Implications for Managers

- Unprotected pump intakes can entrain juvenile stocked fish within 24 hours of release, therefore potentially reducing the survival rates of recently stocked fish near pump intakes and consequently affecting stocking success.
- Addressing this issue could help minimize fish losses at the intakes. This may be achieved by installing fish protection screens at intakes at suitable sites. Alternatively, avoiding stocking near intakes or stocking fish outside the pumping period are other options to avoid entrainment of recently stocked fish.

extracted water are lost at pump intakes within the Murray–Darling Basin (MDB), Australia (Boys *et al*. 2021). However, this may be a conservative estimate given that other studies point to entrainment rates of greater than 30 fish per ML (Hutchison *et al*. 2022), and some instances of up to 1130 fish per ML (Norris 2015). In 2020–2021, the MDB provided 4.9 million ML of water for irrigation, accounting for 62% of Australia's total water use for this purpose (ABS 2022). This water was predominantly sourced from surface water, harvested from farm dams, irrigation channels and watercourses (e.g., rivers, streams) (Leblanc *et al*. 2012). Given that there are thousands of licensed pumps extracting water from rivers of the MDB, the cumulative effect of entrainment on fish populations is potentially large. For example, it is conservatively predicted that up to two million fish per year may be removed across the northern portion of the MDB in New South Wales (NSW) alone (Boys *et al*. 2021). This includes the greater Macquarie catchment, which is an important agricultural region supporting growth of food and fibre (including cotton), which is dependent on irrigation (Green *et al*. 2011; Steinfeld *et al*. 2020). Irrigation not only leads to a net loss of flow within the catchment (Herron *et al*. 2002), it also results in the direct entrainment of native fish species (Baumgartner & Boys 2012; Boys *et al*. 2021). Furthermore the entrainment of other aquatic organisms and debris can clog pumps and sprinklers, resulting in increased maintenance and economic consequences.

To mitigate declining populations of native fish, millions of hatchery-bred fish are released into the MDB every year (Forbes *et al*. 2015). This serves both recreational fishing purposes, as well as conservation objectives (Gillanders *et al*. 2006; Lyon *et al*. 2012; Victorian Fisheries Authority 2022). In the 2020/2021 season, the Victorian Fisheries Authority stocked more than seven million native freshwater fish, including more than 2.5 million Murray Cod *(Maccullochella peelii)* known by the local Wiradjuri People as Gugabul, Gudung, Munyaa and Mungi (Mitchell, 1838) across 120 sites (Victorian Fisheries Authority 2022). Almost a third of all these native fish (1.9 million) were stocked in rivers or creeks. In the same year, NSW hatcheries stocked over five million freshwater fish, including more than 1.3 million Murray Cod in NSW waterways (NSW DPI 2021). These stocked Murray Cod may be susceptible to entrainment at pump intakes and irrigation diversions (Bretzel *et al*. 2023), though this has yet to be confirmed. Fish losses into irrigation pump intakes have been the subject of several studies in Australia and internationally (Poizat *et al*. 1999; Baumgartner *et al*. 2009; Boys *et al*. 2013). However, comparatively little research has been conducted worldwide to assess the effect of irrigation pumps on hatchery-bred fish stocked into rivers. Here we examine data collected as part of a long-term study quantifying fish losses (Bretzel *et al*., under review) at two major irrigation pump intakes on the Macquarie River between 2020 and 2021. During routine sampling there was an abrupt increase in the number of juvenile Murray Cod of a similar size range in the pumped water. This coincided with stocking events 24 h prior upstream of the two pump intakes. We hypothesised that the increased numbers of juvenile Murray Cod entrained during two of the sampling events was due to the nearby stocking events. We tested this hypothesis by conducting genetic parentage analysis of entrained fish to determine if they were of hatchery origin.

Methods

Study species

Murray Cod is an iconic species endemic to the MDB in Australia that is culturally important to Indigenous Peoples and forms the basis of a popular recreational freshwater fishery (Humphries 2023). The species has declined since European settlement and is listed as 'Vulnerable' under the Federal *Environment Protection and Biodiversity Conservation Act 1999* and listed as 'Endangered' under the *Flora and Fauna Guarantee Act 1988* (Victoria). Their decline was due to a combination of factors including overfishing, river regulation, and competition with invasive species (Rowland 2005; Todd *et al*. 2005; Ingram *et al*. 2011). Murray Cod are also susceptible to entrainment at water diversions during different life stages (Koehn & Harrington 2005; Baumgartner & Boys 2012; Boys *et al*. 2012), which has the potential to effect recruitment success. Murray Cod have been stocked into rivers across the MDB to support depleted populations and to create recreational fishing opportunities (Rowland 2005; Ingram *et al*. 2011). In some cases, these stocking activities have contributed to an increase in Murray Cod abundances and distribution and are vital to the maintenance of the population in some impoundments (Forbes *et al*. 2015).

Study river

The Macquarie–Wambuul River (hereafter Macquarie River) is a major river of the MDB. It originates in the Great Dividing Range and flows northwest across central west NSW, passing through or near towns including Bathurst, Dubbo, Narromine and Warren before entering the Macquarie Marshes and draining into the Barwon

River upstream of Brewarrina. The sampled reach of the river supports the largest amount of irrigation within the Macquarie River, with this irrigation development established following the construction of Burrendong Dam in 1970 (Green *et al*. 2011). The flows of the Macquarie River are regulated by the release of water from Burrendong Dam for urban and agricultural water supply, flood mitigation and environmental flow delivery. The volume of extracted water from the Macquarie River is moderately high in comparison to other catchments in the MDB (CSIRO 2008). Intensive irrigated agriculture occurs between Narromine and Warren, where most of the regulated flow is extracted at several large pump intakes. Between 2019 and 2020, the total entitlement for water users in the regulated parts of the Macquarie River catchment (upstream and downstream of Burrendong dam) was about 725,000 ML (Department of Planning and Environment NSW, Macquarie Water Management Act – Available Water Determinations). Native fish populations have been negatively affected by river regulation in the Macquarie River (Stocks *et al*. 2021). Among several management actions implemented to help recover the native fish populations, stocking of over 309,000 Murray Cod and 313,000 Golden Perch (*Macquaria ambigua*) occurred in the Macquarie River catchment between 2010 and 2021 (DPI NSW).

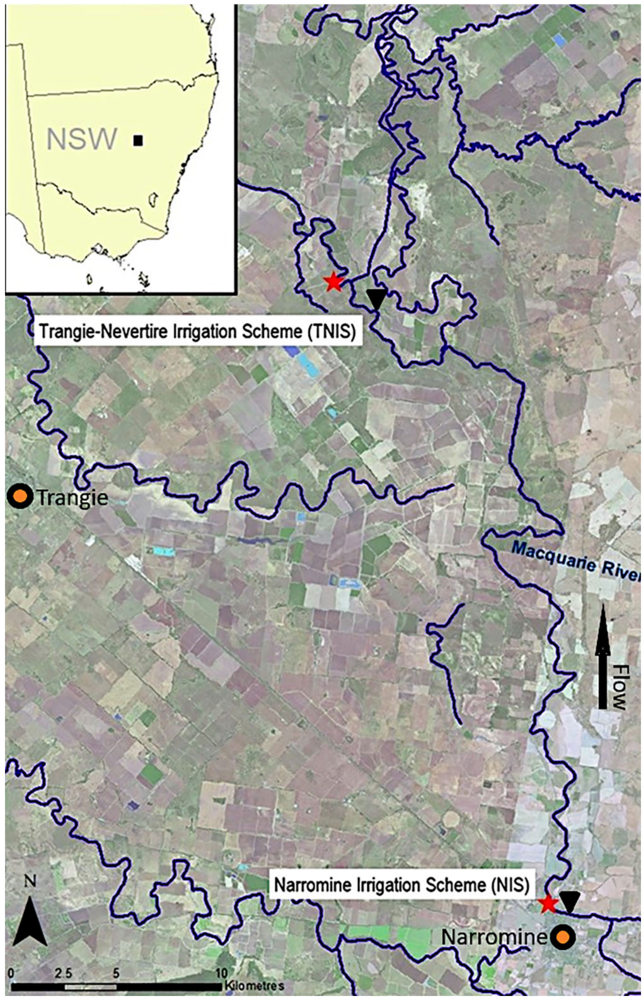

Figure 1. Location of both pump sites at the Macquarie River. The stars indicate the irrigation schemes, and the black triangles indicate the stocking sites.

Study sites

The study was conducted on Wiradjuri Country. Fish sampling was conducted within the irrigation channels of two major pump stations near the towns of Narromine and Trangie: the Narromine Irrigation Scheme (NIS) and the Trangie-Nevertire Irrigation Scheme (TNIS) (Fig. 1). The pumps are operated in response to water orders from farmers, typically running continuously for several days, regardless of the time of day or day of the week. The NIS pumps water from the river via eight electric pumps, which provide a combined maximum pumping capacity of about 1000 ML/day (narromineirrigation.com.au, accessed 6th March 2023). At the time of sampling the NIS pumps were operating at ~112 ML/day. The TNIS consists of five axial-flow pumps capable of pumping a maximum combined capacity of approximately 800 ML/day into the rubber-lined irrigation channel. At the time of sampling the pumps were operating at ~126 ML/day. The TNIS pumps were fitted with a 3 mm wedge wire, brushed-cone fish-protection screen installation. However, at the time of sampling, a flap at the front of the screen was removed, allowing flows and fish to bypass the screens and approach the pumps (Fig. 2). The bypassing of the screen aligned with the experimental design with randomly chosen 22 h blocks of screened and unscreened sampling, to evaluate the fish-protection screen for a study underway. At the pump intake locations along the Macquarie River, the morphology features steep riverbanks and deep pools. The reaches provide fish habitat such as logs and riparian vegetation. The pump intakes at NIS are located within the backwater area of a weir pool with a depth of >4 m and a river width of ~40 m bank-to-bank (depending on water level). At TNIS the depth of the intake/screen location is >2 and ~30 m bank-to-bank (depending on water level). During the sampling period, the Macquarie River had a mean flow rate of 2221.9 ML/day (range: 127.7–22541.9 ML/day; data from Gin Gin weir, Lat: -31.908266 Long: 148.091153, about 2.3 km downstream of TNIS pump station; Source: WaterNSW). Therefore, the pumps in

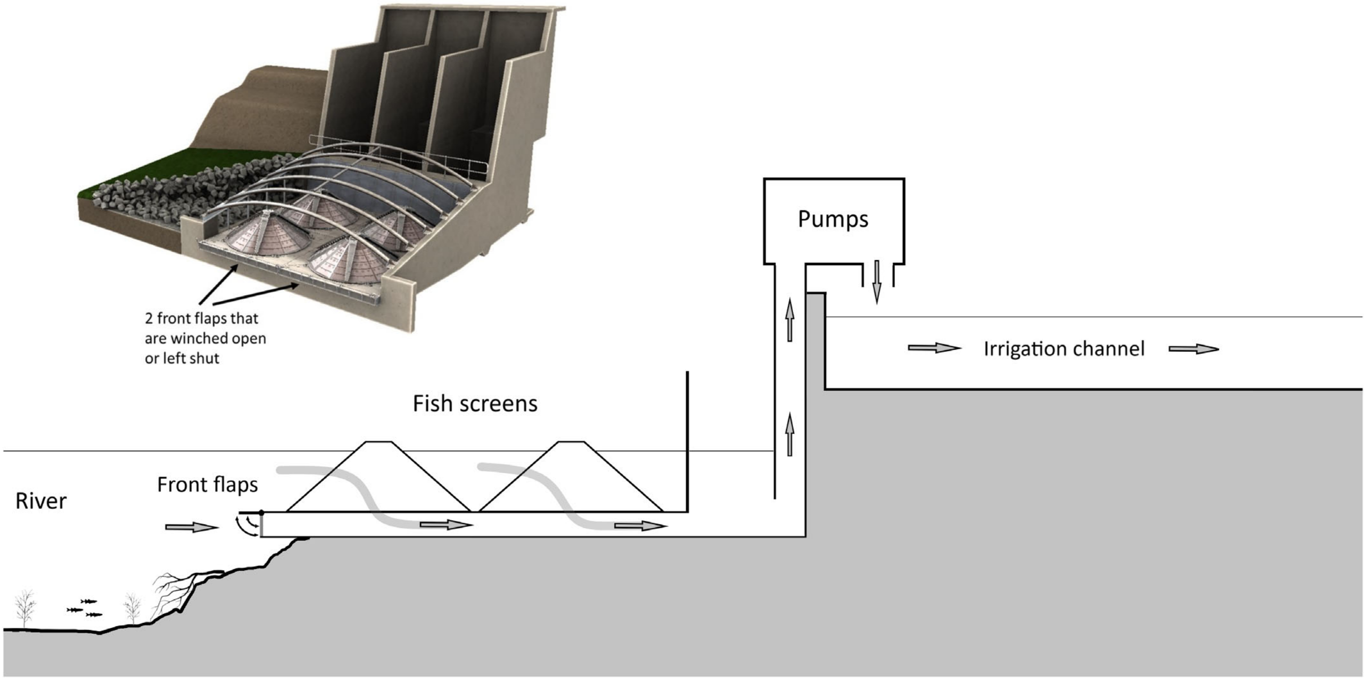

Figure 2. Schematic of the Trangie-Nevertire Irrigation Scheme (TNIS) pump intake including water flows at the pump location and the conical fish screens including the front flaps that were opened to inactivate the screen functionality during randomly chosen 22-h blocks (side perspective by J.B., Screen drawing by AWMA Water Control Solutions).

TNIS and NIS diverted an average of ~5–6% of the total discharge per day when operating during the sampling season.

Fish sampling

A 6 mm knotless mesh funnel-shaped fyke net (15 m × 20 m × 3 m, 6 mm mesh) with a cod end was set across each irrigation channel, approximately 50 m downstream of the pump outlets, facing the pump. Each net was custom-made to ensure it fitted the cross-sectional shape of the irrigation channel and filtered 100% of the flow. At NIS, the net was set from Monday (deployed at 17:00) to Thursday (removed at approximately 17:00) for a total of 20 sampling days between 7th December 2020 and the 18th February 2021 (Fig. 3a). At TNIS, the net was set from Monday (deployed at 17:00) to Friday (removed at ~08:00) each sampling week between the 23rd of November and 3rd of March 2021. The fish-protection screen at TNIS was either in operation (excluding fish) or bypassed (allowing fish to enter, referred hereafter as removed). At TNIS the screen was removed for 16 × 22 h sampling blocks and the screen was in operation for 19 × 22 h sampling blocks (Fig. 3b). At both sites, nets were cleared (i.e., fish caught in the net were removed from the cod end, identified and measured) at least twice daily: in the morning (~08:00) and in the afternoon (~16:00, or in TNIS, when a 22 h block ended). All fish sampled in the fyke nets were measured to the nearest millimetre standard length (SL) and total length (TL) and live specimens were returned to the river if <30 mm TL. Murray Cod >30 mm TL were euthanised with AQUI-S® Versatile Aquatic Anaesthetic before being preserved in 70% ethanol for DNA analysis.

Murray Cod stocking coinciding with sampling

On the 15th December 2020, the New South Wales Department of Primary Industries (NSW DPI) stocked 1000 Murray Cod sourced from the Narrandera Fisheries Centre and at a private hatchery at the Narromine Boat Ramp (−32.22573; 148.245399), approximately 1.1 km upstream of the NIS intake. On the 11th January 2021, NSW DPI also stocked 1500 Murray Cod at the Trangie Ski Hole, approximately 3.7 km upstream of the TNIS pump intakes (Fig. 1). The stocked juveniles had a mean total length of 43.5 mm (Matthew McLellan NSW DPI 2022, personal communication).

Genetic determination of hatchery reared fish

DNA extractions and Diversity Arrays Technology reduced representation sequencing (DArTseq) were performed according to the methods in Kilian *et al*. (2012). A total of 36 Murray Cod were analysed, which were randomly selected among all sampled Murray Cod >30 mm TL from the first (NIS, n = 23) or subsequent two (TNIS, n = 13) clearances after the stocking events. The sequences were analysed together with additional sequences from 474 hatchery brood stock that were collected as part of the FishGen project (Brauer & Beheregaray 2020). The FishGen project has been collecting fin clips from hatchery brood stock for 6 years to enable stocked fish to be identified through genetic parentage testing. Genetic information is available for an estimated ~90% of the brood fish used to produce the Murray Cod stocked into the Macquarie River. In

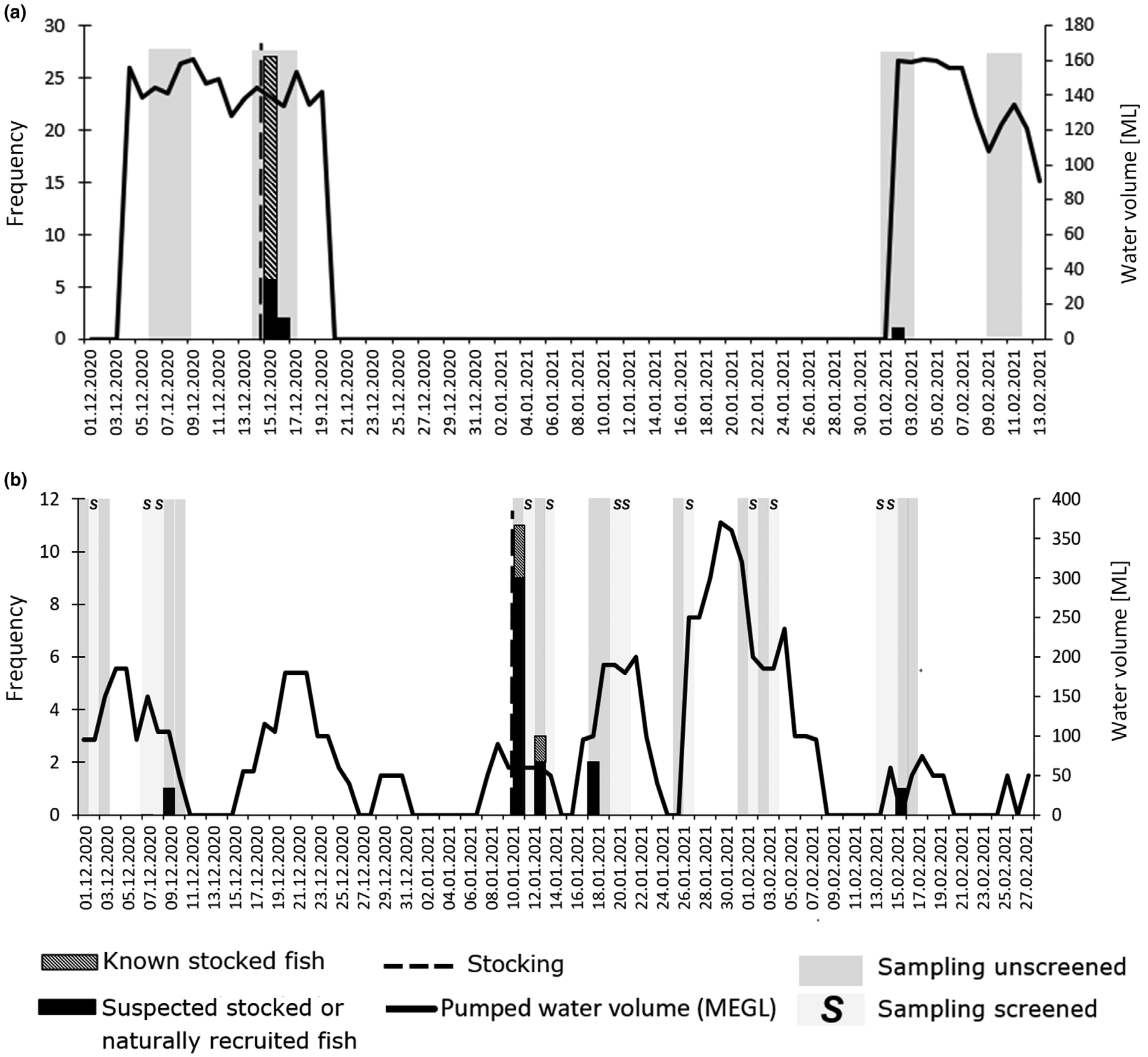

Figure 3. Number of juvenile Murray Cod >25 mm SL sampled in the (a) Narromine Irrigation Scheme (NIS) and (b) Trangie-Nevertire Irrigation Scheme (TNIS) irrigation channels during the sampled period/duration of data collection using fyke nets. The grey bars indicate when sampling was conducted. The fish screen in TNIS was operating occasionally and adjustment was changed in randomly chosen 22 h periods. During each 22-hour period, the fish screen in TNIS had two states: 'screened', indicated by light grey bars with an 'S,' when the front flaps of the screen were closed, and 'unscreened', indicated by dark grey bars when the front flaps were open. Murray Cod sampled after the stocking events without DNA parental kinship were suspected to be stocked due to size similarity and the timing of the sampling.

short, the DArTseq single nucleotide polymorphism (SNP) data were filtered to retain SNPs with a call rate of 100% and an average repeatability score of 100%. Filtering based on minor allele frequency (MAF) was performed separately for parentage (MAF = 0.1) and kinship (MAF = 0.01) analyses to optimize the data for each method. Parentage analyses were performed with 172 SNPs using the likelihood-based pedigree reconstruction software, Sequoia (Huisman 2017) and SNPPIT (Anderson 2010) to screen for parent-offspring relationships between the hatchery brood stock and wild-caught fish. The kinship coefficient (r^b) of Weir and Goudet (2017) was also estimated using 2612 SNPs to further examine relationships between samples.

Results

No juvenile Murray Cod were sampled at the TNIS when the screens were in

Table 1. Numerical distribution of sampled Murray Cod juveniles including the outcomes of the DNA parentage analysis in the Narromine Irrigation Scheme (NIS) and Trangie-Nevertire Irrigation Scheme (TNIS) Irrigation Channels during different sampling surveys in the irrigation season 2020/2021

Site	Sampled total [No]	0–24 h after stocking event [No]	24–72 h after stocking event [No]	DNA analysed [No]	Known stocked fish (one or two parents identified) [No]	Suspected stocked without DNA correlation [No]	Proportion tested/ DNA identified stocked fish [%]
TNIS	18	11	3	13	3	10	23.1
NIS	30	27	2	23	21	2	91.3

operation (Fig. 3b). Murray Cod adults and larvae were sampled at the TNIS but not the NIS. These were not included further in the study given their size excluded them from being stocked fish during the study period. There were 10 and 7 other fish species sampled at the NIS and TNIS respectively (Table 1).

Thirty juvenile Murray Cod were sampled from the NIS ranging in size from 26–43 mm SL with a mean SL of 34.45 ± 4.42 mm (Fig. 4). Twenty-seven were sampled on the morning of 16th December 2020 within 24 h after the stocking of 1000 Murray Cod 1.3 km upstream at the Narromine Boat Ramp. Two further Murray Cod were sampled within 48 h after the stocking event. A single juvenile (SL 43 mm) was sampled on February 2nd 2021, 49 days after stocking. During all other weeks, no Murray Cod of any life stage were sampled in the NIS (Fig. 3a).

Eighteen juvenile Murray Cod were sampled at the TNIS ranging in size from 32–47 mm SL. Sixteen juvenile Murray Cod >30 mm TL were sampled within 7 days after the stocking of 1500 Murray Cod 2.5 km upstream (Fig. 3b) and 11 were sampled within 24 h of stocking. Only two Murray Cod in this size range were sampled 33 days prior (34 mm SL) and 26 days after (47 mm SL) the stocking events. Standard length of the 16 entrained Murray Cod sampled after stocking ranged from 32 to 42 mm, with a mean length of 35.88 ± 2.52 mm (Fig. 5).

Genomic analyses were carried out on 23 and 13 Murray Cod sampled from the NIS and the TNIS respectively. Twenty-four fish (66.7% of all DNA analysed fish; TL mean: 40.29 ± 4.10 mm, Fig. 6) were stocked fish (91.3% and 23.1% at the NIS and the TNIS respectively). Of all individuals caught, at least 70% (NIS) and 17% (TNIS) were stocked fish. Twenty-two of these were assigned two hatchery parents and two were assigned to a single parent (Table S1). Results from both parentage methods were consistent with all 22 parent-offspring trios identified by both Sequoia and SNPPIT (Tables S1–S2). Of the remaining 12 samples (Mean TL: 41.42 ± 3.63 mm) not assigned parents, three pairs of at least half-sibling relationships were inferred among the samples.

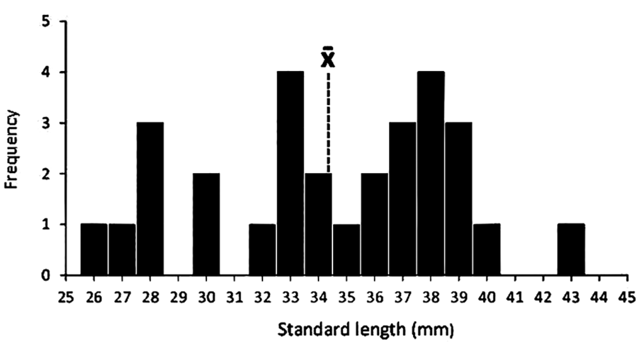

Figure 4. Standard length frequencies of Murray Cod (N = 29, one fish could not be measured because it was too damaged by the pumps) captured from a fyke net in the Narromine Irrigation Scheme (NIS) Irrigation Channel. The dashed line represents the mean length of all measured fish.

Discussion

Here we provide the first direct evidence that a notable proportion of recently stocked Murray Cod from an Australian river were entrained at pump intakes. This supports our hypothesis that Murray Cod stocked nearby pump intakes are susceptible to entrainment. This finding is consistent with some American studies which have shown entrainment of stocked salmonids at water diversions (Simpson & Ostrand 2012; Kowalski *et al.* 2022).

The hypothesis that the entrained juveniles were stocked fish was supported by the similarity in fish lengths among both the entrained and stocked specimens, along with the correlation of peak catch rates with stocking events in the river reach. Genetic parentage analysis confirmed that more than 66% of the genetically tested fish were stocked. These findings are likely conservative given that: (i) the majority of juvenile Murray Cod were sampled within 24 h of stocking, (ii) the size of the entrained fish was similar to the stocked fish and (iii) there were three sibling pairs among the 12 fish not assigned parents. The balance of evidence (i.e., the similarity in size, the timing of the sampling and the lack of other juvenile fish being caught at other sampling times) strongly suggests that those fingerlings without high kinship with any stocked fish were also stocked but that the hatchery parents were not in the database. This is a feasible explanation given that ~10% of the hatchery broodfish are yet to have genetic data collected. Therefore, based on the total number of fish stocked per site, entrainment rates ranged from approximately 1% to 3% of the total number of fish stocked within 24 h of release.

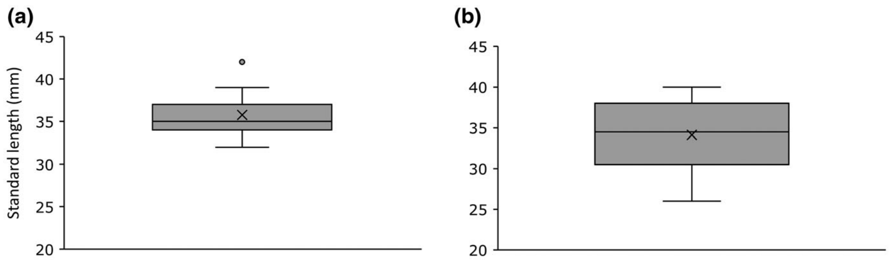

Figure 5. The standard length distribution of all sampled measured Murray Cod sampled within 1 week after stocking at the (a) Trangie-Nevertire Irrigation Scheme (TNIS) and (b) Narromine Irrigation Scheme (NIS) irrigation channel.

Alternatively, if the fish were of wild origin, the proportion of stocked fish is still high and indicates stocking in close proximity to pump inlets poses a risk of entrainment.

The presence of stocked Murray Cod at the TNIS indicates juvenile Murray Cod moved at least 3.7 km downstream from their stocking location. These were likely to be deliberate movements (i.e. not passively drifting downstream) given both stocking sites were located within slow-flowing reaches of the river, with no areas of high current (riffles or runs) between the stocking sites and the intakes, and moderate river discharge (mean flow 2169.7 and 1186.4 ML/day for TNIS and NIS, respectively, measured at Gin Gin weir; Source: Water NSW). Downstream dispersal after stocking has been reported for other hatchery-reared fishes, including juvenile Rainbow Trout (*Oncorhynchus mykiss*) (Bettinger & Bettoli 2002) and subadult Trout Cod (*Maccullochella macquariensis*) (Ebner *et al*. 2006, 2007). It is therefore possible other stocked species exhibiting similar behaviour may also be susceptible to entrainment.

There were differences in the proportion of stocked fish detected at the two sites, with more stocked fish detected at the NIS where the stocking site was closer. However, it is not possible to definitively attribute this solely to the distance to the stocking site based on the data presented here. Previous studies using release-recapture experiments have demonstrated a high variability in entrainment rates at diversions (Gale *et al*. 2008; Bretzel *et al*. 2023). Therefore, we recommend further international research on the entrainment of stocked fish at screened and unscreened intakes. Specifically, for stocked Murray Cod, additional research is necessary to explore their dispersal behaviour upon release into their new environment and the distances they may move in the first critical weeks post-release. This information will provide insights into how far they should be released from pump intakes to minimize the risk of entrainment.

Stocking is an internationally applied management tool to support fish populations around the globe (Cochran-Biederman *et al*. 2015) and with some endangered species largely depending on stocking for their continued survival (Williot *et al*. 2009; Todd *et al*. 2017). While not all fish stocked in the MDB may be susceptible to entrainment, stocking native fish in general requires significant financial investment from entities such as hatcheries, government agencies or recreational fisheries. The loss of even a relatively small percentage of stocked fish at pump intakes represents wasted investment. Furthermore, the loss of Murray Cod in the Macquarie River may also apply to other stocked native species including Trout Cod and Golden Perch. In 2021 and 2022 NSW DPI stocked over 104,000 Golden Perch juveniles in the Macquarie River (Matthew McLellan, DPI NSW 2022 personal communication). About 8000 of these juveniles were stocked at both investigated sites each immediately after our sampling was conducted (on the 9th March 2021,

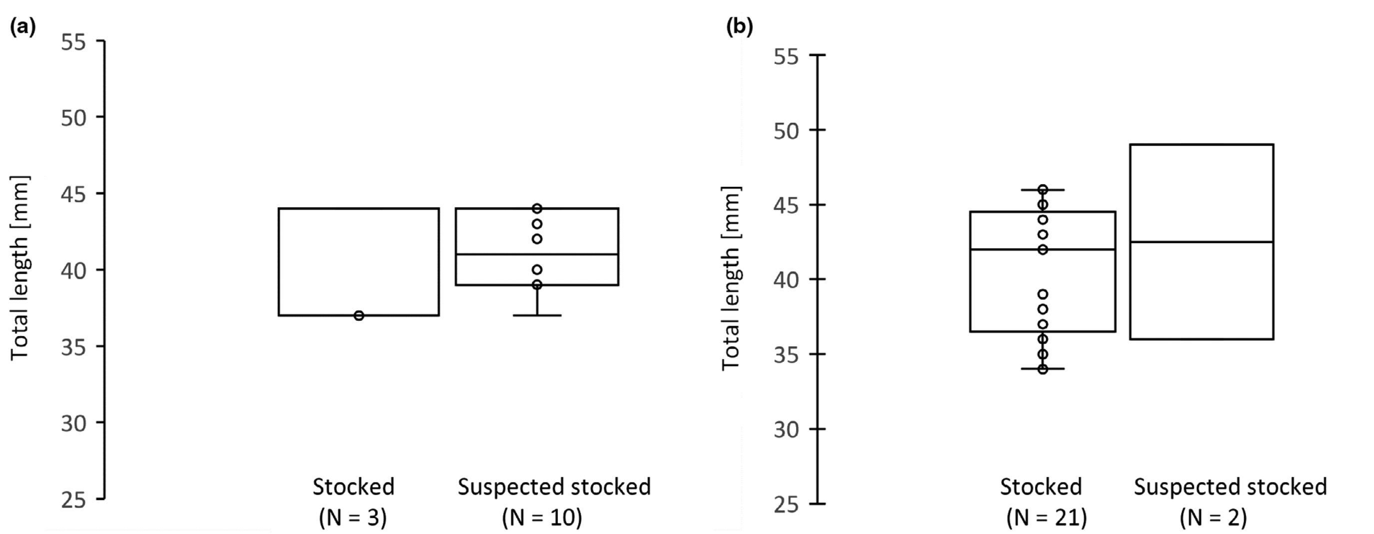

Figure 6. The total length distribution of all DNA analysed Murray Cod sampled within 1 week after stocking at the (a) Trangie-Nevertire Irrigation Scheme (TNIS) and the (b) Narromine Irrigation Scheme (NIS) irrigation channel.

NSW DPI). Between 2009 and 2017 more than 160,000 endangered Trout Cod were stocked in the Macquarie River. Stocking can have variable outcomes on fish populations (Crook *et al*. 2015; Forbes *et al*. 2015). For example, stocking can contribute to successful threatened species recovery (Koehn *et al*. 2013), however, other recent studies have questioned the relative contribution that stocking can make to ecosystem recovery when compared to other rehabilitation methods (Radinger *et al*. 2023; Terui *et al*. 2023). Earlier studies have suggested that entrainment could affect stocking outcomes wherever water is abstracted (Gale *et al*. 2008; Bretzel *et al*. 2023). If stocking is to play a role in assisting with the recovery of fish populations, while boosting recreational fishing opportunities, measures need to be taken to ensure its effectiveness.

There are a number of potential options to prevent the loss of stocked fish at pump intakes: (i) not operating irrigation pumps during the stocking season; (ii) not releasing fish during the peak irrigation season; (iii) not releasing fish within the vicinity of pump intakes; or (iv) installing modern fish-protection screens on pump intakes. The first option is not viable given the stocking period coincides with the peak irrigation season and an interruption in water supply will impact agricultural production. The second option is not viable because, like many other species, stocked Murray Cod are raised in ponds until they have exhausted the natural food supply – they are not raised on artificial pellets. If hatcheries were to stock older fish to avoid the peak irrigation season this introduces additional logistical challenges including size grading and conditioning to an artificial diet. Moreover, the longer fish are kept in hatcheries, the more they are adapted to captivity (Brown & Day 2002; Koehn & Harrington 2006; Crook *et al*. 2015). Option three may be a viable solution for reaches where no water is pumped, but this would not address the general problem of entrainment over the long term and for wild fish. The fourth approach – to install modern fish-protection screens on pumps is a potential solution. Screens like the one that is installed at TNIS (Fig. 2) (but bypassed at the time we captured all entrained Murray Cod juveniles), reduce the approach velocity at the pump intake, and act as physical barrier directing fish away from the structure (Moyle & Israel 2005; Baumgartner & Boys 2012; Walters *et al*. 2012). No stocked Murray Cod were sampled during any screened operations at TNIS. Other screen installations have been shown to protect stocked individuals of Murray Cod, as well as reduce entrainment of wild fish significantly (Boys *et al*. 2021; Bretzel *et al*. 2023). Further research should determine the extent to which fish screens can improve reduce entrainment of stocked fish on a large scale and compare these to other management options.

Our study identifies that fish entrainment at pump intakes has the potential to reduce the effectiveness of stocking efforts. The investigated pumps were, on average, only operating at less than 20% of their maximum capacity during the sampling period. The large number of pumps in the MDB may exert cumulative influences across whole reaches of rivers (Boys *et al*. 2021). Between the townships of Narromine and Warren are ~110 licensed surface water pumps (between 38 mm and 915 mm diameter) over a 130 km reach of river not including the large number of smaller, privately-owned pumps (source: DPIE water surface water licence database). Avoiding stocking fish near intakes presents a direct strategy to address this concern. For locations where this is not practical, the use of modern fish-protection screens offers a viable solution to protect both stocked and naturally recruited fish from entrainment, improving native fish recruitment and aiding the recovery of native fish species. Neglecting this issue not only affects stocking efforts but also poses a possible threat to resident fish communities. Thus, it is imperative to take proactive measures to mitigate the impact of entrainment.

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Conflict of Interest

All authors declare that they have no conflicts of interest and that the manuscript has not concurrently been submitted to another outlet for publication.

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Supporting Information

Additional supporting information can be found in the following online files.

Table S1. Parent-offspring assignments based on 172 SNPs using SEQUOIA.

Table S2. Parent-offspring trios assigned based on 172 SNPs using SNPPIT at a false discovery rate (FDR) of 0.1.