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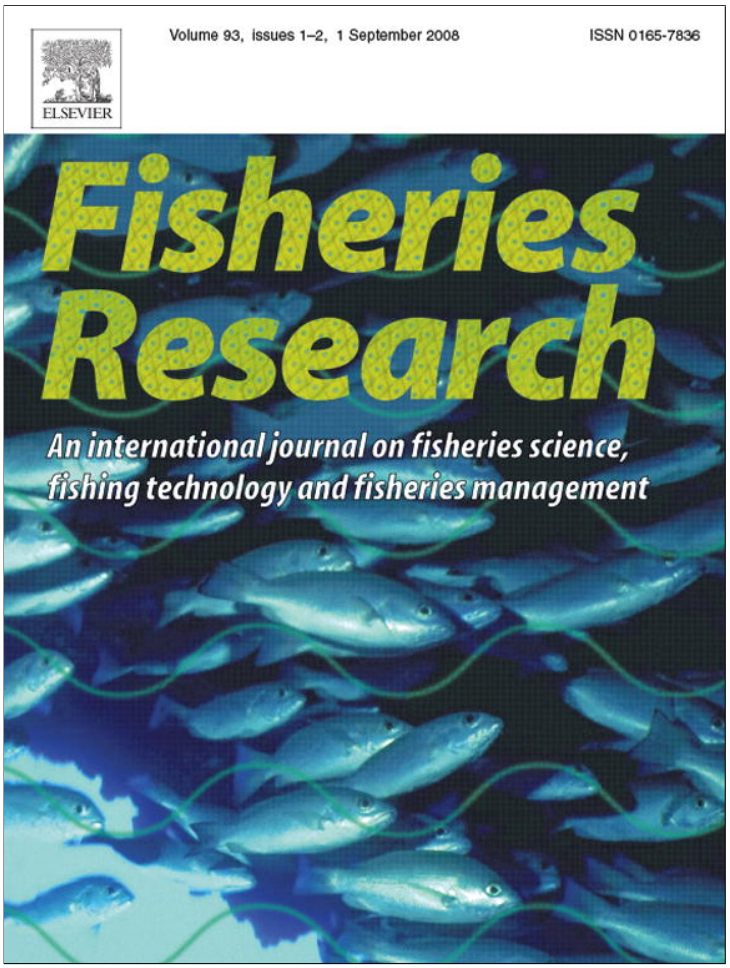

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Evaluating light trap efficiency by application of mesh to prevent inter- and intra-specific *in situ* predation on fish larvae and juveniles

Lorenzo Vilizzi*, Shaun N. Meredith, Clayton P. Sharpe, Rohan Rehwinkel

Murray Darling Freshwater Research Centre and La Trobe University, Lower Basin Laboratory, P.O. Box 3428, Mildura, Victoria 3502, Australia

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ABSTRACT

Amongst passive collecting gear types, light traps have been used extensively to sample the larvae and juveniles of fish in both marine and freshwater environments, and especially so in structurally complex habitats. Although a number of modifications have been proposed to increase efficiency, no account has hitherto been made of the possible loss of trapped larvae and juveniles as a result of within-trap predation by piscivorous fish. To address this issue, we evaluated the efficiency of modified light traps by the addition of mesh (3 mm knot-to-knot wrapped around the entrance chambers), by combining results from a long-term monitoring study with those from a designed field experiment. Abundance of larvae and juveniles collected during the monitoring program was higher in the years following mesh application (hence, beyond monthly variation), and this was supported by the experiment. Based on the latter, light/mesh traps consistently caught only larvae/juveniles, hence excluding adults; whereas the opposite was true of the light/no-mesh trap combination. Also, mesh/no-light traps did not capture any fish, unlike no-mesh/no-light traps, which sampled only adults. Our findings suggest that *in situ* predation on larvae and juveniles within light traps should not be overlooked. The occurrence of piscivorous and cannibalistic behaviour in *Hypseleotris* spp. is also discussed.

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1. Introduction

The advantages of using the presence/abundance of fish larvae and 0+ (or young-of-year) juveniles as an indicator of spawning effort over the sampling of adult fish have been widely documented (cf. Humphries and Lake, 2000, and references therein), although effective implementation of this approach requires adoption of appropriate sampling techniques. Thus, amongst passive collecting gear types (*sensu* Kelso and Rutherford, 1996), light traps have been used extensively in marine environments to sample fish larvae and juveniles (Meekan et al., 2000), but considerably less so in lotic systems. This is mainly because of likely differences in trap effectiveness under variable water velocities (Marchetti et al., 2004), which have been generally overcome by the placement of traps in backwater areas (Kelso and Rutherford, 1996; Humphries and Lake, 2000). Similarly, several structural and light source modifications to a basic design have been made over the years to improve sampling efficiency (reviews in Kelso and Rutherford, 1996; Marchetti et al., 2004). And comparisons have often been done with other sampling approaches (usually relying on active collecting gear types, e.g. Hickford and Schiel, 1999; Marchetti and Moyle, 2000; Lindquist and Shaw, 2005; Pierce et al., 2007), pointing consistently to the importance of using a suite of methods (i.e. active and passive combination) to maximise sampling success.

In Australian rivers of the Murray–Darling Basin (MDB), light traps (specifically, bait traps with a light-stick inside) were first used by Gehrke (1991) and Gehrke et al. (1995) in conjunction with other methods (i.e. gill nets and fyke nets). Gehrke (1994) also evaluated the influence of light intensity and wavelength on the phototactic behaviour of some native fish species and concluded that a yellow light-stick was superior in attracting their larvae. More recently, modified quatrefoil light traps (after Floyd et al., 1984; Secor et al., 1992) were used in a long-term study of the fish community of the Broken and Campaspe rivers in the upper MDB (Humphries and King, 2003). These light traps were found to be an effective sampling method in structurally dense habitats and across a range of water depths (Humphries and Lake, 2000; Humphries et al., 2002).

During a six-year monitoring program in an anabranch system of the lower River Murray (MDB), modified quatrefoil light traps were employed extensively in tandem with drift and tow nets (after Humphries et al., 2002). The use of light traps was justified by the need to assess the influence of temporal and spatial variation in flow on fish spawning response across a range of complex (slackwater) microhabitats that are known to act as nursery for a variety of native fish species (e.g. Humphries et al., 1999;

* Corresponding author. Tel.: +61 3 50514058.
E-mail address: Lorenzo.Vilizzi@csiro.au (L. Vilizzi).

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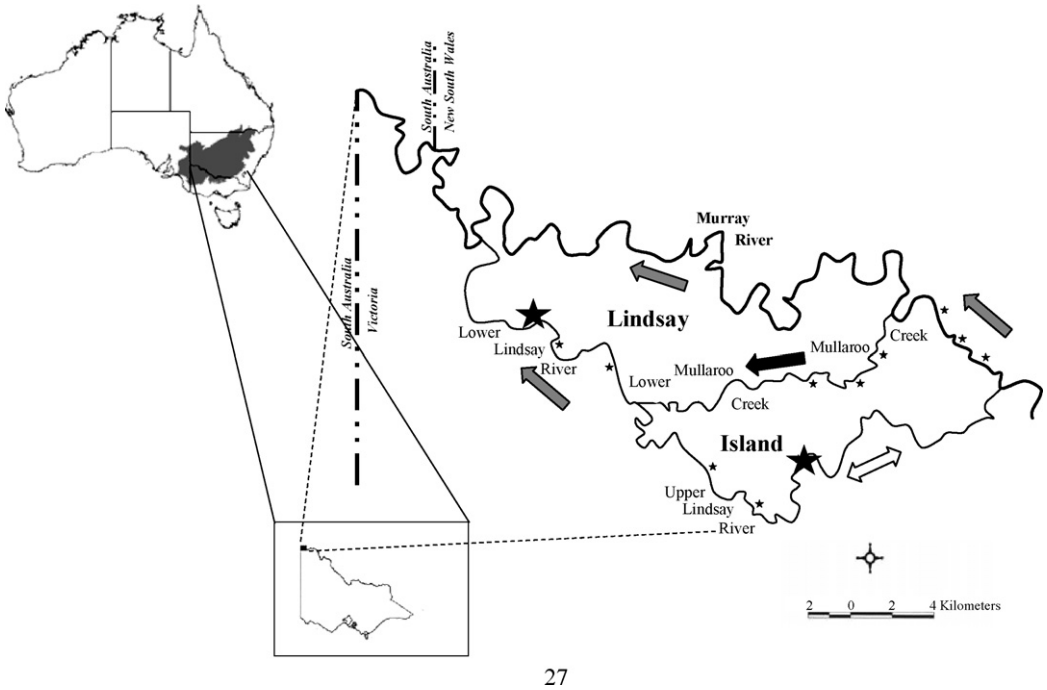

Fig. 1. Map of the Lindsay Island anabranch system (lower River Murray, Victoria, Australia) showing location of both sampling sites (small asterisks) and sampling/experimental sites (large asterisks). Arrows indicate direction of flow (black, fast flow; grey, slow flow; white-double, no flow).

King et al., 2003). However, at the end of the first year of sampling it was considered that adult individuals of several small-body species captured in the traps may significantly bias relative abundances of larvae and 0+ juveniles via *in situ* predation. As a result of this finding, a 3 mm knot-to-knot mesh was wrapped around the entrance chambers of the light traps with a view to excluding potentially piscivorous fish, thereby avoiding within-trap predation of larvae and 0+ juveniles throughout the rest of the sampling program.

As no studies have hitherto addressed specifically the issue of potential predation on fish confined within light traps, the objective of the present paper is to report on the effects of adding mesh based on (1) a long-term time series of fish catches, and (2) a designed field experiment. The occurrence of predatory (cannibalistic) behaviour in carp gudgeons *Hypseleotris* spp. is also discussed.

2. Materials and methods

2.1. Study area

Lindsay Island (34°06′S–141°09′E) is a periodically inundated 15,000 ha dryland floodplain of the lower River Murray (Fig. 1). Bounded by the River Murray to the north and the Lindsay River to the south, Lindsay Island is interwoven by a complex anabranch system which is dually regulated by the major lock and weir systems in the River Murray main channel and by a series of earthen and concrete structures at key anabranch effluent points. Importantly, the interaction of these regulatory structures provides a diversity of flow conditions that support equally diverse biota. Four reaches are encountered on Lindsay Island, and these provide for three different 'flow habitats': the Upper Lindsay River (ULR: no flow), the Lower Lindsay River and Murray River (LLR and MR, respectively: slow-flow weir pools, mean mid-channel water velocity ca. 0.10 m s^{-1}), and Mullaroo Creek (MC: fast flow, ca. 0.27 m s^{-1}).

2.2. Monitoring study

From October 2001 to July 2007 (76 'trips' in total), fish larvae and 0+ juveniles were sampled from the four flow habitats described above. An exception was the MR reach, in which sampling commenced during the 2002/2003 year and continued with the other reaches thereafter. Apart from a period between November 2003 and January 2004, when heavy rains reduced site accessibility and sampling did not occur for 5 weeks, samples were collected from all reaches on a 'quasi-monthly' schedule (that is, every 3–4 weeks) throughout the duration of the study. During most of the first year of the survey (11 trips in total: 10 October 2001–13 May 2002), four sites were sampled from each of the ULR, LLR and MC reaches (total of 12 sites); however, as from 13 June 2002, the inclusion of the MR reach required that only three sites from within each reach be sampled to maintain an equivalent sampling effort as well as to overcome logistic constraints (Fig. 1).

At each site, three modified quatrefoil light traps (cf. *Experiment–Trap design*) were deployed in slackwater patches to increase sampling efficiency and to homogenise catches across reaches. Light-sticks were placed in the core Perspex™ tube of each trap, which were then left overnight and harvested the next morning. Fish were preserved soon after collection in 70% ethanol before being returned to the laboratory for later identification and counting under a dissecting microscope. Distinctions between larvae and juveniles were made as per Humphries et al. (2002), using keys from Serafini and Humphries (2004), with each specimen identified to species (whenever possible): fly-specked hardyhead *Craterocephalus stercusmuscarum fulvus* (Atherinidae), carp gudgeon (group) *Hypseleotris* spp. (Eleotridae), crimson-spotted rainbow fish *Melanotenia fluviatilis* (Melanotaeniidae), flathead gudgeon *Philypnodon grandiceps* (Eleotridae), Australian smelt *Retropinna semoni* (Retropinnidae), and non-native eastern gambusia *Gambusia holbrooki* (Poecilidae) (Lintermans, 2007).

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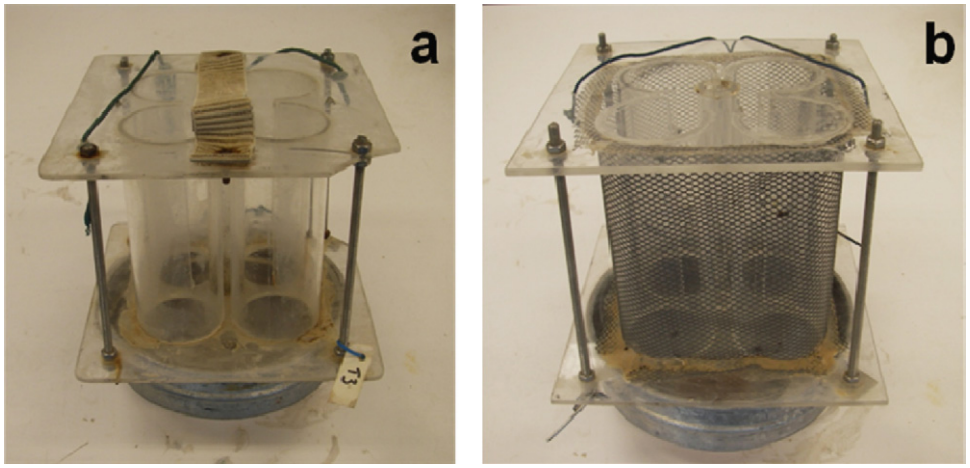

Fig. 2. Modified quatrefoil light traps (after Humphries et al., 2002) (a) without and (b) with mesh, used for evaluating efficiency in capturing fish larvae and juveniles.

Throughout, the term 'year' will be used to refer to the August–July period, i.e. starting from the beginning of the fish spawning season, which has been taken to last from August (early Austral spring) to July (late Austral winter) (Humphries et al., 2002). Also, 0+ juveniles will be hereafter referred to simply as 'juveniles', as all the (small-body) species examined for gastro-intestinal contents and caught in traps during the designed experiment are thought to reach sexual maturity in their first year of life (Pusey et al., 2004).

2.3. Gastro-intestinal contents

All fish sampled in light traps (without mesh) during the first year of the study (2001/2002) were identified and counted as per above. Individuals other than larvae or juveniles (of the small-body species) were first measured to the nearest 1 mm and then prepared for dissection of their gastro-intestinal tract (GIT). This was achieved by laying each fish in a glass Petri dish to expose its left-lateral surface. Using surgical scissors under a dissecting microscope, the GIT was removed and opened, and any fish ingested removed. The latter were identified to species level whenever possible, or otherwise categorised as 'unidentified larvae'. The total number and species of larvae consumed by individual predators were recorded.

2.4. Experiment

2.4.1. Trap design

Following Humphries et al. (2002), modified quatrefoil light traps were constructed from Perspex™ and steel, with a removable 200 μm mesh aluminium sieve attached to the base so that fish larvae/juveniles could be retrieved in a manner similar to Ponton (1994). The entire light trap was 30 cm deep and 22 cm square and the sieve was 20 cm in diameter. In this original design, gaps of 5 mm were present between each tube of the trap "so that larvae could enter, but which prevented larger fish from entering" (Humphries et al., 2002, p. 1312).

In treatment combinations with light (cf. *Layout*), the Perspex™ tube at the centre of the trap held a yellow Cyalume® 12 h light-stick (Omniglow Corporation, W. Springfield, MA, USA). This colour has been shown to be superior in attracting the larvae and juveniles of some species of native Australian fish in turbid waters (Gehrke, 1994; Humphries et al., 2002). In treatment combinations with mesh, trap chambers were encased in 3 mm knot-to-knot mesh (Fig. 2).

2.4.2. Layout

Sixteen traps were set on two consecutive days (16 January 2007 and 17 January 2007) in slackwater areas at the ULR and LLR reaches, respectively. In each case, traps were deployed at sunset on the bottom and harvested the next morning. There were four experimental trap combinations: A (mesh/light), B (mesh/no-light), C (no-mesh/light), D (no-mesh/no-light). Traps were deployed according to a 4 × 4 Latin square design, which was randomly selected (after Kirk, 1995) and remained the same for the two replicate experiments (cf. *Statistical analyses–Experiment*). Traps were placed at ca. 1 m distance apart to account for the possible presence of (spatial) environmental gradients (Potvin, 1993), both perpendicular (i.e. 'edge effect') and parallel to the bank (Fig. 3). The 1 m distance between traps in the Latin square was judged to be a reasonable choice to reduce possible effects of light interference by adjacent traps (Gehrke, 1994).

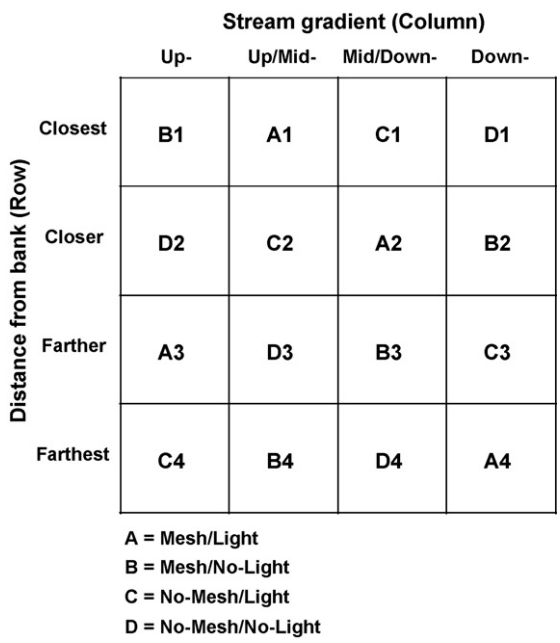

Fig. 3. Latin-square layout for a replicated field experiment to evaluate the efficiency of traps with/without mesh and with/without light-stick.

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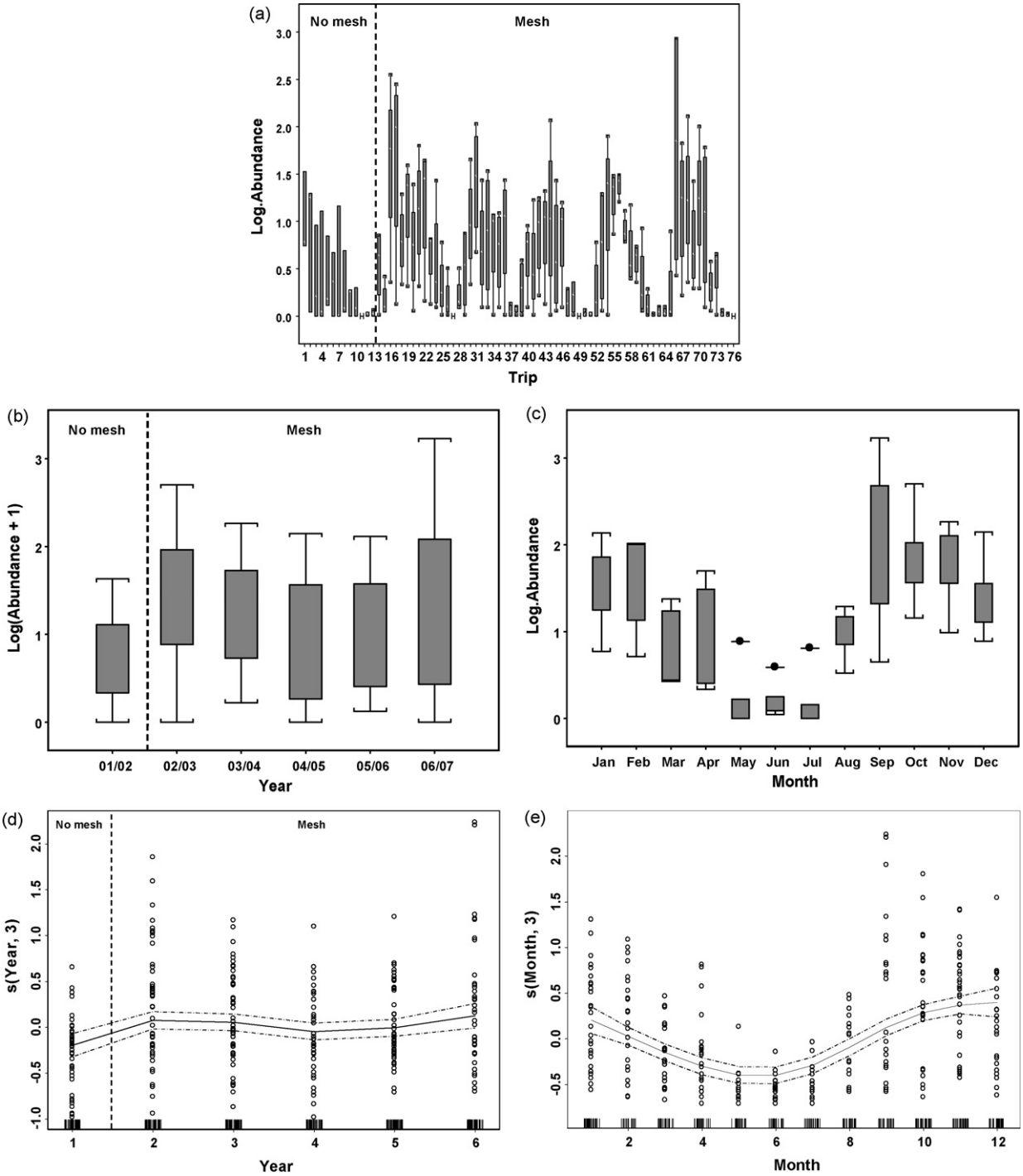

Fig. 4. (a–c) Boxplots (with ± S.E.) of the adjusted abundance of fish larvae and juveniles caught (a) on each sampling occasion (=trip), and pooled over (b) years and (c) months during a long-term monitoring study on Lindsay Island. (d–e) Partial residual plots (with confidence interval and rugplot) for year and month based on a generalised additive model (year and month coded).

2.5. Statistical analyses

2.5.1. Monitoring study

For all computations, raw abundances of larvae and juveniles were adjusted as catch per unit effort (CPUE) based on the number of light traps used. Preliminary comparisons of fish abundances (log + 1 transformed) over the study period were by a two-way ANOVA, with year and month as fixed effects in a completely randomised two-way factorial design (CRF-6,12: Kirk, 1995; Vilizzi, 2005). Because of the different number of observations (=trips) in the resulting year × month combinations, type III sums of squares were used (Milliken and Johnson, 1992). Significant omnibus tests of hypotheses were followed by Šidak-adjusted *a posteriori* pairwise comparisons (SPSS v.15 for Windows). All tests of significance were at $\alpha = 0.05$.

As a second step in the identification of temporal patterns in fish abundance, and with special reference to the application of mesh to light traps, a time series-like approach was attempted. To this end, due to the shortness of the abundance profiles which prevented use of classical time-series analysis techniques (cf. Zuur et al., 2007),

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yearly and monthly patterns in fish abundance were analysed by a generalised additive model (GAM). This was of the form:

$$\log(\text{abundance} + 1) \sim s(\text{year}, 3) + s(\text{month}, 3)$$

where $s(\ldots, 3)$ is a smoothing (cubic spline, hence with 3 d.f.) function of the predictors. The major strength with GAMs is their ability to 'let the data speak for themselves' (Hastie and Tibshirani, 1990), which is achieved by adopting an opposite (albeit complementary) approach to that of parametric regression-based models (including ANOVA). The model was implemented in S-Plus 2000 Professional Release 3 for Windows.

2.5.2. Gastro-intestinal contents

Species composition of the larvae ingested by *Hypseleotris* spp. was modelled by Bayesian estimation based on a multinomial distribution, with an uninformative Dirichlet distribution used as prior (Gelman et al., 2004). As some of the larvae ingested could not be identified, these were assigned in equal proportions to the species of larvae identified. This is equivalent to assuming that all species are ingested and decay in the gut beyond recognition at the same rate. For estimation of the mean length (TL) of predatory *Hypseleotris* spp., an uninformative uniform prior was used (McCarthy, 2007). Models were implemented in OpenBUGS (Spiegelhalter et al., 2007) by sampling 100,000 times from the posterior distribution by Markov chain Monte Carlo methods, after discarding a 'burn-in' sample of 10,000 (McCarthy, 2007).

2.5.3. Experiment

A Latin square design (LS-4: Kirk, 1995; Vilizzi, 2005) was employed, with traps in the field arranged accordingly. Trap was the (fixed) treatment factor with four levels (i.e. the mesh–light combinations: A, B, C, and D as in Fig. 3), and Row and Column were the blocking ('nuisance') factors. The latter were also fixed, following Quinn and Keough (2002). As the Latin square randomisation was the same for the two separate experiments (cf. *Experiment–Layout*), a measure of within-cell variation was possible with $n = 2$ (Mead, 1988). ANOVAs on the total number of fish caught (i.e. summed over all species) were carried out separately on the larvae/juveniles and adult components of the catch. Due to the presence of several 0 values causing the data not to meet the assumptions of normality and homoscedasticity (also after transformation), permutational ANOVA (PERANOVA: Anderson, 2001) was used. Design matrices for all terms in the (Latin square) model were specified manually using a combination of program XMATRIX (Anderson, 2003) and Microsoft® Office Excel 2007. The factors in the model were then tested individually with program DISTLM v.5 (Anderson, 2004), based on 9999 permutations of the 16 groups of two experimental units each resulting from the double-blocking of the Latin square design (Anderson and ter Braak, 2003). Significant omnibus tests for effects in the replicated design were evaluated by *a posteriori* Fisher–Hayter tests (Kirk, 1995).

3. Results

3.1. Monitoring study

Overall, there was high variability in catches, with abundance over the study period following a pronounced seasonal pattern (Fig. 4a and c). Also, there was an indication of an increase in abundance in the years following application of the mesh (Fig. 4b). ANOVA resulted in statistically significant differences for the month and year effects separately, as the latter did not interact significantly (Table 1, top). *A posteriori* pair-wise tests indicated lower abundances in the first 2001/2002 'no-mesh' year relative to the 2002/2003, 2003/2004 and 2006/2007 'mesh' years.

Similar to ANOVA, GAM resulted in a significant effect of both year and month (Table 1, bottom), with fish abundance modelled as a smooth function of the above predictors. Partial residual plots (Fig. 4d and e) evidenced the increase in abundance following mesh application as well as monthly changes.

Table 1
ANOVA results (based on a completely randomised two-factor design) for testing changes in fish larvae and juvenile abundance caught in light traps over a long-term monitoring study as a function of year and month

Source	d.f.	MS	*F*	*P*
Year	5	0.923	10.775	**0.002**
2001/2002 < 2002/2003	–	–	–	**0.001**
2001/2002 < 2003/2004	–	–	–	**0.047**
2001/2002 < 2006/2007	–	–	–	**0.005**
Month	11	2.601	30.368	**<0.001**
Year × month	51	0.186	2.176	0.121
Error	8	0.086		
s(year, 3)[a]	2		9.102	**<0.001**
s(month, 3)[a]	2		50.684	**<0.001**

Main effects and *a posteriori* pair-wise comparisons (Fisher–Hayter) are given ($\alpha = 0.05$; significant effects in bold).
[a] Generalised additive model results for cubic spline functions of the predictors. See also Fig. 4.

Table 2
Summary table for gastro-intestinal contents analysis of fish caught in light traps without mesh

Species	Dissected	Fish with larvae	Ingested larvae
Australian smelt	56	0	0
Hypseleotris spp.	1051	58	84 (total)
Fly-specked hardyhead (larvae)			5
Hypseleotris spp. (larvae)			15
Crimson-spotted rainbow fish (larvae)			13
Unidentified (larvae)			51
Crimson-spotted rainbow fish	27	0	0
Flathead gudgeon	1	0	0
Fly-specked hardyhead	160	0	0
Total	1295	58	168

The total number of dissected fish, of fish consuming larvae, and of species of larvae ingested are reported.

3.2. Gastro-intestinal contents

The gastro-intestinal tracts (GIT) of 1295 fish in total were dissected, revealing that 58 of these fish, notably all *Hypseleotris* spp., were consuming larvae (Table 2). The 84 larvae in total removed from the GIT of *Hypseleotris* spp. consisted of fly-specked hardyhead (5.9%), *Hypseleotris* spp. (17.9%), and crimson-spotted rainbow fish (15.5%), plus a consistent number of unidentified individuals (60.7%). The latter were a result of mechanistic damage likely to have occurred during capture and consumption of prey, and/or decay of larvae in the GIT of the predator. Bayesian estimates of the species structure of the larvae ingested by *Hypseleotris* spp. (Table 3)

Table 3
Bayesian posterior probabilities and credibility intervals for the distribution of species of larvae ingested by *Hypseleotris* spp. caught in light traps without mesh

Species	Observed	Bayesian estimates			
		Mean	S.D.	2.5%	97.5%
Fly-specked hardyhead	0.262	0.264	0.047	0.178	0.361
Crimson-spotted rainbow fish	0.381	0.379	0.052	0.281	0.483
Hypseleotris spp.	0.357	0.356	0.051	0.260	0.460

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Table 4
Permutational ANOVA results (based on a 4 × 4 Latin square design: replicated over two reaches) for evaluating the efficiency of traps (as measured by number of fish caught) with/without mesh and with/without light-stick in slackwater areas at two different reaches of Lindsay Island (Fig. 1)

Source	d.f.	MS	$F^{\#}$	P^{MC}
Larvae/juveniles				
Trap	3	994.531	3.716	**0.035**
Row	3	130.531	0.488	0.694
Column	3	117.614	0.439	0.729
Error	16	267.594		
Adults				
Trap	3	1595.031	12.593	**<0.001**
Row	3	638.448	5.041	**0.013**
Column	3	396.781	3.134	0.054
Error	16	126.656		

Row and Column are the 'nuisance' factors controlling for potential gradients in the spatial layout (cf. Fig. 3). $F^{\#}$ = pseudo-F; P^{MC} = Monte Carlo probability value (best for small sample sizes). Significant effects in bold ($\alpha = 0.05$).

showed similar probabilities for predatory *Hypseleotris* spp. ingesting larvae of their own species or of crimson-spotted rainbow fish, and a lower probability of feeding on fly-specked hardyhead larvae.

Lengths (TL) of predatory *Hypseleotris* spp. ($n = 32$; not all specimens measured) ranged 15–40 mm (mean 26.4 ± 0.8 mm S.E.), with only three individuals <22 mm (namely, 15, 17 and 19 mm). Using an uninformative prior for the mean, the average length of *Hypseleotris* spp. consuming larvae was 26.4 mm (95% credible interval: 24.7–28.1 mm).

3.3. Experiment

There was a highly significant statistical difference between trap types in number of fish caught (Table 4). Larvae/juveniles and no adults were caught in the mesh/light (Type A) combination only (Fig. 5a); on the contrary, only adults (hence, no larvae/juveniles) were present in the no-mesh/light (Type C) combination and, interestingly, also in the no-mesh/no-light (Type D) traps (Fig. 5b); finally, in traps with mesh but without a light-stick (mesh/no-light: Type B) no fish in either developmental period were caught (Fig. 5a and b). The number of adults caught in Type C traps was significantly higher than in Type D traps (Fig. 5b). Also, a statistically significant Row effect (i.e. distance from bank) was detected in the dataset for the adult fish, with higher catches recorded in traps (i.e. Types C and D) closest to the bank relative to those located farther and farthest (Fig. 5c). Out of the 189 individuals sampled in combinations C1 and D1 (cf. Fig. 3), 91 were *Hypseleotris* spp., 73 eastern gambusia, and 21 fly-specked hardyhead, the rest consisting of two flathead gudgeon and two Australian smelt.

4. Discussion

The present study has shown that the addition of mesh to light traps improved their efficiency in catching larvae and juveniles by excluding predatory fish. Importantly, this finding was supported by a combination of a long-term monitoring study and a field-based designed experiment. Also, an additional outcome of the experiment was that adult *Hypseleotris* spp. was the only species preying upon the larvae and juveniles of several small-body species, including their conspecifics.

4.1. Increased efficiency

Unsurprisingly, results from the designed experiment as to the effect of adding mesh to light traps were more 'clear-cut' when compared to the outcomes of the monitoring study. This is an

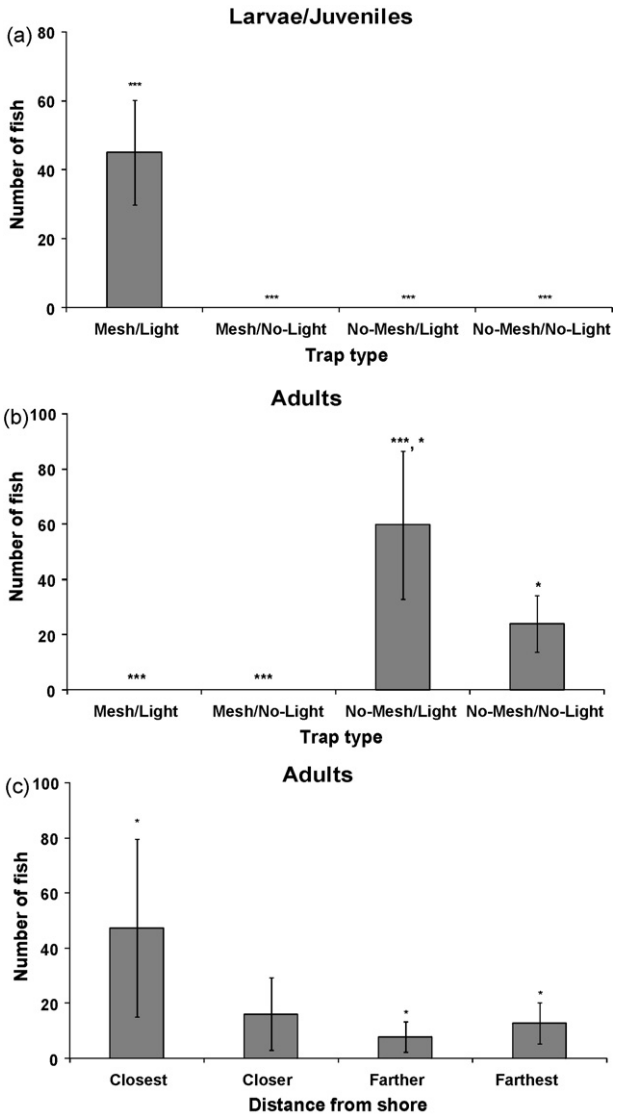

Fig. 5. Mean number (±S.E.) of (a) fish larvae/juveniles and (b) adults caught with different combinations of traps and of (c) adults along a gradient (cf. Fig. 3) in two slackwater areas of Lindsay Island (data pooled). Statistically significant ANOVA differences are marked by asterisks (cf. Table 4).

immediate consequence of the intrinsic difference between experiments and 'quasi-experiments' (*sensu* Cook and Campbell, 1979), with the former allowing for more complete manipulation and control, and the latter being more prone to generality and realism. This becomes evident when considering the entire gamut of research strategies, in which experiments, quasi-experiments, surveys, case studies, and naturalistic observations (*sensu* Kirk, 1995) are arranged in that order along the manipulation–generality continuum defined above. Therefore, based on the outcomes of the present study we have reason to believe that the observed trend towards an increase in the abundance of larvae and juveniles in yearly catches following mesh application was effectively due to an increase in the efficiency of the sampling gear. Notably, this result has been corroborated by (1) replication of the 'mesh' treatment over five (out of the total six) consecutive years of the monitoring quasi-experiment, making the latter (loosely) comparable to a before–after time series with multiple replication of the 'after' periods (Stewart-Oaten and Bence, 2001), and (2) a controlled experiment, which also allowed for isolation of potentially confounding spatial gradients. This dual approach, in which applied

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field studies are complemented with experimental investigations carried out under controlled conditions, is not uncommon in fisheries research (cf. Marchesan et al., 2005).

A number of studies have investigated the behaviour of fish in presence of light stimuli using passive sampling gear in general (e.g. Marchesan et al., 2005, and references therein), and the efficiency of different light sources and intensities in capturing the larvae and juveniles of fish with light traps in particular (e.g. Gehrke, 1994; Marchetti et al., 2004). Also, several authors have addressed the problem of bias in catches introduced by employment of light traps (Kelso and Rutherford, 1996). In this regard, and given our findings, we argue that issues of *in situ* (inter-specific and/or intra-specific) predation within the confined ambient of a trap should not be overlooked in future studies.

Thus, it is remarkable that in our experiment (i) larvae and juveniles only were sampled in the mesh/light trap (Type A) combination (with no adults caught), and that adult fish only were captured in (ii) the no-mesh/light (Type C) and (iii) the no-mesh/no-light traps (Type D). Specifically, the first result unarguably points to complete effectiveness of the mesh to prevent adult fish from entering the traps. This is further supported by evidence from field observations during the monitoring study indicating that accidental displacement of the sieve under a light trap would often cause *Hypseleotris* spp. to enter the latter, resulting in complete absence (as a likely effect of predation) of larvae (Vilizzi, personal observation). Equivalently, the second outcome reflects the 'non-effectiveness' of no-mesh/light (Type C) traps at catching larvae and juveniles, thus complementing the previous one. On the other hand, the presence of only adults in the no-mesh/no-light (Type D) combination could be explained as the result of a number of factors. These include: (i) the traps acting as structural refugia; (ii) the confined space conditions causing *in situ* predatory behaviours (as per the Type B-like traps used in the first year of the monitoring study); (iii) the possibility that reduced levels of light emitted by adjacent lighted traps may have caused fish to swim (erratically and/or accidentally) into the non-lighted ones.

As regards point (iii), light emitted from traps with a light-stick (namely Types A and C: Fig. 3) did not appear to induce a phototactic/photokinetic influence on fish. In fact, had this been the case then one would have expected to see the mesh/no-light (Type B) combination also capture fish, and specifically their larvae and juveniles only given the fully efficient screening effect provided by the addition of mesh (in Type A traps). However, this was not observed. Also, the arrangement of the traps within a Latin square design (Potvin, 1993; Quinn and Keough, 2002) would automatically adjust for any effect due to residual glow emanating from the lighted traps (Types A and C) to the non-lighted traps (Types B and D) (cf. Fig. 3). Assuming the veridicity of the above, the likelihood of predatory adult fish having consumed larvae and juveniles from within the traps, as per point (ii), would be confuted, thus providing support for explanation (i) that the traps may have acted as refugia.

Losses of individuals within traps due to predation could be reduced by regular harvesting during the deployment phase. Indeed, light traps can contribute to quantify and resolve the distributions and abundances of fish larvae (Doherty, 1987), and frequent checking at regular intervals has been recommended to provide larvae in 'excellent condition' (Faber, 1981). Yet, this practice may not be feasible in large-scale studies, due to intrinsic spatial and temporal constraints. This was indeed the case with the present monitoring program as well as with Humphries et al.'s (2002). On the contrary, in a smaller-scale setting Kubecka (1996) used modified Breder traps in the littoral zone of the Elbe backwaters and Klicava reservoir (Czech Republic). In that study, catches from traps, which were deployed over 24-h cycles and inspected every 2–4 h, were found to 'underestimate' the abundance of the larvae and juveniles of several species (in fact, no individuals were caught therein), which were instead sampled effectively with shore seines. Although this naturally led Kubecka (1996) to conclude as to the ineffectiveness of Breder traps at capturing young fish, which was explained as a behavioural avoidance response of the latter, the question remains as to whether *in situ* predation may has also played a role.

Further research on the dynamics of within-trap predation, such as latency, frequency, and extent of predatory attacks, may help elucidate the mechanisms of *in situ* predator–prey interactions in particular, and further our understanding of the bias and selectivity introduced by the use of trap-based fishing methods in general (Millar and Fryar, 1999).

4.2. Piscivory and cannibalism in *Hypseleotris* spp.

The onset of piscivory and, especially, cannibalism in fish as a result of habitat segregation has been widely documented in culture environments (cf. Baras and Jobling, 2002), and often dismissed as mere laboratory artefact (Dionne, 1985). However, it is remarkable that in the present study *Hypseleotris* spp. was the only species displaying piscivorous behaviour (including cannibalism). These opportunistic carnivores are known to consume a wide variety of prey, including terrestrial insects and micro- and macro-invertebrates (Meredith et al., 2003; Stoffels and Humphries, 2003; Pusey et al., 2004), and have been recently reported to feed on small gudgeon (Balcombe and Humphries, 2006). The latter finding would therefore provide evidence for piscivory in *Hypseleotris* spp. occurring under natural settings, as postulated by Meredith et al. (2003). Clearly, given overall dietary similarities with most of the other small-body species caught in the light traps (Lintermans, 2007), the occurrence of piscivory and cannibalism in *Hypseleotris* spp. could be interpreted as a species-specific behavioural response.

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