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Management and Ecology Note

Identifying critical periods of non-native fish dispersal from aquaculture sites

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Global aquaculture activities tend to be highly dependent on culturing alien species, with their voluntary and/ or accidental introduction into the wider environment an increasing ecological concern (De Silva et al. 2010). The movement of fishes between countries and biogeographic regions for aquaculture can also result in the accidental transfer of 'hitch-hiking species' (Savini et al. 2010; Blakeslee et al. 2010), enabling the long-distance dispersal of non-commercial alien species that would otherwise never be introduced into new regions (Blakeslee et al. 2010). Following their introduction into aquaculture in a new region then, depending on the 'openness' of the aquaculture facility, opportunities for their dispersal into the wild potentially exist, particularly where the biosecurity of rearing facilities is low, providing minimal barriers to natural dispersal (Marchini et al. 2008).

Freshwater aquaculture of cyprinid fishes is routinely completed in pond systems that usually have some connection to adjacent water courses, at least for short-time periods, such as during pond drain-down for fish harvesting (Horvath et al. 2002). This potentially provides opportunities for the unintentional release of fishes of non-commercial interest that might have been accidentally introduced to the site during fish movements. Indeed, this has been implicated in the release of a number of alien fishes into the wild from aquaculture sites in Europe, particularly the highly invasive topmouth gudgeon *Pseudorasbora parva* (Gozlan et al. 2010). Their local dispersal from aquaculture sites has facilitated their colonisation of freshwaters in at least 32 European countries and whose initial long-distance dispersal from China was through being accidental contaminants of batches of Asian carps in aquaculture (Gozlan et al. 2010).

The risk management of alien fishes is strongly reliant on preventing the initial introduction (Davies et al. 2013) and then dispersal prevention (Britton et al. 2008, 2010). Although there is extant knowledge on how to prevent *P. parva* being released accidentally into aquaculture ponds via utilising auditing processes (Davies et al. 2013), there is little known about their dispersal rates from sites following their release and how this is affected by on-site activities. Consequently, the aim here was to assess the dispersal of *P. parva* from an aquaculture site during normal operation and compare this to their dispersal during periods of pond drain-down.

The study was completed on a former aquaculture facility in Southern England where *P. parva* were licensed for holding and where previous work had revealed limited natural dispersal (Pinder et al. 2005). As part of an ongoing eradication programme for *P. parva* from the UK (Britton et al. 2010), this site of 42 ponds was being de-watered prior to chemical treatment to extirpate the species. Each pond was at least 400 m^{-2} in area and 2 m depth, and discharged into a rectangular overflow channel of 400 m length via an underground connecting pipe (12 cm diameter) that was plugged during normal operation, i.e. there was no water egress. This overflow channel then discharged into a settlement pond of approximately 200 m^{-2} via an unscreened outflow (50 cm width). Water then discharged from the settlement pond into an adjacent stream via an un-screened pipe (30.5 cm diameter).

Assessment of the dispersal rates of *P. parva* was completed in two phases. Phase one was completed in July 2012 and 2013, periods of the *P. parva* reproductive season when larvae and juveniles were most likely to be present and drifting from the site (Pinder et al. 2005), and was to assess drift under normal conditions when no ponds were being drained. A drift net with a rectangular opening of 24 cm x 40 cm that lead to a 250 μm mesh net with a removable end-cap (EFE & GB Nets, Bodmin, UK) was installed in front of the discharge pipe of the settlement pond, so all water leaving the site passed through the net. This was set for one hour starting at 09.00. As this captured no fish, it was re-set and fished continually over a 24 hour period, with checking every 6 hours when the net was removed and contents emptied into a sorting tray. Captured fish would be euthanized (anaesthetic overdose; MS-222) and subsequently counted and measured in laboratory conditions (fork length, nearest mm), enabling the number of dispersing fish per hour to be calculated. Concomitantly, the flow of water passing through the net was measured using a Stream Flowmeter (NHBS Ltd. Devon, UK)

The second phase was completed in July 2014 when two aquaculture ponds were being drained down that were both known to contain *P. parva*. A drift net was again placed in front of the discharge pipe, commencing three hours before the two ponds were drained, with checking hourly. The plugs on the two ponds were then released, with the drift net then checked hourly for the next 24 hours, using the same protocol as outlined above. For both phases of the study, the volume of water passing through the drift net was determined from $Q = A\bar{u}$ (Buchanan & Somers 1969), where Q is the discharge (m^{-3} s^{-1}), A is the cross section of the drift net occupied by water (m^2) and $\bar{u}$ is the water velocity ($m \cdot s^{-1}$).

During Phase 1, no fish were captured in the drift net in either 24 hour period when mean flow rate of water passing through the drift net was 0.08 ± 0.01 $m \cdot s^{-1}$ in 2012 and 0.07 ± 0.01 $m \cdot s^{-1}$ in 2013. This was despite *P. parva* being observed in the aquaculture ponds on site, including larvae and young-of-the-year. In Phase 2, no fish were captured in the drift net in the initial three hours of fishing when the two ponds were still full and the mean flow was 0.07 ± 0.01 $m \cdot s^{-1}$. The water from the two ponds was then released, discharging their contents initially into the overflow pond, then the settlement pond, and then through the drift net prior to being discharged into the stream. Over the next 22 hours, the flow of water through the net was increased to a mean of 0.47 ± 0.13 $m \cdot s^{-1}$, with *P. parva*, plus other fishes, captured in the drift net during each subsequent hour of monitoring. A total of 196 P. parva (42.1 ± 0.72 mm), 42 three spined stickleback *Gasterosteus aculeatus* (34.8 ± 1.3 mm), 6 bullhead *Cottus gobio* (48.1 ± 2.2 mm) and 2 tench *Tinca tinca* (114.5 ± 6.5 mm) were captured. In the hours when more than 5 *P. parva* were captured, whilst there were some significant differences in *P. parva* lengths, these were not significantly related to mean flow per hour or time since the drain-down started (R^2 = 0.04, $F_{1,13}$ = 0.55, P = 0.47; R^2 = 0.05, $F_{1,13}$ = 0.53, P = 0.49). The relationship between the number of dispersed fish per hour, the mean flow rate in that hour and time since drain-down commenced was also not significant (R^2 = 0.04, $F_{1,13}$ = 0.55, P = 0.47; R^2 = 0.05, $F_{1,13}$ = 0.53, P = 0.49, respectively; Fig. 1a,b). During the period of pond discharge, a calculated 2,377,842 litres of water passed through the drift net, with the cumulative number of fish dispersing from the site since the commencement of the drain-down being significantly related to the cumulative volume of water released (R^2 = 0.94, $F_{1,17}$ = 313.74, P <0.01; Fig 1c) and cumulative time since the drain down commenced (R^2 = 0.83, $F_{1,17}$ = 51.4, P < 0.01; Fig. 1d).

Thus, under the normal activities of the aquaculture site, no *P. parva* were detected drifting out of the site, but this altered during the drain-down operation when relatively high numbers of *P. parva* were captured passively dispersing from the site following their displacement by elevated flows. Moreover, their lengths indicated they were primarily mature fish, not larvae or juveniles, and thus their potential release into the wider environment during their reproductive season could have implications for the subsequent establishment of populations, particularly given this relatively high ‘propagule pressure’ (Britton & Gozlan 2013). It suggests that pond aquaculture must increase biosecurity during key husbandry and harvesting processes in order to minimise dispersal opportunities on sites where non-native fish are present, especially those that are small bodied like *P. parva* (Gozlan et al. 2010). This should assist prevention of the small-scale dispersal of non-native fishes into the wild that often occurs following a long-distance dispersal event, and thus help prevent secondary invasions from developing.

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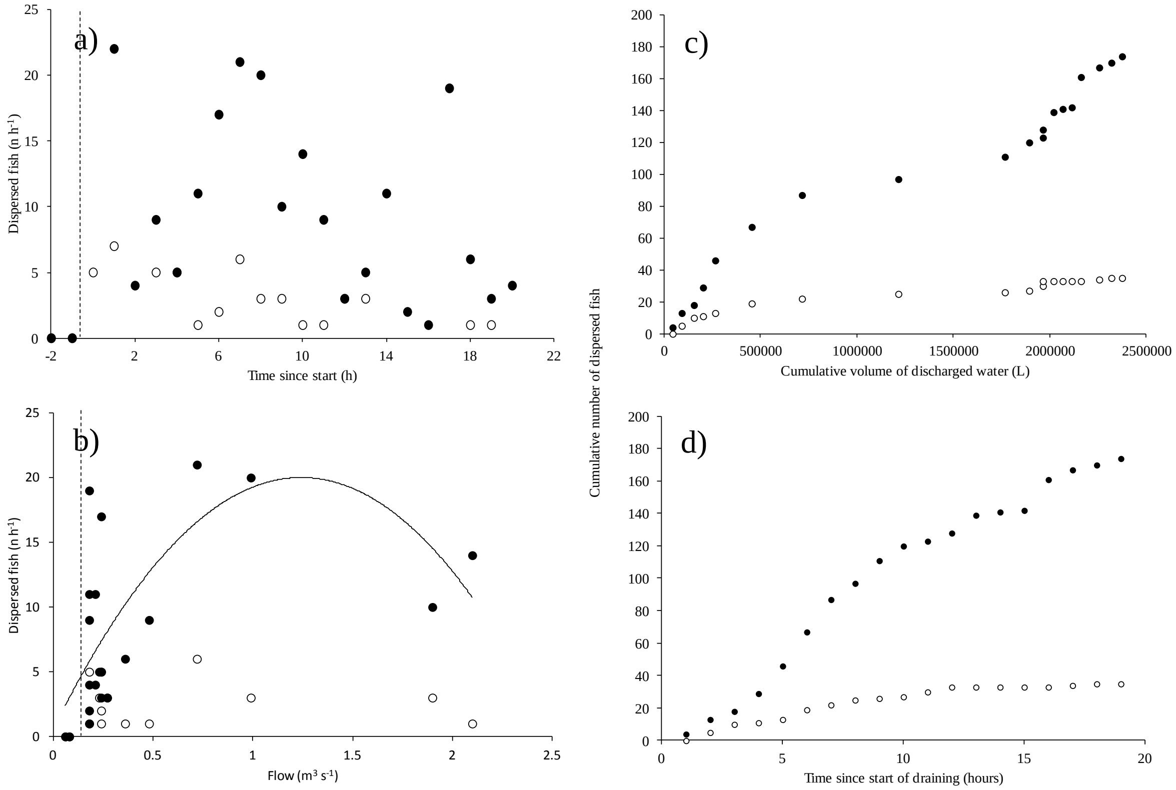
Figure captions

Figure 1. Relationship of the number of fishes dispersed from aquaculture site with (a) discharge velocity and (b) time and just before and during drain down exercise; and cumulative number of fish dispersed from the aquaculture site versus total volume of water released (c) and time (d). Flow is in $m^3 s^{-1}$; ● *P. parva*; ○ *G. aculeatus*. Dashed line denotes the flow rates pre- (left) and post-pond draining (right).

Figure 1.



a)
b)
c)
d)
Dispersed fish (n h-1)
Time since start (h)
Flow (m3 s-1)
Cumulative number of dispersed fish
Cumulative volume of discharged water (L)
Time since start of draining (hours)