A preliminary risk assessment for stocking Giant trevally and Bigeye trevally in tropical and sub-tropical impoundments

Queensland Government

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The Department of Agriculture and Fisheries proudly acknowledges all First Nations peoples (Aboriginal peoples and Torres Strait Islanders) and the Traditional Owners and Custodians of the country on which we live and work. We acknowledge their continuing connection to land, waters and culture and commit to ongoing reconciliation. We pay our respect to their Elders past, present and emerging.

Contents

Background **4**
The value of stocked impoundment fisheries in Queensland **5**
Past research into impoundment fish stocking in Queensland **5**
Current state of Fisheries in near-coastal tropical and sub-tropical impoundments Queensland **6**
Potential advantages of stocking trevally **7**
- Fast growth 7
- Rapid swimming speeds 7
- Popularity with anglers 7

Trevally Risk assessment **8**
- Adaptability to freshwater 8
- Cold tolerance 9
- Catchability in freshwater 10
- Genetics 10
- Disease risk 11
- Threat to rare and threatened species (running upstream) 12
- Capacity of impoundments to support a population of trevally 13
- Loss over the dam wall downstream 13

Conclusions **14**

List of figures

Figure 1: Large Giant Trevally electrofished in freshwater in north Queensland. 9

Background

Prior to 1986, fish stocking in Queensland was rare and primarily research driven. Species such as Saratoga, Silver Perch, Sleepy Cod and Sooty Grunter were bred and distributed to various waters to evaluate survival and potential for establishment (Hamlyn 1998). In 1986, the Queensland government, with support from recreational fishing groups, began the Recreational Freshwater Fishing Enhancement Program. The focus of this program was to develop new fisheries in impounded waters.

Prior to the enhancement program, most impoundments contained species of only limited interest to anglers (Hamlyn 1998). The impoundments prevented upstream passage of important diadromous recreational fishing species, such as Australian Bass and Barramundi, and in many impoundments, conditions were not suitable for regular natural recruitment of riverine species such as Golden Perch, Silver Perch and Murray Cod.

Species stocked in the first 12 years of the program included Australian Bass, Golden Perch, Mary River Cod, Murray Cod, Silver Perch, Southern Saratoga, Barramundi, Sooty Grunter and Snub-nosed Garfish (Hollaway 1998). In the early part of this program, species were not always stocked within their natural range. For example, Murray-Darling strain Golden Perch were stocked east of the Great Dividing Range into south-eastern Queensland impoundments. Silver Perch were also stocked east of the Great Dividing Range and Southern Saratoga (native to the Fitzroy Basin) were stocked in impoundments in coastal catchments south of the Fitzroy Basin. Murray Cod were stocked in Boondooma Dam in the Burnett River catchment and into Fairbairn Dam in the Fitzroy-Dawson Rivers catchment. Murray Cod were also stocked into the Cooper Creek catchment in the Lake Eyre Basin (Hollaway 1998). Stocking Murray Cod outside its natural range is now considered inappropriate and no such further stockings of Murray Cod are permitted (Hollaway 1998). However, it appears that self-sustaining Murray Cod populations may have established upstream and downstream of Fairbairn Dam.

Queensland now has a translocation protocol which endeavours to ensure that most species of fish are only stocked within their natural range. The protocol not only applies to species of fish, but also to genetic strains within a species. Translocations are strictly controlled to prevent irreversible damage to native fish communities. New translocations will only be considered if there is very good evidence that the risks are minimal, and preference is given to species that cannot reproduce in their new environment so that such translocations can be reversible (Jackson 1998). Under this policy some historical translocations such as Southern Saratoga, Golden Perch and Silver Perch into south-eastern Queensland impoundments have been permitted to continue (Jackson 1998), but virtually all other translocations have been stopped.

There is still interest in further diversifying impoundment fisheries in Queensland through stocking, but the species being considered are all primarily euryhaline or diadromous species that can live in freshwater but require access to seawater to breed. Diversification options are largely restricted to near coastal impoundments that would have occurred within the natural range of these species. Suggested new species have included Jungle Perch *Kuhlia rupestris,* Mangrove Jack *Lutjanus argentimaculatus*, Bigeye Trevally *Caranx sexfasciatus* and Giant Trevally *Caranx ignobilis*. Of these species only Mangrove Jack have been trialled in any impoundments to date. The development of this fishery has been hampered by the limited number of fingerlings produced by hatcheries.

For a new species to become permitted for use in the recreational fish stocking program it must be demonstrated to be of low risk to the receiving environment and existing fishery in the impoundment. The species must also be demonstrated to produce a viable fishery within the impoundment. Meeting these requirements necessitates both desk top assessment and field-based research. Stocking trials for a risk assessment are planned for Jungle Perch in south-eastern Queensland and stocking trials (this study) are being planned for Giant Trevally and Bigeye Trevally in sub-tropical central Queensland and in tropical north Queensland. This document comprises the desk top based risk assessment component for the two trevally species. It also provides some context as to why these species are being considered for Queensland Impoundments.

The value of stocked impoundment fisheries in Queensland

Many recreational species do not naturally recruit in impoundments, either because the dam walls block their spawning migration routes, or because they require flowing water for breeding. Therefore, on-going stocking is required to maintain the fishery. However, impoundments can produce exceptionally fast-growing fish and very productive fisheries.

There are at least 80 stocked waters in Queensland; primarily large impoundments and weir pools. Stocking is organised through more than 70 community-based fish stocking groups. These groups have stocking plans that are reviewed and approved by Fisheries Queensland. Fish stocking groups raise funds for fish stocking, and additional funding is sourced through the Stocked Impoundment Permit Scheme (SIPS) (Queensland Dept of Agriculture and Fisheries 2023 Stocked Impoundment Permit Scheme working group | Department of Agriculture and Fisheries, Queensland (daf.qld.gov.au)). Sixty-three impoundments receive funding through SIPS, whereby a permit is required to fish in the stocked waters covered under the scheme. In 2020-21 SIPS raised $1,168,156 for stocking activities (Queensland Dept of Agriculture and Fisheries 2022 SIPS 2020-2021 financial summary | Department of Agriculture and Fisheries, Queensland (daf.qld.gov.au)).

The impoundment fish stocking program in Queensland has been highly successful and provided both social and economic benefits to various regions of Queensland. A study by Hamlyn and Beattie (1993) at Lake Leslie, near Warwick in the northern Murray-Darling Basin found that for every dollar spent on stocking fish, $18 was spent in the local community by tourist anglers. Rutledge *et al*. (1990) found that for every dollar invested into the stocking program at Tinaroo Dam near Atherton, there was a return of $31 back to the local economy. A study by Rolfe *et al.* (2005) at three Queensland impoundments (two in the south Burnett region and one in central Queensland) showed annual expenditure by fishers at each of the three impoundments was between $0.95 million and $1.47 million, with most expenditure being into the local economy. Total economic value of fishing at each of the three dams was estimated to be $1.07 million, $3.2 million and $4.54 million. A study by Gregg and Rolfe (2013) estimated the total annual economic value of recreational fishing at 31 SIP dams in 2013 to be $95.3 million. There have not been any more recent studies on the economic value of Queensland impoundments, but in 2023 the total value of SIP dams can be expected to be considerably higher than the 2013 figure.

Giant Trevally and Bigeye Trevally are both highly rated sportfish. It is thought that by adding these species to selected Queensland Impoundments there is potential to further increase the economic value of stocked impoundments by attracting more tourist anglers to central and north Queensland, and at the same time providing a benefit for local anglers.

Past research into impoundment fish stocking in Queensland

There has been significant research completed on stocked impoundment fisheries in Queensland that has contributed to the development and enhancement of these fisheries. Hutchison *et al*. (2006) evaluated the effect of stocking size on stocking success for four species of stocked fish. They also investigated effects of different predators, release locations and water levels in the impoundments at the time of stocking on relative survival of stocked fingerlings. This work led to substantial improvements in the post-release survival of fingerlings and thus the cost-effectiveness of stocking. Application of this research was particularly beneficial to the Barramundi stocked impoundment fishery, when stocking of Barramundi fingerlings switched from <20 mm total length (TL) to >50 mm TL. Further work by McDougal *et al*. (2008) demonstrated that in impoundments dominated by high numbers of large Barramundi, recruitment of stocked Barramundi fingerlings became poor. It is now recognised that in such impoundments, stocking of 30 cm Barramundi is more cost effective and leads to better results (Malcolm Pearce, Fisheries Manager DAF pers. com.). Similarly, Hutchison *et al*. (2006) provided circumstantial evidence that recruitment of Australian Bass fingerlings to the fishery is problematic when large Barramundi are plentiful. They attributed this to the slow growth of Australian Bass, leaving them particularly susceptible to predation by Barramundi.

Other than optimal size at release to minimise predation, conditioning to predators has also been investigated. Exposure of Murray Cod fingerlings to predators prior to stocking was shown to double post-release survival compared to predator-naïve fingerlings (Hutchison *et al*. 2023). It is possible that this technique may also advantage other stocked fingerling species.

Russell *et al*. (2009) investigated impacts of stocking Barramundi in impoundments and rivers in the wet tropics of Queensland. This work showed that Barramundi showed no inclination to move upstream into smaller tributary streams where they would be more likely to encounter or impact on prey species that are of conservation significance. Juvenile Barramundi stocked into Tinaroo Falls Dam mostly moved away from tributary streams and into the main body of the dam.

During flood events it is possible for Barramundi to escape from some impoundments into riverine areas downstream. Russell *et al*. (2009) found no evidence of loss of genetic diversity in the Johnstone River catchment because of stocking, but suggested increased stocking densities in other areas could provide different results. They also suggested a need to develop and implement appropriate hatchery protocols to ensure the future genetic viability of Barramundi fisheries in Queensland. Leahy *et al*. (2022) found that in the dry tropics of Queensland, stocked fish made up only 3% of the downstream fishery, but hatchery ancestry was detected in 21% of the catch. According to Leahy *et al*. (2022), the strong representation of hatchery ancestry highlights the importance of stocking regulations to support local genetic diversity and evolutionary traits.

Another key area of research investigated whether habitat enhancement could improve fishing in impoundments. Norris *et al*. (2020) examined the response of barramundi to the introduction of 197 durable (mostly PVC) Fish Attracting Structures (FAS) placed into open water sites in Kinchant Dam near Mackay. Electrofishing catch rates for Barramundi around the introduced structures was much higher than in sites with no structure and not significantly different to catch rates around existing dam infrastructure (e.g., dam rock walls which were closed to anglers), or from around weed beds (difficult for anglers to fish). The results indicated FAS attracted Barramundi in similar proportions to existing complex habitat in the dam. Catch rates of Barramundi almost tripled at intervention sites where FAS were installed, compared to control open water sites. The work provided evidence that fish might be able to be drawn to areas where it is easier and more desirable for anglers to target fish in an impoundment.

In similar work in south-eastern Queensland, use of 576 timber and PVC FAS by Australian Bass and Golden Perch was investigated. Acoustic telemetry suggested that FAS created new hotspots for both species of fish. There was an upward trend in angler catch rates post-introduction of FAS and an improved perception of the fishery by anglers (Norris *et al*. 2021).

Habitat enhancement work has also been completed in a northern Murray-Darling Basin impoundment to improve a Murray Cod fishery. A total of 346 habitat sites that combined concrete culverts with piles of rock were installed in Leslie Dam. The structures included 700 culverts and over 1,500 tonnes of rock. This work has not yet been formally published, but anecdotal evidence suggests that Murray Cod are using the installed structures, and the structures may be improving survival of stocked cod fingerlings. An electrofishing survey has noted Murray Cod and Golden Perch around these structures (Greg Ringwood DCCEEW, pers comm.).

All the above research has led to improvements in the quality and sustainability of impoundment fisheries in Queensland. Further enhancements could be provided through diversification of existing fisheries.

Norris and Hutchison (2023) reviewed stock enhancement practices in Australia and around the world. This included a review of both habitat enhancement and rehabilitation, and stocking. Norris and Hutchison (2023) found that the mobility and dispersal of the released organism and the connectivity of the stocked environment, both appear to play a significant role in the success and economic feasibility of stocking programs. The best results were reported for closed systems such as impoundments. Therefore, diversification via stocking is most likely to be successful in impounded waterbodies.

Current state of fisheries in near-coastal tropical and sub-tropical impoundments Queensland

Impoundments within 50 km of the coast and less than 100 m above sea level north of Bundaberg are generally dominated by stocked Barramundi fisheries. Although Sooty Grunter may have also been stocked into some of these waters, they are generally present in very low abundance. It is likely predation of Sooty

Grunter fingerlings and sub-adults by Barramundi may be suppressing their numbers. Therefore, the Barramundi dominated near-coastal subtropical and tropical impoundments do not offer diverse angling options. In contrast, impoundments south of Bundaberg (both near-coastal and inland), generally contain between three and six recreational fishing species. Barramundi impoundment fisheries are popular, but these waters have the potential to become even more attractive to anglers and more economically beneficial by expanding fishing experiences available through diversification. Within Australia, freshwater Barramundi fishing is not unique to Queensland. Providing more diverse options could tip the balance in favour of anglers to visit Queensland for their tropical freshwater fishing experiences.

Potential advantages of stocking trevally

Fast growth

Both Bigeye Trevally and Giant Trevally are known to be fast growing. Juvenile Bigeye Trevally of 50 to 85 g, fed 6 to 8% of their body weight, have been reported to attain 300-450 g in 150-180 days in cages on the West coast of India (Rajesh *et al*. 2015). Another study of Bigeye Trevally recorded daily growth rates of 1% for fish fed trash fish mixed with corn oil at a rate of 10-15% their bodyweight per day (Parantu *et al*. 2020). Giant Trevally fed at a rate of 10% of their bodyweight increased in weight from 19 g to 213 g in 10 weeks (Pattipeiluhu *et al*. 2021). Juvenile Giant Trevally fed twice a day to satiation had specific growth rates per day ranging from 3.44% to 4.05% depending on the type of feed used (Nguyen *et al*. 2022). In Kochi, Kerala, India, Giant Trevally stocked in cages at 6 cm (TL) reached a mean body weight of 1.388 kg in 9 months. Fish were fed 15-20% of their biomass for 7 days and then the feed rate was gradually reduced to 3-4% (Kappen *et al*. 2018). Wild male Giant Trevally in Hawaii reached maturity and 465 mm fork length (FL) in 2.8 years and females reached 594 mm FL and maturity in 4.4 years (Pardee *et al*. 2021). Abdussamad *et al*. (2008) estimated that Giant Trevally in Bangladesh reach 73 cm in length and 5.5 kg in weight in 12 months. The growth of the wild Hawaiian fish is slower than reported for captive Giant Trevally and wild fish in Bangladesh, but growth rates can vary depending on food availability and temperature. Fish growth rates in impoundments can be rapid due to the high prevalence of prey. For example, Barramundi growth rates in Tinaroo Dam are much faster than those of lower riverine Barramundi (Russell *et al*. 2015).

Having a rapid growth rate is advantageous for a fish that is to be stocked into a Barramundi dam. Fast growing fish will be vulnerable to predation for a shorter time-period than slow growing species like Australian Bass or Sooty Grunter. It is also more cost effective for hatcheries to rear fast growing fish to a larger size for stocking. Thus, it may be feasible to rear trevally to 100 or 150 mm for stocking, whereas this may not be feasible for Sooty Grunter or Jungle Perch *Kuhlia rupestris*. Barramundi, which also have a fast growth rate, are currently the only species reared beyond fingerling size for stocking into Queensland waterways. Another advantage of fast growth rates is that stocked fish will quickly reach angling size, perhaps within a year of stocking.

Rapid swimming speeds

Juvenile trevallies are also known to have fast swimming speeds, and this could be advantageous to escape predation. Young Giant Trevally of 16.5 mm standard length (SL) recorded a critical swimming speed of 40 cm s^{-1}. For each millimetre increase in standard length, critical swimming speed increased by 2.7 cm s^{-1} (Leis *et al*. 2006). We expect to stock Giant Trevally and Bigeye Trevally at sizes larger than 50 mm TL, so swimming speeds of stocked fish can be expected to be much faster. The trevally species Green Jack *C. caballus* with a mean size of 22 cm FL has been reported to have a maximum sustained speed (over 30 min) of 99.4 ± 14.4 cm s^{-1} and a mean critical speed of 102.5 ± 13.7 cm s^{-1} (Dixon *et al*. 2012). Although not the same species as the trevallies proposed for stocking trials, all these species have similar body morphologies, thus swimming speeds can be expected to be comparable at similar sizes.

Popularity with anglers

Both Bigeye Trevally and Giant Trevally are recognised as great sportfish by anglers, both within Australia and internationally (Diggles 2014, Diggles 2016). Giant Trevally have a large following among anglers, with some fishers willing to invest substantial financial resources to target these fish (Diggles 2014). As both these trevally species have high recognition and popularity among anglers there is a high probability that a successful stocking program using one or both species into Barramundi dominated impoundments will attract more anglers to fish those waters from intrastate, interstate, and international locations.

Trevally Risk assessment

Before new species are widely stocked, it is important to evaluate the risk of such an investment, both for feasibility and potential environmental risks. There needs to be confidence that a new stocking program can create a viable fishery that is of minimal risk to the environment and existing fisheries at the same location. Some elements of a risk assessment can be answered reasonably from a desk top study, whereas other elements may require field trials. In the risk assessment below, we tackle those questions that can be reasonably answered from available published information and flag those areas that require field assessment (the basis of this current project). Given that both Giant Trevally and Bigeye Trevally cannot breed in impoundments, any negative impacts detected in a stocking trial will be reversible through cessation of stocking and fishing down the stocked population.

Basic questions regarding feasibility include how well adapted to freshwater the two trevally species are, are they be able to overwinter in the stocked impoundments, and will they be catchable in freshwater. Potential risks include genetic swamping, or dilution (which ycould occur if stocked fish mix with wild conspecifics downstream), introducing a disease to the impoundment through stocking of a new species, predation of rare and threatened species (especially if trevally run upstream into small tributary streams), and the risk that trevally could significantly reduce the number of prey species in the dam, with consequent impacts on the carrying capacity of the impoundment for both trevallies and existing Barramundi fisheries. All these issues are addressed below.

Adaptability to freshwater

Many people ask the question, can Giant Trevally and Bigeye Trevally really live in freshwater? A common perception is that these are strictly marine species. In fact, several species of trevally are known to enter freshwater, including Bigeye Trevally, Giant Trevally, Brassy Trevally *C. papuensis* (all Indo Pacific Species) and the Atlantic species Crevalle Jack *C. hippos*.

Allen *et al*. (2002) lists Bigeye Trevally as occurring in freshwater rivers in northern Australia. In Australia Bigeye Trevally have been caught by anglers in freshwater billabongs (Bodeker 1971) and in freshwater rivers during electrofishing surveys. The Queensland Long-term Monitoring program recorded Carangidae spp and Bigeye Trevally during electrofishing surveys of the freshwater reaches of several tropical Queensland rivers (Jebreen *et al*. 2002). Bigeye Trevally occur 200 to 300 km upstream in the Sepik River, Papua New Guinea (Allen 1991). Bigeye Trevally have also been recorded moving upstream through fishways on several rivers in Queensland (Andrew Berghuis, Aquatic Biopassage pers. com., Tim Marsden, Ausfish Passage, pers.com.). Freshwater adapted Bigeye Trevally are sold online through the freshwater aquarium trade and can be easily located via online searches. Sub-adult Bigeye Trevally and Giant Trevally 30-40 cm TL have previously been held in a freshwater tank for several months at the Deception Bay Fisheries Research Station, where they fed and grew normally (Queensland Department of Agriculture and Fisheries unpublished data). Therefore, there is ample evidence that Bigeye Trevally can live in freshwater.

Giant Trevally are also known to tolerate freshwater environments and are considered an ideal candidate species to investigate linkages between genotype and phenotype in the context of freshwater adaptation by marine fishes (Pickett *et al*. 2022). Giant Trevally have also been caught by anglers in freshwater in Australia. Several videos are available on-line of recreational fishers catching Giant Trevally in freshwater locations between the Gold Coast and Far North Queensland. The Queensland Department of Agriculture and Fisheries have also electrofished Giant Trevally in freshwater in tropical rivers, including one large specimen around 90 cm in total length (Figure 1) (Andrew McDougal, Fisheries Biologist Pers. Com.). Sub-adult Giant Trevally 30-40 cm TL were held in a 7,000 L freshwater tank for several months at Deception Bay Fisheries Research Station (Agriculture and Fisheries unpublished data). Giant Trevally are also sold through the aquarium trade as freshwater adapted fish. These can easily be found on-line, although some fish sold as Giant Trevally are misidentified Bigeye Trevally.

In the Philippines there is a semi-landlocked freshwater population of Giant Trevally. These fish live in the large (24,356 Ha) freshwater crater lake, Lake Taal (Willette and Padin 2014; Mutia *et al*. 2018; Torres and

Santos 2020). To spawn, Giant Trevally migrate downstream from the lake through an outlet river (Pansipit River) to reach the ocean and juveniles migrate back upstream into the lake (Villadolid 1937; Mercene and Alzona 1990; Alaira and Rebancos 2014). The lake is also used for freshwater cage culture of Giant Trevally (Alaira and Rebancos 2014). Large Giant Trevally are also known to make an annual migration into freshwater in the Mtentu River in South Africa as featured in a BBC Earth documentary https://www.mtentu.co.za/mtentu-river-king-fish . In common with Bigeye Trevally, there is ample evidence for the adaptation of Giant Trevally to survive in freshwater environments.

Figure 1: Large Giant Trevally electrofished in freshwater in north Queensland.

Cold tolerance

There is no published research on the lower thermal tolerances of both trevally species, but there are records of sea temperatures where these trevally have been recorded. For example, Bigeye Trevally are reported to occur in ocean areas ranging from 19.5 ºC to 31.5ºC (Reef Life Survey 2023a) and Giant Trevally have been reported from sea temperatures ranging from 16.8 ºC to 31.3ºC (Reef Life Survey 2023b). An acoustic tracking survey of Giant Trevally in the South China Sea recorded them in temperatures ranging from 21.5ºC to 35.4ºC (Chiang *et al*. 2023). Lower temperatures would not be expected since the South China Sea is in a tropical area. Both trevally species extend further south in marine-estuarine distribution on the east coast of Australia (Sydney) than Barramundi (Gold Coast, based on recent electrofishing results of the authors). Prevalence of both trevallies in freshwaters appears to be greater in tropical areas (authors' own observations), which suggests that the lower winter temperatures of inland waters compared to marine waters at the same latitude could be influencing their occurrence in freshwater in the southern part of their range. Giant Trevally and Bigeye Trevally are trapped in some brackish to freshwater lakes on the Gold Coast. They enter these lakes as juveniles through locks or grated tidal inlets, and eventually grow too large to exit through the grates. The mean winter temperatures recorded in these lakes is between 16ºC and 17ºC (Waltham and Connolly 2013), but there are no reports of what the lowest winter temperatures are in these lakes. According to local anglers, Giant and Bigeye Trevally appear to persist in these lakes in most years although a kill of large Giant Trevally was reported from Emerald Lake during one exceptional winter cold snap in June 2022, but not from any of the other lakes. This cold snap coincided with a rainfall event, so there was some debate as to whether the kill was caused by cold or through poor quality water running into the lake (ABC News, 2022).

The fact that trevally can persist in relatively small shallow lakes on the Gold Coast over most winters suggests a high probability of successful overwintering in the proposed lowland near-coastal large impoundments north of Bundaberg. These northern impoundments can be expected to be warmer than the small Gold Coast lakes. The impoundments (excluding weir pools) at full supply level in this area range from 920 Ha to 8200 Ha in surface area. These large volumes of water would provide some buffering against low winter temperatures. By restricting stocking of trevally to large volume, low altitude, near coastal waterbodies north of Bundaberg, there should be a low risk of cold water related fish kills. The further north an impoundment is located the lower the risk should be.

Loss of trevally to low water temperatures could be a higher risk in small shallow lakes closer to South-east Queensland, and at lakes more than 50 km from the coast or at altitudes greater than 100 m ASL. Although Barramundi are stocked in some lakes like this, it is not proposed to stock trevally in such waterbodies.

Catchability in freshwater

We know anecdotally that anglers already catch Bigeye and Giant Trevally when fishing in east coastal freshwater waterways. These catches normally occur when anglers are targeting other species like Australian Bass, Barramundi, Sooty Grunter or Jungle Perch. However, there are no comprehensive catch data for these species in freshwater and none for impoundments, as these fish currently do not exist in impoundments. The only way to evaluate catchability is to monitor angler catch after trevally have been stocked in an impoundment. Monitoring angler catch from fishing club catch data and boat ramp interviews are both proposed components of the current FRDC project. It is also planned to evaluate angler satisfaction levels and attitudes to trevally species in impoundments pre and post their stocking.

Genetics

There are two key genetic risks associated with stocking. The first relates to inappropriate translocation of genetic strains of fish outside of their natural range. If such fish escape downstream to marine-estuarine areas to breed with local strains of the same species, this may result in a loss of genetic integrity (Kohout *et al.* 2012, Valiquette *et al*. 2014) and may lead to fish that are less well adapted to the local environment. The Queensland translocation policy prohibits such activities. The second risk is that stocked fish (even if from the appropriate strain) could risk swamping the wild gene pool with a lower diversity cohort of fish, having a negative impact on genetic diversity of wild populations and reducing effective population size, even if increasing the total census population size (Hagen *et al*. 2020). Both risks are manageable with appropriate stocking policies.

To address the first risk, DAF have collected genetic samples of Bigeye Trevally and Giant Trevally from the east coast between the Gold Coast (South-east Queensland) and Cairns (north Queensland). DAF have also received samples of tissue from both species from the South African Institute of Aquatic Biodiversity as outliers. Prior to any stocking taking place, these samples will be analysed to determine if both Bigeye Trevally and Giant Trevally comprise one or more genetic stocks along the east coast of Queensland. This will guide broodstock collection for the stocking trials and assist in development of guidelines for hatcheries should either species become permitted for stocking in the future.

Research on the phylogeography of Giant Trevally in the Indo-Pacific, suggests that there is a high degree of mixing of genes across vast geographic areas (Glass *et al*. 2021). This suggests it is highly likely that Giant Trevally on the east coast of Queensland will all be one stock. There is nothing currently published on the stock structure of Bigeye Trevally across broad geographic regions.

There are several management actions that can minimise the risk of negative impacts of stocking on genetic diversity of wild populations. As noted earlier in this document, at current stocking levels for Barramundi in the dry tropics of Queensland, stocked fish made up only 3% of the downstream fishery, but hatchery ancestry was detected in 21% of the catch (Leahy *et al*. 2022). It is not planned to stock either trevally species at the same density as Barramundi. Stocking rates will most likely be between 25% and 50% that of barramundi. Both trevallies are pelagic predators that force bait fish to the surface creating highly visible bust-ups. This should make stocked impoundment trevally easier for anglers to detect and target. Therefore, it is expected that a lower stocking density will still provide a viable fishery for these species. Stocking at lower densities should help reduce genetic risks should fish move downstream. To further reduce the risk of loss of genetic diversity through stocking, broodstock should be turned over regularly and each hatchery spawning event should involve several males and females. The broodstock management guidelines developed under their NSW Hatchery Quality Assurance Scheme is a good model to follow (NSW Department of Primary Industries 2019). Should the trevally species become permitted for stocking, hatcheries should not be permitted to source their broodstock from stocked fish in impoundments. Rather, they be required to collect fish from the wild, either as adults or sub-adults, and preferably not from an estuary immediately downstream from an impoundment stocked with trevally.

For the current project it is proposed to conduct trial stockings of both trevally species into Kinchant Dam. Kinchant Dam is a large off-river storage that is filled via pumping from the Pioneer River. It has an extremely small natural catchment. Spilling is extremely rare and only occurs in extreme weather events. The small catchment also means any such spills are generally of short duration. Therefore, in terms of the probability of significant numbers of fish swamping downstream populations, this dam is a very low risk site for initial stocking trials. In Awoonga Dam, it is proposed to use acoustic tags to track upstream and downstream movements of 30 Giant Trevally and 30 Bigeye Trevally. If these fish are lost over the dam wall and mix with wild fish, this very small number of fish are unlikely to have a significant genetic impact.

Disease risk

Wild trevallies (Carangidae) are known to carry parasites and be susceptible to various diseases, but this is common to all fish species. Very little has been published on the occurrence of diseases and parasites for Giant Trevally. Given that this species has been cultured for some time in Asia, this is rather surprising. All descriptions of parasites hosted by this species come from studies of wild fish and not cultured fish. Chandran *et al*. (2023) described a Myxosporean parasite *Auerbachia ignobilis* from the hepatic bile ducts of *Caranx ignobilis*. It was found in 212 out of 276 Giant Trevally collected from Indian waters. Histological studies did not reveal any pathological changes. Both Giant Trevally and Bigeye Trevally have been found to be intermediate hosts for a trematode parasite *Bucephalus varicus* that infects pearl oysters (Sakaguchi 1966). An acanthocephalan parasite (a type of Helminth) *Tenuiproboscis keralensis* was found to inhabit the hind gut region of several fish hosts from the south-west coast of India, including Giant Trevally (Kaur *et al*. 2017). A nematode *Anisakis* spp. was found in three Giant Trevally out of a sample of four collected from the Makassar Strait, Indonesia (Anshary *et al*. 2014).

Bigeye Trevally have had various marine parasites and a bacterium identified from them. However, none of these reports are from Australian waters which probably reflects limited research on diseases and parasites of this species in Australia. In New Caledonian waters, two digeneans (flukes) from the family Acanthocolpidae have been identified from Bigeye Trevally (Bray and Justine 2012). A study of metazoan fish parasites in Segara Anakan Lagoon in Indonesia identified 31 ectoparasites and twelve endoparasites from seven economically important species of fish. One of the seven species was Bigeye Trevally (Rueckert *et al*. 2009), but the species had a lower parasite diversity and load compared to most species. This was especially so for ectoparasites. For Bigeye Trevally one species of parasitic copepod was recorded along with a parasitic isopod (Gnathiidae) and a monogenean from the gill filaments (Axinidae). A Nematode (*Anisakis* sp.) was recorded as an endoparasite from the stomach wall (Rueckert *et al*. 2009). A study of crustacean fish parasites in Segara Anakan Lagoon found two parasitic copepods *Caligus* c.f. *confusus* and *Peniculus* c.f. *scomberi* on Bigeye Trevally. The first species occurred on the gill filaments as an adult and the calimus larval stage occurred on the gill filaments and in the mouth cavity. The second copepod species was found attached to the dorsal fin. A parasitic isopod (Gnathidae) was also found on the gill filaments (Yuniar *et al*. 2007). *C. confusus* has also been found in gills of Bigeye Trevally in South Africa (Grobler *et al*. 2002).

A study of metazoan parasites on 422 Bigeye Trevally in Acapulco Bay Mexico identified 32 species of parasites. There were five Monogenea (gills), thirteen Digenea (intestine), one Acanthocephala (intestine), one Cestoda (intestine), three Nematoda (mesentery and intestine), seven Copepoda (gills) and two Isopoda (gills). The component communities (all life cycle stages) and infracommunities in Bigeye Trevally were characterised by low parasitic species numbers, low parasitic diversity and dominance by a single species of monogenean, *Neomicrocotyle pacifica* (Violante-González *et al*., 2020). The nematode *Procamallanus* (*Procamallanus*) *annulatus* was found in six out of eight Bigeye Trevally collected from the Red Sea in Egypt. (Hussein *et al*. 2020).

We were only able to find a single reference to a bacterial infection in Bigeye Trevally and we found no such references for Giant Trevally. Bigeye trevally from the Persian Gulf have been found infected with *Photobacterium damselae damselae* (Hassanzadeh *et al*. 2015). This bacterium can cause ulcers, and haemorrhaging in the eye, gills, operculum, fins and skin (Hassanzadeh *et al*. 2015). It is highly likely that other species of bacteria may also impact on Giant Trevally and Bigeye Trevally, but nothing has been reported in the literature. Fish under stress through things like poor water quality, temperature extremes or poor handling are more likely to be susceptible to bacterial infections.

We have been unable to locate any literature referring to nodaviruses in either Bigeye Trevally or Giant Trevally. Nodaviruses that affect fish belong to the genus *Betanodavirus*, one of which is the Striped Jack Nervous Necrosis Virus (SJNNV). As its name suggests this virus frequently occurs in the Carangid, Striped Jack, *Pseudocaranx dentex*. The virus causes neural necrosis in larval Striped Jack (Nishizawa *et al*. 1995). It is probable that Giant Trevally and Bigeye Trevally larvae may be susceptible to a strain of SJNNV or a related *Betanodavirus*. Given that Giant Trevally fry are currently produced for grow out in Indonesia and have also been produced in Taiwan, Vietnam and the Philippines, it would be expected that if Betanodavirus infection in this species was common, something should have been published by now.

Testing of cultured cell lines of Bluefin Trevally *C. melampygus* (a species known to hybridise with both Giant Trevally and Bigeye Trevally) has shown that these cells can be infected by hematopoietic necrosis virus, infectious pancreatic necrosis, spring viremia carp virus, viral haemorrhagic septicemia virus, and snakehead rhabdovirus (Zhao and Lu 2006). However, infecting cultured cell lines invitro is not equivalent to detecting infections in wild fish.

It is clear both trevallies can be infected by various metazoan marine parasites and at least one bacterium. However, it appears that the parasite load on these species is generally not particularly high or diverse (Rueckert *et al*. 2009; Violante-González *et al*. 2020). All reported parasites in the literature are marine in origin. Broodstock fish for hatchery production of Bigeye Trevally and Giant Trevally will generally be collected from marine and estuarine conditions. Giving new broodstock a short period in freshwater should remove the vast majority of ectoparasites adapted to higher salinity environments. Similarly, fingerlings of these species raised in saltwater ponds or saltwater tanks would lose most ectoparasites when transferred into freshwater tank conditions prior to stocking. Endoparasites may not be eliminated from organs of stocked fish when transferred into freshwater, but those endoparasites that have a free swimming marine larval phase will probably be unable to recruit in a freshwater environment.

The chances of introducing a novel disease or parasite to an impoundment through stocking of either trevally species is low. Both trevallies will be native to the catchments where they are stocked and any parasite of the trevallies that can survive in freshwater is already likely to be present. The disease and parasite risk should be no greater than it is for current Barramundi stocking activities.

It is possible that Bigeye Trevally and Giant Trevally larvae or fry may be susceptible to a *Betanodavirus*. *Betanodavirus* testing prior to stocking of Barramundi is compulsory and the same guidelines can also be introduced for both trevallies. Betanodaviruses are already endemic to the catchments where stocking is proposed.

For this research project, several precautions should further limit risk of spread of any parasites or diseases. All incoming seawater water at BIRC is ozone treated. The freshwater supply is town water that has been chlorine treated and is then dechlorinated prior to use in RAS systems. All RAS systems use UV treatment of both seawater and freshwater. Thus, sources of diseases and parasites are very limited. All broodstock are tested for *Betanodavirus* prior to being used in the breeding program to prevent risk of vertical transmission of the virus to fry. Newly captured broodstock are given a holding period in freshwater to eliminate marine ectoparasites. Fingerlings will be transitioned to freshwater prior to stocking, which should eliminate any ectoparasites (unlikely to be present if the fish are tank reared and not pond reared) and the general health of the fish will be monitored. The fish will require a general health clearance by Biosecurity Queensland prior to stocking and this check includes testing a subsample of fish for *Betanodavirus*.

Threat to rare and threatened species (running upstream)

One concern with stocking of new species is the potential for negative impacts on rare or threatened species through predation. This of particular concern in the wet tropics, where rare amphibians and rainbowfishes occupy small tributary streams (Burrows 2004). This would be less of a concern in the lowlands near coastal impoundments (outside of the wet tropics) proposed for future trevally stocking, but it could be possible (although unlikely) for stocked trevally to migrate far upstream into small tributaries where rare and endangered species may occur.

Rare and threatened species are unlikely to occur in the impoundments. The impoundments have history of 10-20 years or more of Barramundi stocking, so it is likely that any species present are already compatible with large predatory fish. Some of the impoundments also have natural populations of Blue Catfish (*Neoarius graeffii*) present, which although not popular with anglers, represent another considerable indigenous predator.

Russell *et al*. (2009) found that Barramundi do not run upstream into small tributaries but prefer to remain in the impoundment. It is likely that both trevallies will behave similarly, as available prey would be greater in an impoundment than in a small tributary. However, field trials are needed to confirm this.

Kinchant Dam lacks significant tributaries. It is supplied by pumping from the Pioneer River. Its small natural catchment consists of short ephemeral streams that are dry gullies for most of the time. Kinchant Dam is where we plan to stock thousands of trevally fingerlings for a trial of growth, relative survival, impact on prey density and catchability. The lack of significant or perennial tributaries makes it an ideal site to investigate these aspects without impacting on rare and threatened tributary stream species. To study the potential impact of trevally on rare and threatened species, Awoonga Dam has been selected. This dam has a major tributary (Boyne River) which in turn has smaller tributaries. It is planned to release up to 30 acoustically tagged sub-adult trevally of each species into this large waterbody. Acoustic receivers will be placed at the mouth of significant tributaries and then further upstream to determine if trevally will penetrate very far upstream from the impoundment. This will give an indication of the potential risk of either of the trevallies impacting on threatened fauna in tributaries and help inform decisions on whether these trevallies should become permitted species for impoundment stocking in the future and whether there should be restrictions as to which waterbodies can be stocked into. Given the small number of fish to be used for the Awoonga Dam trial, information of potential threats can be collected with minimal risk to the local tributary stream fauna.

Capacity of impoundments to support a population of trevally

Trevally are highly-active predatory fish and potentially could consume high numbers of prey fish and crustaceans. Barramundi are also large predators and have the potential to consume large numbers of prey species. Adding trevally to dams that already contain Barramundi will add further predation pressure to impoundments. Whether there are sufficient prey species to support this additional predatory pressure requires investigation. Four of the dams proposed for future trevally stocking have full supply surface areas between 4,325 ha and 8200 ha. The smallest of the potential trevally dams is Kinchant Dam with a full supply capacity of 920 ha. The four largest dams are probably stocked well below their carrying capacity for Barramundi. The most likely dam for reaching critical stocking levels is Kinchant Dam because of its smaller size. Norris *et al*. (2020) found Bony Bream *Nematalosa erebi* and Fly-specked Hardyhead *Craterocephalus stercusmuscarum stercusmuscarum* to be highly abundant in the dam. Mean size of barramundi captured was more than 80 cm TL. At the time of sampling (2018-2020), the impoundment did not appear to be prey limited. Therefore, it can be concluded that it would be acceptable to trial the stocking of trevallies in Kinchant Dam at moderate levels of stocking relative to Barramundi.

The stocking of trevally will create an opportunity to monitor impacts on prey numbers and on Barramundi condition in Kinchant Dam. Non-lethal gastric lavage will also be used to confirm what prey species the trevallies consume. If trevally have minimal impacts when stocked at moderate levels in Kinchant Dam, then it would be reasonable to conclude that they are unlikely to have significant impacts on prey densities when stocked at moderate levels in the much larger waterbodies that have been suggested as potential trevally dams. Should trevally be found to have a major impact on prey densities, then either trevally stocking rates need to be revised down, or stocking at other sites should not be initiated. As trevallies cannot breed in impoundments, any impacts on prey can be reversed over time through fishing down of the trevally population and natural attrition. It is advisable to survey the fish assemblage to determine if prey densities are high as part of an approval process before adding trevally to the stocking permit of any new dam. However, it should be noted that barramundi stocked in impoundments grow much faster than their wild riverine counterparts (Russell *et al*. 2015), and this suggests that prey abundance is not currently a constraining factor in these environments.

Loss over the dam wall downstream

Like all catadromous species, trevally will no doubt attempt to migrate downstream to access marine breeding areas during dam spill events. Whether only adult trevally will attempt to migrate, or whether this will also include smaller sub-adults could affect the viability of the impoundment fisheries. Infrequent spill events pose less risk to fishery viability, allowing greater opportunity to rebuild trevally populations between spills. Also, if only a small to moderate proportion of the stocked population migrate downstream, then the fishery could also remain viable, even if spills were annual events.

The five most likely dams for stocking of trevally are Fred Haigh Dam, Awoonga Dam, Kinchant Dam, Peter Faust Dam and Ross River Dam. These are all large waterbodies, within 50 km of the coast and below 100 m in altitude. Water level data available online from Sunwater, Gladstone Area Water Board and Townsville

Regional Council were examined to determine spill frequencies. Kinchant Dam, which functions as an off-river storage has only spilled in 1991, 2012 and 2017. Thus, risk of downstream loss would be very low in most years. Awoonga Dam had its wall raised in 2002 to 40 m AHD and spilled from January 2013 until May 2013 following heavy rain from cyclone Oswald. The dam did not spill between 2018 to 2023, despite a series of La Nina years. In general, there can be expected to be long periods between spillages, so downstream loss risk would be low in most years. The long gaps between spill events would provide both trevally species a good chance to grow to large sizes due to extended residence times. Spilling in Peter Faust Dam is rather erratic. It didn't spill for a period of nearly 20 years, then spilled three times between 2011 and 2014 but has not spilled since. Fred Haigh Dam spilled several times in the early 1990s, then five times between 2011 and 2017, but hasn't spilled since. There could be periods when fish might have access downstream regularly for several years, but long periods of no downstream access where fish can mature to large sizes in freshwater can also be expected. The situation at Ross River Dam is similar, there can be periods of four to five years where the dam doesn't spill, with single spill events in between, but there can also be periods of three to four years with annual spills. There should be periods where downstream escapement is infrequent enough for fish to reach large sizes, but there could be periods where fish may have an opportunity to head downstream within 12 months of stocking in the dam. Ranked in order from least risk to highest risk of loss in spill events are Kinchant Dam, Peter Faust Dam, Awoonga Dam, Fred Haigh Dam, and then Ross River Dam.

In general, there is a high probability of establishing fisheries for large fish most of the time in three of the dams and some of the time in two of the dams. Similar risks would apply to Barramundi and successful fisheries have been established in at least four of the dams. The situation for Ross River Dam is currently unknown, as attempts to establish a Barramundi fishery there have only commenced recently, and the dam has not yet been opened by Townsville Regional Council to recreational fishing. We will investigate the proportion of fish that may go over in a spill by placing acoustic receivers downstream of Awoonga Dam. There is a chance there may be a spill event during the period after acoustically tagged trevally have been released in the dam. However, such data cannot be guaranteed as it is dependent on a natural over-topping flow event, which are infrequent and unpredictable.

As noted in the genetics section above, to minimise the genetic risks from downstream loss, trevallies will be stocked at lower densities than Barramundi, and broodstock and spawning events will be managed to keep stocked fish genetically diverse.

Conclusions

The evidence suggests both trevally species are well adapted to freshwater environments. Risk of winter fish kills can be reduced by confining stocking to large near coastal impoundments north of Bundaberg. Fast growth rates and fast swimming speeds should help minimise the risk of stocked trevally fingerlings being predated by Barramundi, Blue Catfish and other piscivores. If necessary, stocking at sizes above 100 mm could further reduce the risk of predation. Monitoring of experimental stockings will be able to provide definitive data on growth rates of trevallies in impoundments.

It is highly unlikely that trevallies would introduce novel diseases and parasites to the waters where they may be stocked. Both trevally species are native to the catchments where stocking is proposed, so any diseases or parasites that occur in stocked trevally can also be expected to be endemic to those catchments. Most marine parasites would be killed or inhibited from completing their life cycle in freshwater. Hygienic rearing conditions and disease testing prior to stocking will further reduce any risks. Risks should be no greater than for the current Barramundi stocking program.

It is unlikely that trevallies will run upstream into small tributary streams where they may put threatened species at risk, however this will be tested in the Awoonga Dam catchment through acoustic tracking of both trevally species. Loss of fish downstream is likely when dams spill. Such events are erratic and there are likely to be significant periods of time between spill events that allow establishment of a trevally fishery. Acoustic tracking may provide some information on the proportion of fish that go downstream on a spill event, but there is a possibility that a spill event may not occur during the two-year period we acoustically track fish in Awoonga Dam.

When fish are lost downstream there is a low risk of genetic impacts on wild populations. This risk can be reduced by stocking trevallies at moderate levels, using multiple fish for spawning events, having regular turnover of broodstock, and through ensuring broodstock are not collected from impoundments or from estuaries immediately downstream of impoundments stocked with trevallies. Stocked fish must also be of the appropriate genetic strain for the region.

It is possible that trevally could impact on prey species density and therefore the Barramundi carrying capacity of a dam. Kinchant Dam is an ideal site to test this risk. The risk will be minimised by only stocking moderate densities of the trevally species. Past data on prey abundance in Kinchant Dam suggests there is extra capacity to cope with the addition of new predatory species. Any impacts on prey densities will be reversible as trevallies cannot breed in impoundments.

Catchability of trevallies in impoundments is an unknown. We know anglers already catch trevally in freshwater environments, but the only way to know with certainty how trevallies will perform as a fishery is to monitor it through a stocking trial.

Overall, risks appear to be low enough for a stocking trial of Giant Trevally and Bigeye Trevally to proceed. The stocking trial will provide additional information on the performance of the fishery (*e.g.*, angler catch and satisfaction rates, trevally growth rates, relative survival rates) and provide conclusive answers regarding impacts on prey densities, carrying capacity, tendency for upstream migration into tributary streams and potentially downstream loss.

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