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Growth and viability of hatchery-reared *Argyrosomus japonicus* released into open and semi-closed systems

M. D. TAYLOR

Sydney Institute of Marine Science, Mosman, NSW, Australia and Evolution and Ecology Research Centre, School of Biological, Earth and Environmental Science, University of New South Wales, New South Wales, Australia

D. S. FIELDER

Port Stephens Fisheries Institute, New South Wales Department of Industry and Investment, Taylors Beach, New South Wales, Australia

I. M. SUTHERS

Sydney Institute of Marine Science, Mosman, New South Wales, Australia and Evolution and Ecology Research Centre, School of Biological, Earth and Environmental Science, University of New South Wales, New South Wales, Australia

Abstract Hatchery-reared *Argyrosomus japonicus* (Temminck & Schlegel) were released into estuaries of varying habitat between 1996 and 2004, and growth and recruitment to the fishery evaluated. Fish stocked earlier in summer had significantly faster growth rates ($P < 0.01$), and post-stocking mortality ranged from 1.1% to 11.7% within 7 day post-release. *Argyrosomus japonicus* stocked in the Georges River in 2003 and 2004 yielded fishery independent recapture rates up to 0.2%. For *A. japonicus* stocked in Smith's Lake in 1997 and 2004, growth rates, timing of recaptures and increases in commercial catches suggested recruitment to the fishery by 18 months. The 1997 stocking led to a 30-fold increase in *A. japonicus* catch, but stocking was not financially viable, with a cost:benefit ratio of 2.1. Small, shallow coastal lagoons may represent experimental units for refining stocking strategies, but are not optimal for *A. japonicus*. The potential for density-dependent effects, and complex relationships between growth, habitat and mortality, highlighted the need for a thorough understanding of species – system interactions. Pilot releases can contribute to this understanding, particularly assessment of habitat requirements, and season, site and size-of-release.

KEYWORDS: growth, release habitat, release strategies, Sciaenidae, season of release, stock enhancement.

Introduction

Marine stocking is gaining favour as a method of fisheries enhancement, with some marine programmes producing economic or biological successes (Leber & Arce 1996; McEachron *et al.* 1998), despite a history of failures (e.g. Svåsand *et al.* 2000). A responsible approach to marine stock enhancement involves undertaking pilot studies to assess the effects of marine enhancement and develop strategies that maximise the benefit of stocking and minimise environmental impacts (Blankenship & Leber 1995). In Australia, releases of marine finfish species has a relatively short history, and stocking has been limited to pilot investigations with no ongoing programmes (Taylor *et al.* 2005b).

Argyrosomus japonicus (Temminck & Schlegel) is an apex predator in estuarine and coastal waters of

Correspondence: Matthew D. Taylor, Sydney Institute of Marine Science, Building 22, Chowder Bay Road, Mosman, New South Wales 2088, Australia (e-mail: mattytaylor@unsw.edu.au)

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southern Australia, southern Africa and China (Silberschneider *et al.* 2009). A detailed description of species biology and fishery can be found in Griffiths (1996, 1997) for South Africa and Ferguson *et al.* (2008) for southern Australia. In New South Wales, *A. japonicus* is growth overfished and there are concerns about sustainability, with the bulk of the fishery targeting immature fish (Silberschneider & Gray 2008). Also, the magnitude of recreational fishing pressure on this species has only recently been realised (975 t in 2000; Henry & Lyle 2003) and far exceeds commercial pressure (250 t in 2000; Silberschneider & Gray 2008). As a consequence, hatchery-releases have been proposed as an intermediary solution while a recovery programme for *A. japonicus* is developed (Taylor & Piola 2008), and will likely expand into an integral component of the species management plan (Blankenship & Leber 1995; Taylor *et al.* 2005b).

In the context of the responsible approach to fisheries enhancement, initial investigations into *A. japonicus* stock enhancement were undertaken in intermittently opening coastal lakes and riverine estuaries in New South Wales. Specifically, the study used experimental releases to evaluate the growth of released fish in estuaries of differing habitat, and to evaluate potential outcomes of *A. japonicus* releases for the fishery.

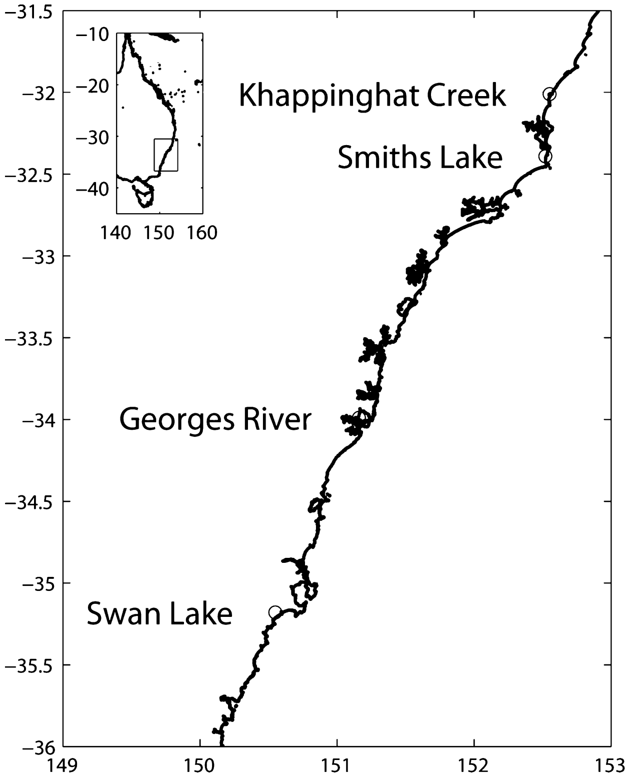

Figure 1. Map illustrating the spatial distribution of study sites used in the study.

Methods

Study area

Coastal lakes used in this study included Swan Lake (35.18° S, 150.55° E), Khappinghat Creek (32.01° S, 152.55° S) and Smiths Lake (32.39° S, 152.52° E; Fig. 1). All three lakes are shallow (0.5–6 m) intermittently opened coastal lagoons of 14, 1 and 11 km^2 area respectively, with primarily agricultural and national park catchments. The riverine estuary used was the Georges River (33.99° S, 151.16° E; Fig. 1), a medium-sized estuary of area 12 km^2 and depth range 1–20 m, located in the southern Sydney metropolitan area. The river has a primarily urbanised catchment and discharges into a large open embayment (Botany Bay, 33.98° S, 151.20° E), before flowing into the Tasman Sea.

Marking and release of fish

Cohorts of juvenile *A. japonicus* were grown using extensive rearing techniques (Fielder & Bardsley 1999). Fish were marked using established batch immersion protocols (Table 1; Taylor *et al.* 2005a), in either a 600 mg L^{-1} of oxytetracycline hydrochloride solution (OTC in seawater diluted to a salinity of 5), or 30 mg L^{-1} of alizarin complexone (ALC). After marking, fish were transported to the release sites at a maximum density of 30 kg m^{-3} in a 6000-L transporter tank or two 600-L transporter tanks supplied with pure oxygen at 1–2 L min^{-1}. Water quality conditions were checked for changes every 30 min whilst in transit, and buffered with sodium carbonate to maintain pH ~8. Fish were acclimatised to conditions at the release site by exchanging water in the transport tank over 60 min, before release into the estuary. A subsample of 100 fish from each stocking cohort was used to calculate initial total length (TL, mm).

Transport-related mortality was assessed for the 2003 and 2004 Smiths Lake and Georges River stocking events by counting the number of deceased fish in the transporters after stocking. Stocking-related mortality was monitored by placing 30 fish in four, 1 m^3 floating cages at the release site and monitoring for 7 day. These fish were fed 1- to 2-mm fishmeal-based pellets once daily during this period, and then removed from the cages and counted.

Table 1. Cohorts of *Argyrosomus japonicus* released in New South Wales estuaries

Estuary	Release date	Mark	Release size mean ± SE (mm TL)	No. released	No. recaptured	Post-release mortality (%) (mean ± SE) after 7 days	Historic landings (mean ± SE) 1940/41–2004/05 (kg)*
Khappinghat Creek (coastal lake)	January 1996	OTC	40.3 ± 5.5	25 000	0	–	None
Swan Lake (coastal lake)	March 1997	OTC	51.3 ± 5.9	28 000	0	–	17.1 ± 6.8
Smiths Lake (coastal lake)	March 1997	OTC	76.7 ± 6.7	21 600	64	–	133.4 ± 23.2
	May 2003	OTC	79.6 ± 0.9	42 000	0	3.3 ± 3.3	
	February 2004	OTC	47.4 ± 0.4	18 000	5	4.5 ± 2.2	
Georges River (riverine estuary)	May 2003	OTC	82.5 ± 1.2	54 000	71	1.1 ± 1.1	2667.2 ± 277.1
	March 2004	ALC	77.2 ± 0.8	5 200	11	11.7 ± 4.4	

*Data from NSW Department of Industry and Investment Commercial Catch Statistics Database.

Post-stocking surveys

Swan Lake, Smiths Lake and Khappinghat Creek were sampled for *A. japonicus* using multi-panel gill nets (10, 5-m panels of 13, 19, 25, 32, 38, 45, 50, 55, 60 and 70 mm mesh butted together randomly) for 2 years after stocking. Georges River was sampled for *A. japonicus* using an otter trawl (6 m mouth, 12 m length, 0.6-mm cod-end mesh size) and multi-panel gill nets for up to 2.5 years post-release. Trawls were towed for 5 min, depending on site, in deep holes surrounding the release site, and gill nets were set at dawn or dusk in deep holes around the release site for 1–5 h. Fish were also provided on an intermittent basis from the commercial fishery in Smiths Lake, and the recreational fishery in the Georges River for 2 years post-release (as Georges River is a recreational fishing haven). All captured *A. japonicus* were euthanized in ice slurry upon landing, measured for TL (mm) and weight (g) and sagittal otoliths removed. Otoliths were embedded in epoxy resin (Streurs Epofix, Copenhagen, Denmark), sectioned through the core using a diamond edge wafering saw, and examined for a fluorescent OTC or ALC mark (Taylor *et al.* 2005a).

Analysis

Cohort growth rates were evaluated using a linear regression between length (mm) and age (days) for *A. japonicus* recaptured within 2 years, with the model coefficients indicating the cohort-wide growth rates. The increase in TL since stocking was calculated for each fish by subtracting the length-at-capture from the mean length at release, and these data were converted into individual post-stocking growth rates in mm day^{-1}. Post-stocking growth rates and post-release mortality were compared among cohorts using a single-factor ANOVA, and differences interpreted using Hochbergs GT2 pairwise comparisons. The potential contribution to the commercial catch was evaluated in the context of state-wide and estuary specific historical commercial *A. japonicus* landings, which were extracted from the NSW Department of Industry and Investment Commercial Catch Statistics Database. All statistical analyses were undertaken in SPSS (SPSS, Chicago, IL, USA).

Results

No juvenile *A. japonicus* were recaptured in either Khappinghat Creek or Swan Lake, or from the Smiths Lake 2003 stocking (Table 1). Khappinghat Creek and Swan Lake opened to the sea during heavy rainfall 4 and 3 months after stocking, respectively, and juvenile *A. japonicus* were observed swimming out of Swan Lake during the opening (M. Angle, personal communication). Smiths Lake was also opened to the sea during heavy rainfall 3 weeks after the 2003 release. Transport mortality measured for the Smiths Lake and Georges River releases in 2003 and 2004 was $<1\%$. Average post-stocking mortality was usually $<5\%$ and peaked for the 2004 Georges River cohort (11.7%; Table 1), but differences in $\log_{10}$-transformed post-stocking mortality measurements were not-significant amongst release events ($F_{3,13} = 1.36$, $P = 0.31$).

Argyrosomus japonicus from the 1997 and 2004 Smiths Lake stocking grew at ~0.9 and 0.6 mm day^{-1} respectively (Table 2; Fig. 2). The minimum length at which *A. japonicus* can legally be retained by the fishery is 45 cm, and this represents approximately 18 months growth post-stocking (Taylor *et al.* 2005b). In the year immediately prior to the 1997 release, *A. japonicus* catch was negligible in Smiths Lake (<10 kg yr^{-1}). After fish stocked in 1997 recruited to the fishery, the commercial landings of *A. japonicus* increased to 140 kg yr^{-1}, and then peaked at 210 kg yr^{-1} 1-year later (Fig. 3), compared with a

Table 2. Linear regression for growth of released *Argyrosomus japonicus*

Cohort	Model coefficient (growth rate, mm day^{-1})	r^2-value	F-value	P-value
Smiths Lake 1997	0.897	0.96	2360.91	<0.01
Smiths Lake 2004	0.586	0.99	394.44	<0.01
Georges River 2003	0.658	0.97	1106.20	<0.01
Georges River 2004	0.979	0.92	108.34	<0.01

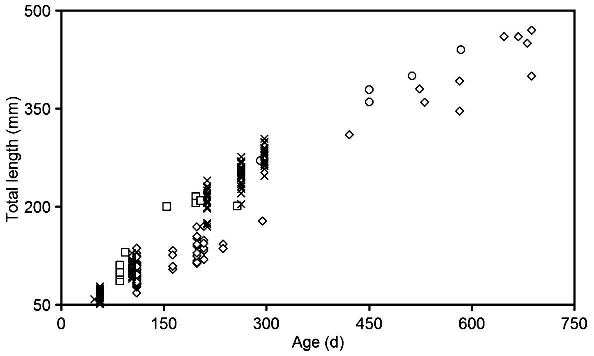

Figure 2. Length–age relationship for recaptured *Argyrosomus japonicus* released in Smiths Lake in 1997 (×), Smiths Lake in 2004 (○), Georges River 2003 (◇) and Georges River 2004 (□).

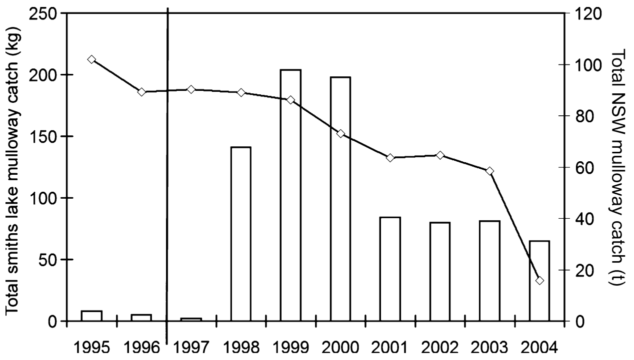

Figure 3. Increase in commercial Smiths Lake *Argyrosomus japonicus* landings following the 1997 release. Time of stocking is indicated by a solid black line, and landings appeared to increase when released fish entered the fishery 18 months later, despite a decrease in the total NSW catch (◇).

downward trend in state-wide landings during this period. The commercial fishery was not measured for size- or age-structure, or the presence of otolith marks after this release event (with the exception of a limited number of fish provided from the fishery), so the exact contribution of released fish to the catch increases in Figure 2 was not directly assessed.

Argyrosomus japonicus from the 2003 and 2004 Georges River stocking grew at 0.7 and 1.0 mm day^{-1} respectively. A single-factor ANOVA indicated that the four cohorts for which recaptures were obtained (Table 1) grew at different rates ($F_{3,155}$ = 126.88, P < 0.01) and pairwise comparisons revealed highly significant differences between all cohorts (P < 0.01), with the 2004 Georges River cohort having the highest growth rate, followed by the 1997 Smiths Lake cohort, the 2004 Smiths Lake cohort, then the 2003 Georges River cohort (Fig. 2). Higher growth rates were observed in fish stocked earlier in the summer, as there was a significant negative linear relationship between growth rate (mm day^{-1}) and a Seasonal Index (expressed as the number of days between the commencement of the previous summer and the stocking event) where Growth rate = 1.496 – 0.005 Seasonal Index (r^2 = 0.65, $F_{1,155}$ = 282.19, P < 0.01).

Discussion

Over 193 800 *A. japonicus* were released into New South Wales waterways during the course of this study, and whilst some stockings completely failed, stocked fish were found to grow and recruit to the fishery for the 1997 and 2004 Smiths Lake releases, and all Georges River releases.

The release of fish into intermittently opening coastal lakes was proposed as an opportunity to test stocking strategies in a closed or semi-closed ecosystem, analogous to a natural mesocosm (Taylor *et al.* 2005b). The lack of recaptures from several coastal lakes underlines the importance of choosing release habitat suitable for the species to be stocked. Recent research indicates that juvenile *A. japonicus* has a strong association with deep, rocky holes within estuaries (Taylor *et al.* 2006b), which do not occur in the coastal lakes stocked in the present study. This does not preclude the use of coastal lakes as confined experimental units to optimise release strategies for species other than *A. japonicus*, but does underline the importance of choosing appropriate species when using these systems. The absence of spawning habitat (Cappo *et al.* 2002), physical barriers to natural recruitment such as sandy berms, and minimal key habitat to support juvenile fish (Taylor *et al.* 2006b), most likely contribute to the lack of juveniles (Robinson *et al.* 1982) and historically low *A. japonicus* landings within New South Wales coastal lakes (Table 1).

The total cost associated with the 1997 Smiths Lake stocking was $16 148 (Table 1; commercial rearing price $AU0.01 mm^{-1}, plus $1000 stocking costs).

Assuming negligible natural recruitment, commercial landings of 707 kg over 7 year (Fig. 3), and a market price for *A. japonicus* of \$AU11 kg^{-1} (Taylor *et al.* 2005b), a rudimentary cost:benefit calculation for the 1997 Smiths Lake release was 2.1. Therefore, even with ~30-fold increase in annual landings of *A. japonicus*, the stocking of Smiths Lake was not financially viable, although the value of the recreational harvest within the estuary is unknown. Whilst the Smiths Lake releases failed to yield landings greater than the maximum recorded in Smiths Lake (591 kg, 1972), recruitment of stocked fish to the fishery coincided with landings well over the historical mean (± SE) of 133.4 ± 23.2 kg yr^{-1} (Table 1), and annual landings appeared to stabilise for a number of years post-release (Fig. 3).

Fishery-independent recaptures from the 2003 Georges River cohort (54 000 stocked) represented 0.1% of stocked fish, while the much lower number of fish stocked in March 2004 (5 200) presented a slightly higher recapture rate of 0.2%. Immediate post-stocking mortality was < 5% in most cases, with the exception of the 2004 Georges River cohort, which was 11%. *Argyrosomus japonicus* from this cohort were subjected to an extra transfer during harvest, which may have resulted in a higher post-stocking mortality. Modelling of the carrying capacity for *A. japonicus* in the Georges River indicated an optimal stocking density of ~17 500, 80-mm fish for the system (Taylor & Suthers 2008). Given these estimates, there is a possibility that the river was overstocked in 2003, which may contribute to the differences in recapture rates observed; exceeding the estimated carrying capacity may have influenced density-dependent growth, survival and dispersal responses (Munro & Bell 1997).

All cohorts grew at significantly different rates, and this was partially attributed to a seasonal index, reflecting the period of growth during warmer summer/autumn temperatures. There are, however, other factors affecting this relationship, such as different sizes at release. The timing of release is important to the success of stocking events for several reasons. These include timing of the stocking event to coincide with peaks in the abundance of key forage species; timing the stocking event to coincide with size-modes of wild conspecifics (Willis *et al.* 1995; Leber *et al.* 1997) to minimise cannibalism; maximising exposure to warmer waters for faster growth (e.g. Sanchez-Lamadrid 2002); and rapidly outgrowing elevated vulnerability to predation in early life history stages. These factors are often related; for example, summer flounder *Paralichthys dentatus* (L.) released early in the nursery season survive better because they are able to grow faster, and are larger when they undertake an ontogenetic habitat shift out of the nursery habitat to areas of higher predation (Kellison & Eggleston 2004). Conversely, higher mortality of queen conch *Strombus gigas* (Linné) released in summer was attributed to the higher summer temperatures, increased feeding rates and abundance of fish and invertebrate predators, such as the tulip snail *Fasciolaria tulipa* (L.) (Stoner & Glazer 1998). In the case of *A. japonicus*, increased recaptures from releases earlier in summer may be a result of higher growth, which decreases predation vulnerability, and improves access to forage resources (e.g. Taylor, Fielder & Suthers 2006a). Recruitment of wild *A. japonicus* juveniles to estuarine habitat occurs from spring to late summer (Silberschneider & Gray 2008), so releases in spring would have the added benefit of coinciding with recruitment of wild cohorts (Leber *et al.* 1997).

This study highlighted the need for pilot releases to optimise stocking strategies and assess stocking effects (Blankenship & Leber 1995; Taylor *et al.* 2005b), and the importance of choosing release habitat appropriate for the species to be stocked. *A. japonicus* released into intermittently opening coastal lakes recruited to the fishery, but recaptures and recruitment to the fishery were variable and the practice was not financially viable. *A. japonicus* released in riverine systems appeared to be more successful in terms of growth and recaptures, especially when releases were carried out earlier in summer. Whilst models that draw on trophic relationships and understanding of population dynamics allow the estimation of an appropriate stocking density (Cowx 1999; Lorenzen 2008; Taylor & Suthers 2008), release techniques are ideally resolved using pilot releases in the target systems. The union of these approaches will provide the best outcome from fisheries enhancement efforts, whilst minimising the risks and costs associated with fish releases.

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