Aquat Ecol (2009) 43:569–576
DOI 10.1007/s10452-008-9192-9

In-stream behaviour of threatened fishes and their food organisms based on remote video monitoring

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Received: 27 August 2007 / Accepted: 16 April 2008 / Published online: 25 April 2008

Abstract Can remote underwater video be used to investigate the in-stream behaviour of small fishes and decapods? Diel activity of two threatened freshwater fishes (*Macquaria australasica* and *Gadopsis bispinosus*), a palaemonid prawn and an atyid shrimp, was established from remote underwater video in a pool of an upland stream in the current study. Decapods and large fishes (>5 cm TL) were nocturnal, whereas, small fishes (<5 cm TL) were diurnal. The suitability of using underwater video to quantify short-term (seconds) behavioural interaction among individuals was also demonstrated, with early-juvenile-phase *Gadopsis bispinosus* exhibiting interference competition on 35% of occasions when two or more individuals were observed. This study demonstrates that remote underwater video is useful for observing the in-stream behaviour of threatened freshwater fauna where other techniques are not viable, and presents sub-sampling of video as a means of reducing video processing time in assessing fish diel activity patterns.

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Keywords Gadopsidae · *Macrobrachium* · Observer effect · *Paratya* · Percichthyidae

Introduction

Remote data collection including the use of underwater video is enabling aquatic ecologists to understand ecosystems at scales that were not previously possible (Porter et al. 2005; Jan et al. 2007). Remote underwater video provides a means of observing aquatic biota including fishes and other mobile fauna (e.g. decapods) with minimal observer effect. The technique has been used to estimate fish size, density and diversity (Willis and Babcock 2000; Cappo et al. 2004; Shortis et al. 2007 and references therein), investigate the effectiveness of sampling gear (e.g. Grant et al. 2004) and observe fish behaviours including predation and diel activity (Holbrook and Schmitt 2002; Jan et al. 2007) in moderate to high visibility marine and freshwater systems. In particular, there is scope for using underwater video to study threatened species by non-destructive means and with minimal observer effect. Historically, field studies of Australian freshwater fishes have relied primarily on capture-based sampling techniques including netting and electro-fishing (e.g. Gehrke and Harris 2000), although, at times direct observation of fishes have been made from the stream bank or by snorkelling (Cadwallader and Rogan 1977; Merrick and Midgley

1981; Bishop et al. 1995; Pusey and Kennard 2001; Hattori and Warburton 2003). Research of Australian freshwater fish based on remote underwater video is a logical extension of this approach in non-turbid environments.

The Cotter River is a clear cobble-bottomed upland stream with generally low turbidity (White et al. 2006). The river is the last stronghold within the Australian Capital Territory (ACT), for two remnant populations of threatened fishes, the nationally endangered Macquarie perch *Macquaria australasica* Cuvier 1830 (Percichthyidae) and the locally vulnerable two-spined blackfish *Gadopsis bispinosus* Sanger 1984 (Gadopsidae)(Lintermans 2002). There have been intermittent auto-ecological studies (Lintermans 1998; Ebner and Lintermans 2007) and a commitment to long-term monitoring of these populations (Lintermans and Rutzou, ACT Parks and Conservation Service, unpubl. data; Lintermans, Environment ACT, unpubl. data); however, these efforts have focused on large fish (>5 cm total length (TL)) and the ecology of the early-juvenile-phase (<5 cm TL) of either species in the Cotter River or elsewhere, is poorly known. Large fishes of the Cotter River are known to feed on small fishes and macroinvertebrates, especially shrimps and prawns (Lintermans 1998, 2002; Ebner et al. 2007). Prey are known to exhibit diel habitat use patterns as a function of the risk of visual predation in aquatic systems (Pittman and McAlpine 2001; De Robertis 2002; Kronfeld-Schor and Dayan 2003; Aguzzi et al. 2007). However, this phenomenon has not been investigated in the Cotter River.

Observations from the stream bank and by snorkelling have revealed that these species can be diurnally active in the early-juvenile-phase (Ebner and Lintermans 2007). Early-juvenile-phase *G. bispinosus* are benthic, whereas, early-juvenile-phase *M. australasica* use much of the water column at about 2–5 weeks post-hatch (Ebner and Lintermans 2007). It is hypothesised that the latter species is especially vulnerable to predation by resident alien rainbow trout *Oncorhynchus mykiss* (Walbaum 1792) and brown trout *Salmo trutta* Linnaeus, 1758 (hereafter collectively referred to as trout). Remote underwater video represents a means for clarifying aspects of the ecology of *M. australasica* and *G. bispinosus* in the early-juvenile-phase with minimal observer effect.

The aim in the current study is to assess the suitability of underwater video as a technique for observing behaviour of these two species and other aquatic fauna of the Cotter River. Specifically to: (a) determine if trout feed on early-juvenile-phase *M. australasica*; (b) determine the diel activity pattern of small fauna (<5 cm TL) including the early-juvenile-phase of the two threatened fishes, shrimps and prawns, and; (c) to investigate the strategies for sub-sampling or stratifying video records to reduce labour requirements in the video-processing phase.

Methods

The type of multiplexer based video system that was used is described fully in Mills et al. (2005), although, video information was recorded at the stream bank and there was no need to transmit information from a floating pontoon in the current study. On 13 January 2003, six monochrome video cameras were positioned randomly underwater within a single pool, Bracks Hole, in the Cotter River, ACT. Cameras were mounted 0.6 m above the benthos by a clamp attached to a stand to view a 0.5 × 0.5 m quadrat of substrate delineated by a metal frame. An infrared light source (Mills et al. 2005) was placed at the front corner of each quadrat facing away from the camera and programmed to turn on half an hour before sunset and turn off half an hour after sunrise. Following the first night of filming when it was apparent that this lighting was insufficient to distinguish small animals (e.g. shrimps, *Paratya australiensis* Kemp 1917 (Atyidae) and prawns *Macrobrachium australiense* Holthuis 1950 (Palaemonidae)), three cameras were removed from the pool to enable placement of a second light source halfway along the sides of the quadrat to illuminate the rear of the quadrat in association with the three remaining cameras. We assumed that infrared light was not visible to the fauna and did not impact upon animal behaviour (Partridge 1990). Filming ceased at 1300 h, 17 January 2003. Figure 1 shows a single frame of an adult *M. australasica* as recorded on camera.

Initially, each 3-h videocassette that had been used in recording (including those from the initial six camera set-up) was viewed for a short period (about five minutes) by a single observer on a 68 cm flat screen television from a time-lapse videocassette

Fig. 1 A single video frame of an adult *Macquaria australasica* illuminated by infrared lights (one light can be seen on the right) and recorded by Camera 3 at night. A 0.5 × 0.5 m quadrat is visible on the benthos providing an indication of scale

recorder to determine the video quality and general patterns of fish activity. Video from Camera 1 was generally of poor quality (due to condensation inside the lens) and therefore only footage from Camera 2 and Camera 3 was examined in detail based on a single diel period from 1200 h, 16 January 2003 to 1200 h, 17 January 2003. Record was made of species, time that each individual entered and exited the quadrat (h, min, s), total length (TL, cm) and any behavioural interactions among individuals. Species were identified from external morphological features and locomotive motion and shrimps and prawns were distinctly reflective under infrared lighting at night. Where fishes could not be confidently identified a record was made as 'unidentified fish'. Rainbow trout and brown trout could not be differentiated from one another (individuals filmed by day were of insufficient size to observe markings; markings were not sufficiently visible on a large individual that moved rapidly across the field of view at night). In order to check the reliability of video processing, a second technician repeated the process based on Camera 3 only, and recorded almost identical output data (three small fishes had been overlooked by one of the observers).

Total length (±0.5 cm) of fish and crustaceans was measured on the screen, by scaling the proportion of the quadrat width viewed on the screen to the known width of the quadrat (i.e. 50 cm). In order to assess the measurement error associated with animal proximity and angle to the camera, we filmed and measured fish silhouettes (3 cm, 6 cm and 30 cm TL) on the benthos at left, middle and right within the front, centre and back of the quadrat. The process was repeated with silhouettes at 15 cm above the benthos (although, the largest silhouette was out of view at some positions). The TL of individuals swimming in midwater close to the camera lens was overestimated by this process (mean ± SE of 31.7% ± 4.2 for fish at 15 cm above benthos, $n = 22$), however, the majority of individuals were located close to the benthos and early-juvenile-phase fishes could be clearly differentiated from larger fishes (9.8% ± 1.1 for fish at 0–5 cm above benthos, $n = 27$). Large prawn *M. australiense* (>3 cm TL) were differentiated from shrimp *P. australiensis* and small prawn (≤3 cm TL), and small (≤5 cm TL, early-juvenile-phase) and large fishes (> 5 cm TL) were differentiated. In order to investigate diel activity patterns, observations of each taxon were plotted in hourly time classes according to camera. Data were subsampled as three randomly selected (a) 5-min periods (15 min total) and (b) 1 min periods (3 min total), per hour, and plotted for comparison with the complete dataset.

In the absence of observations of trout feeding on early-juvenile-phase *M. australasica*, or any occasion where both species were in view simultaneously, quantitative records of intra-specific interactions involving *G. bispinosus* in daylight hours were used to investigate the use of the remote underwater video technique for observing short-term (i.e. occurring in seconds or less) behaviour. A chase-flee interaction was recorded when an individual chased one or more individuals within the confines of the quadrat. A neutral interaction was recorded when two fish were in the quadrat simultaneously and no aggressive behaviour was witnessed. When three individuals were present in the quadrat simultaneously one of three combinations was recorded: (a) three neutral interactions; (b) one aggressive and two neutral interactions or (c) two aggressive and one neutral interaction.

Results

Continuous video from two cameras over 24-h produced 1,389 observations of fauna, comprising 621 and 772 observations on Cameras 2 and 3, respectively (Table 1). The majority of these observations were of

Table 1 Total number of observations of each species entering the quadrat (expressed as a percentage in brackets) as observed by Cameras 2 and 3 over a 24-h period

Taxa	Number of observations			
	Camera 2	Camera 3	Mean	Total
Teleostei				
Gadopsidae				
Gadopsis bispinosus	290 (47)	408 (53)	349	698
Percichthyidae				
Macquaria australasica	184 (30)	82 (11)	133	266
Salmonidae				
Trout	10 (2)	1(0)	6	11
Cyprinidae				
Carassius auratus	6 (1)	5 (1)	6	11
Unidentified fish	21 (3)	109 (14)	65	130
Decopoda				
Palaemonidae				
Macrobrachium australiense (large)	47 (8)	32 (4)	40	79
Atyidae and Palaemonidae				
Paratya australiensis & small *M. australiense*	49 (8)	125 (16)	87	174
Parastacidae				
Cherax destructor	12 (2)	6 (1)	9	18
Euastacus	2 (0)	0 (0)	1	2
Total	621 (100)	768 (100)	695	1,389

fishes, particularly *G. bispinosus* and to a lesser extent *M. australasica*, and decapods (Table 1). Trout (either *O. mykiss* or *S. trutta*) were observed on 10 occasions on Camera 2 and once on Camera 3 (Table 1). The majority of these observations on Camera 2 were related to two trout chasing one another in and out of the quadrat repeatedly within a 1-min period (Table 1). Figure 2a–c) show that small fishes (<5 cm TL) were primarily diurnal, whereas, larger fishes were nocturnally active or evading the camera by day. There was an indication that large fishes were most active around dusk and dawn (Fig. 2a–c). A substantial number of observations were made of *P. australiensis* and small *M. australiense* ($n = 174$) and large *M. australiense* ($n = 79$) (Table 1). Large *M. australiense* were only observed at night ($n = 79$). Similarly, *P. australiensis* and small *M. australiense* were primarily seen at night (Fig. 2), when they were often swimming in the water column.

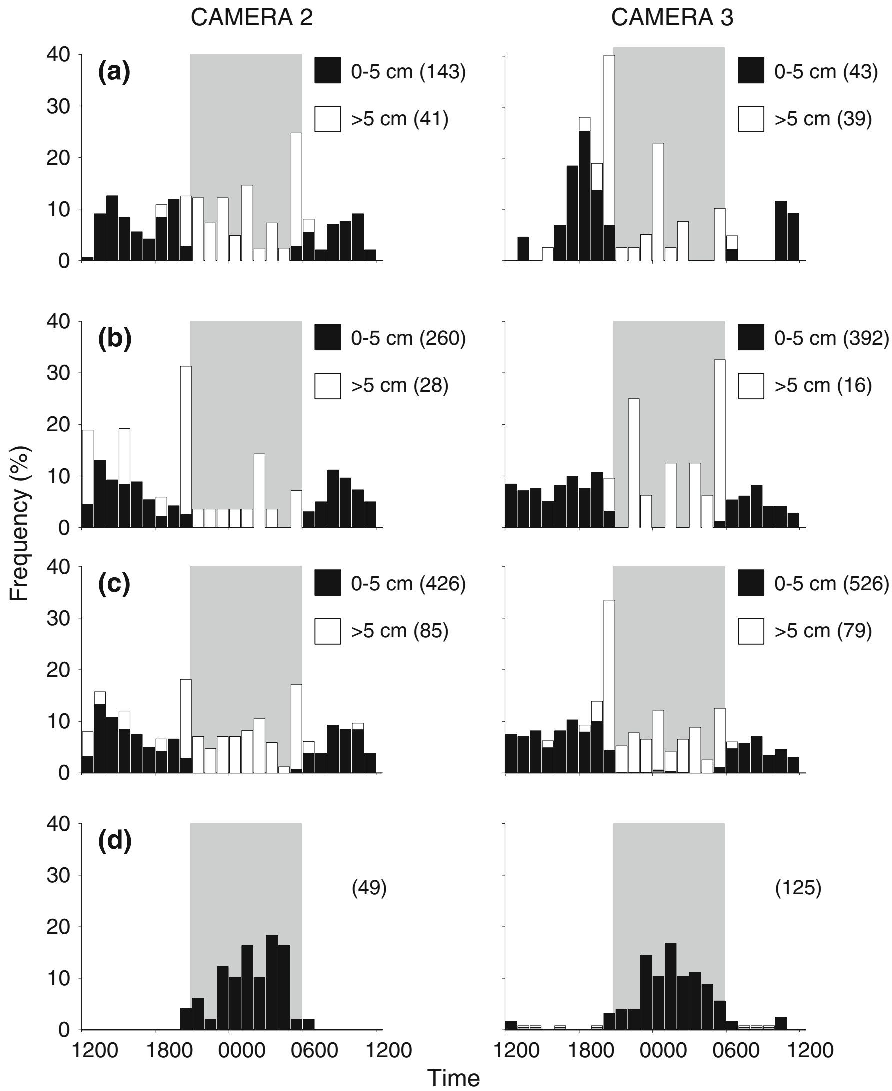
The pattern of diurnal activity exhibited by early-juvenile-phase *G. bispinosus* and *M. australasica* was discernable following 15-min sub-sampling of hourly observations. However, this pattern became less evident with 3-min sub-sampling of hourly observations, this being a function of the reduction in total number of observations (Fig. 3). Inspection of video footage collected on six cameras at the beginning of the sampling period and on three cameras later in the sampling period confirmed patterns of nocturnal behaviour of shrimps, prawns and large fishes and diurnal activity of small fishes across multiple diel periods.

Aggressive interactions (chase-flee behaviour) comprised 35% of all observed intra-specific interactions involving *G. bispinosus* (114 interactions on Cameras 2 and 3 combined). All of these aggressive interactions involved an individual of equal or larger size chasing another individual (Table 2). Thirty-nine of 40 of these aggressive interactions involved individuals in the early-juvenile-phase. On one occasion, an individual of 9 cm TL was observed chasing an individual of 6 cm TL. On just four occasions on Camera 2 and seven occasions on Camera 3, three individuals occurred in the quadrat, simultaneously.

Discussion

Fish and decapod crustaceans are known to undertake ontogenetic shifts in diel activity and habitat use as a function of predation risk and specifically tradeoffs between body size and light-mediated visual

Fig. 2 Changes in the frequency of observing (**a**) identified *M. australasica*, (**b**) identified *G. bispinosus*,(**c**) all fish (including individuals not identifiable to species level), and (**d**) shrimp and small *M. australiense* expressed as a proportion of the total observations over a diel period commencing 1200 h, 16 January 2003. Total number of observations is shown in brackets on each graph. Shading indicates night



predation (Pittman and McAlpine 2001; De Robertis 2002; Kronfeld-Schor and Dayan 2003; Aguzzi et al. 2007). In the current study diel activity of two threatened fishes, a palaemonid prawn and an atyid shrimp, was established from underwater video monitoring and use of infrared lighting in an upland stream pool. Whilst repeated enumeration of individuals on fixed cameras undoubtedly occurs, this approach provides an effective means for quantifying the diel activity patterns of aquatic communities (e.g. Jan et al. 2007) where continuous observation is otherwise difficult or impossible.

Findings that a freshwater palaemonid and an atyid were nocturnal concur with other reports of these taxa (e.g. Johnson and Covich 2000; Short 2004). Early-juvenile-phase *M. australasica* and *G. bispinosus* were diurnal, whereas, large fishes (>5 cm) were crepuscular or nocturnal. This represents the first evidence that both of these threatened fishes are confined to be active in the day while in the early-juvenile-phase. Foraging capability of early-juvenile-phase fishes and/or predator avoidance may explain this activity pattern (De Robertis 2002; Reebs 2002). Night versus day feeding capability of early-juvenile-phase *M. australasica* and *G. bispinosus* remains to be investigated (e.g. Job and Bellwood 2000, 2007). Whereas increased activity of large benthic predators was observed at night relative to day in the current study (Fig. 2). That large *M. australasica* and *G. bispinosus* were nocturnal, conforms to patterns

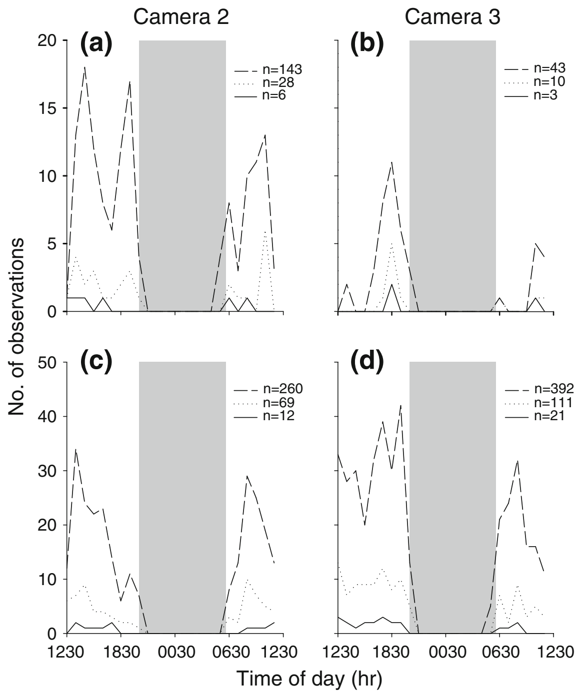


Fig. 3 Number of early-juvenile-phase (<5 cm TL) *M. australasica* (**a**, **b**) and *G. bispinosus* (**c**, **d**) observations per hour on two cameras in a diel period (commencing 1200 h, 16 January 2003) based on real-time (dashed line); a 15-min sub-sample per hour (dotted line) and a 3-min sub-sample per hour (solid line). Shading indicates night

Table 2 The frequency of aggressive and non-aggressive interactions and the effect of relative body size on the outcome of encounters between early-juvenile-phase *G. bispinosus*

	Number of interactions				
	Camera 2	Camera 3	Mean	Total	
Aggressive interactions					
Chaser larger	9	13	11	22	
Chaser of same size	9	9	9	18	
Chaser smaller	0	0	0	0	
Subtotal	18	22	20	40	(35%)
Neutral interactions	26	48	37	74	(65%)
Total	44	70	57	114	(100%)

revealed by radio-tracking (Ebner and Lintermans 2007) or ad hoc spotlighting in the Cotter River catchment (Ebner, personal observation).

The current study in conjunction with others highlights the importance of night-time activity of large Australian aquatic fauna and in particular adult phase percichthyids (Pen and Potter 1990; Crook et al. 2001; Pusey and Kennard 2001; Ebner and Lintermans 2007; Thiem et al. 2008). Consequently, we join Johnson and Covich (2000) in recommending caution when interpreting models of stream habitat-use based exclusively on diurnal surveys (e.g. Maddock et al. 2004; Boys and Thoms 2006). The basis for the nocturnal activity of the large native fishes in the current study is unknown, but could represent a strategy for avoiding diurnally active piscivorous birds and/or competition with introduced trout species, and may or may not have an evolutionary basis. Experiments are to be recommended for answering this question since the outcomes have important implications for the management of threatened fish populations and introduced species (Ebner et al. 2007).

Whilst automated software analysis has decreased the time required to process video records, manual processing is still required in distinguishing multiple species and complex behaviour (Ruff et al. 1995; Hatch et al. 1997; Jan et al. 2007). The 24-h continuous video from two cameras took a technician about 17 days per camera to process, prior to data analysis in the current study (although substantially less time would be required if data were only required for a single species or in regard to a single type of behaviour). The current study has demonstrated the benefit of viewing sub-samples of film to establish the diel activity pattern of two threatened fishes. More generally, the amount of video viewed in a sub-sample will be a function of the frequency of occurrence of the feature of interest (e.g. presence/absence of species) and should be estimated in a pilot study. The example provided in Fig. 3 shows that a pattern of diurnal juvenile fish activity remains when one quarter of the total video is processed but not when 5% of the total video is used. The sub-sampling process is also likely to be valuable for providing a preliminary exploration of large continuous video records (e.g. Jan et al. 2007) as a basis for identifying periods for more comprehensive processing. For example, large fish activity was especially pronounced around dawn and dusk in the current study.

Trout interactions with either threatened fish species were not effectively investigated here. Trout were rarely observed on film in this study despite (a) video-independent confirmation of their presence during filming, and (b) day-time observations in the weeks prior to filming indicating that trout were the most conspicuous species in the pool (Ebner, unpubl. data). Increasing the number of cameras and/or camera field of view should be a priority in future efforts to investigate trout interactions with early-juvenile-phase *M. australasica*. To this end, horizontally oriented cameras are recommended rather than downward facing cameras, since this study has found (a) early-juvenile-phase *M. australasica* are diurnal and short-range infrared lighting is not required, and (b) trout were likely evading the cameras or were positioned above the field of view. Additionally, camera resolution also impacts taxonomic identification capability and should be considered carefully when designing ecological studies and purchasing equipment. Nevertheless, the value of the remote underwater video technique for observing short-term (seconds) behaviour was clearly demonstrated through the quantitative records of intra-specific interactions involving *G. bispinosus.* Specifically, *G. bispinosus* exhibited a high level of interference competition (35% of interactions, Table 2) in the early-juvenile-phase in the current study.

We conclude that (a) sub-sampling of continuous video can be used to minimise the amount of video processing required to quantify fish behaviour, and (b) that diel activity patterns of fauna can be used as a basis for stratifying effort in the video processing phase. There is scope for application of remote underwater video in clear water freshwater ecosystems. Possible research applications include: threatened species research where non-destructive techniques are especially relevant; examination of the effectiveness of existing survey techniques; and the quantification of real-time behaviour of aquatic fauna including biotic interactions and habitat-use. Remote underwater video and in particular real-time imaging also provides a means of engaging the community and promoting awareness of aquatic ecosystems, at a time when many aquatic species including native Australian fishes are threatened with extinction.

Acknowledgements Gerald Verdouw and Jake de Hoog (SciElex) and Dave Mills and Jayson Semmens (Tasmanian Aquaculture and Fisheries Institute) provided technical advice regarding the use of video equipment. Suggestions from Jayson Semmens, Jason Thiem, Ben Broadhurst, Mark Lintermans, Richard Norris, Don Fletcher and three reviewers improved the manuscript. Environment ACT and Transgrid funded the study. Filming was conducted in Ngunnawal Country.

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