Pre-deployment acclimatisation of farmed ballan wrasse (*Labrus bergylta*) to sea-cage conditions promotes behaviour analogous to wild conspecifics when used as cleaner fish in Atlantic salmon (*Salmo salar*) farms

Adam J. Brooker[1]*, Andrew Davie[1], Eric Leclercq[1-2], Benjamin Zerafa[1] and Hervé Migaud[1]

[1]Institute of Aquaculture, University of Stirling, Stirling FK9 4LA, Scotland, UK.

Tel: +44 (0)1786 467881 / Fax: +44 (0)1768 472133

[2]Present Address: Lallemand Animal Nutrition, Blagnac, 31702, France.

*Corresponding author

E-mail: a.j.brooker@stir.ac.uk

Telephone: +44 (0)1786 467881

Address: Institute of Aquaculture, University of Stirling, Stirling FK9 4LA, Scotland, UK.

Abstract

Ballan wrasse (*Labrus bergylta*) are used as cleaner fish in commercial Atlantic salmon farming to remove ectoparasitic sea lice. While the delousing performance of wild wrasse is usually good, that of farmed wrasse is variable, possibly because of different conditions in hatcheries and sea cages. In this study, three passive-acoustic telemetry (PAT) trials were conducted at a salmon farm to compare the behaviour of wild and farmed wrasse and test the effect of acclimatising farmed wrasse to sea-cage conditions before deployment. Up to 40 fish were monitored simultaneously for 60–124 days by triangulating tag positions within a hydrophone array every 6–10 secs. This data was used to assess fish depth and preferred cage locations and calculate activity, orientation and home ranges.

Wild wrasse occupied shallower depths (13.3 ± 2.4 m) than farmed wrasse, which remained near the bottom of the cages (18.2 ± 1.7 m). Swimming activity was higher in wild wrasse with significant diurnal variations due to nocturnal quiescence on 68% of observed days. Wild wrasse rapidly developed large home ranges (616.8 ± 110.1 m^2), preferring cage corners. Hatchery-and-sea-cage acclimatisation improved the behaviour of farmed wrasse; they rapidly moved up the water column (9.08 ± 2.05 m after 1 week) and established home ranges (514.3 ± 146.6 m^2), and they developed diurnal activity patterns, which may indicate a positive response to acclimatisation.

Acclimatising farmed ballan wrasse to sea-cage conditions positively improved and encouraged behaviours similar to those seen in wild wrasse, including diurnal rhythms and the establishment of home ranges, and is recommended for all farmed wrasse prior to deployment to improve delousing performance.

Keywords: Passive-acoustic telemetry, cleaner fish, biological control, acclimatisation, sea lice, salmonid aquaculture

1 INTRODUCTION

In North Atlantic salmon-farming regions, the use of cleaner fish as a component of integrated pest management strategies against the salmon lice *Lepeophtheirus salmonis* and *Caligus* spp. has increased significantly in the past decade. Two species of cleaner fish are currently being farmed, ballan wrasse (*Labrus bergylta*) and lumpfish (*Cyclopterus lumpus*). Norway is the biggest producer of cleaner fish with 30.6 million farmed in 2018 (63% of total deployed, Norwegian Directorate of Fisheries, www.fiskeridir.no/English/Aquaculture/Statistics/Cleanerfish-Lumpfish-and-Wrasse), while UK production levels in 2018 were 103,000 and 2,753,000 for ballan wrasse and lumpfish, respectively (Munro and Wallace, 2018). Securing a sustainable supply of farmed cleaner fish and becoming self-sufficient is a key priority in meeting the demands of the industry.

While reaching this target may be achievable given the current pace of progress in cleaner fish research and infrastructure investment, it is necessary to ensure that the farmed cleaner fish are robust and perform effectively once deployed at sea through good health and welfare. Indeed, improving the survival and delousing performance of farmed cleaner fish may allow their stocking densities to be reduced while maintaining optimal delousing, thereby reducing the number of fish required. However, while wild wrasse are effective delousers in commercial salmon sea cages (Treasurer, 2002), as are farmed wrasse in experimental tank studies (Leclercq et al., 2014a), the performance of farmed wrasse in sea cages has been questionable. It is possible that the anecdotal reports of variable performance of farmed wrasse in sea cages, in contrast to their effective performance in tank studies (Leclercq et al.,

2014a), may be due to the environmental conditions experienced by the fish in sea cages. In hatcheries, ballan wrasse are fed pelleted feeds in tanks, under artificial light regimes and at a controlled temperature, whereas sea-cage volumes are much larger with open boundaries, the fish are subject to ambient conditions, e.g. seasonal day/light and temperature regimes and tidal cycles, and supplementary feed is often provided in the form of feed blocks (Leclercq et al., 2015). Furthermore, the presence of large salmon within the sea cage may act as a stressor to farmed ballan wrasse, which have had no previous exposure to other fish species.

While the behaviour of wild and farmed ballan wrasse have not previously been compared and sea-cage acclimatisation has not previously been tested, in other species, particularly in salmonids, the behaviour of fish reared in a hatchery has been proven to be very different to wild fish. Hatchery reared fish are more aggressive at higher densities (Fenderson and Carpenter, 1971), more prone to predation (Jackson and Brown, 2011) and less successful at foraging (Brown and Laland, 2002). However, acclimatisation and conditioning regimes during the hatchery phase have been shown to improve foraging behaviour (Brown et al., 2003), improve predator response (Jarvi and Uglem, 1993) and decrease stress (Näslund et al., 2013).

Delousing performance in cleaner fish is difficult to assess in sea cages: routine lice counts on salmon provide an estimate of the lice population within each sea cage, but this can be influenced by factors such as environmental conditions, lice population dynamics and implemented lice management methods (Brooker et al., 2018a); individual cleaner fish can be sacrificed and the lice in their guts counted, but routine destructive sampling depletes the valuable stock over time. Passive-acoustic telemetry (PAT) has been proven as an effective method for observing the fine-scale activity of individual cleaner fish in salmon sea cages

(Leclercq et al., 2018) and was used in the present study to quantify the swimming behaviour of ballan wrasse in sea cages as a proxy for delousing behaviour. While the overall performance of the cleaner fish population in each sea cage determines their efficacy against the sea lice levels within the farm, the behaviour of each fish contributes to the performance of this population. Therefore, observing the behaviour of individual sentinel fish allows an estimate of the range of behavioural phenotypes within a population and improves our understanding of the requirements of the fish, encouraging good husbandry practices to improve welfare.

The aims of this study were to (1) compare the behaviour of wild-caught and farmed ballan wrasse in sea cages at a commercial Atlantic salmon farm, and (2) investigate the impact of sea-cage acclimatisation on the behaviour of farmed ballan wrasse.

2 MATERIALS AND METHODS

2.1 Study site

The investigation was performed at a commercial Atlantic salmon sea farm comprised of three groups of four sea cages (56.69 °N, 5.14 °W, Loch Leven; Mowi Scotland Ltd, UK). The study used two adjacent sea cages within one group of four floating square steel platforms (HP 2000, Wavemaster, AKVA Group, Inverness, Scotland) each holding a double-sized net bag (24 × 24 m square; 15 m (at edges) to 20 m (at centre) depth inverted pyramid; 18 mm mesh) for *in-situ* biofouling control by switching the net bag and air-drying.

Atlantic salmon were fed a commercial extruded diet (BioMar (UK) Ltd) to visual satiation twice daily using surface rotor spreaders and underwater video monitoring (Akvasmart CCS feed system, SmartEye 360 twin camera; AKVA Group). Two sinking wrasse hides (1 m Ø

weighted ring; 2 m high; plastic fake kelp; Leclercq et al., 2018) were suspended from a rope at opposite corners of each cage at 8–12 m depth (Fig. 1), and wrasse feed blocks suspended from ropes were offered weekly adjacent to the hides (600 g blocks, n = 2 / cage; Leclercq et al., 2015). Mean sea lice counts were obtained weekly on 10 salmon/cage. Salmon and cleaner fish mortalities were removed daily using hand nets and an air-lift pump connected to a bottom collector (LiftUP Akva AS, Eikelandsosen, Norway); no significant mortality events occurred during the study.

2.2 Acoustic telemetry system

A PAT system (HTI-Vemco Inc., Seattle, WA, USA) was used to record the positions of acoustic-tagged ballan wrasse during each trial. The acoustic tags (795 LD; 6.8 × 20.0 mm; 0.55 g in water) emit at a single frequency (307.2 kHz) and each one is programmed with a unique, user-defined pulse rate interval (PRI) to allow tag identification (Ehrenberg and Steig, 2009). The 3D positioning of each tag pulse (up to 20 cm resolution) is achieved by measuring the time delay to at least four hydrophones and triangulating its position. Before the study commenced, an array of eight underwater hydrophones (Model 590, omni-directional) was deployed around the perimeter of both experimental sea cages as described by Leclercq et al. (2018) (Fig. 1).

2.3 Experimental fish

Three trials using PAT were conducted at the site: (1) a comparison of wild-caught *vs.* farmed ballan wrasse in 2015, (2) an investigation of the effect of (a) hatchery acclimatisation and (b) hatchery-and-sea-cage acclimatisation on farmed ballan wrasse survival and behaviour in 2016 (Table 1).

Prior to the start of the trial 1, the experimental cages were stocked in October 2014 with Q2 2014 Atlantic salmon, and when the trial commenced, the cage contained approximately 34,600 salmon with a mean weight of 3.42 kg. Wild labrids captured from Arisaig, West Coast of Scotland (n = 3,200, 7.2 % of salmon stock at time of deployment) were deployed into the cage, and the deployed population was comprised of ballan wrasse (57.9 %), goldsinny wrasse (*Ctenolabrus rupestris*; 29.9 %), corkwing wrasse (*Crenilabrus melops*, 7.6 %), rockcook wrasse (*Centolabrus exoletus*, 3.7 %) and cuckoo wrasse (*Labrus mixtus*, 0.9 %). Prior to the start of the experiment, the mean mortality in the wild wrasse population was 0.0001% per day. For tag implantation, wild ballan wrasse were captured from the experimental cage using non-baited creel pots deployed at 6–12 m depth, slowly raised to the surface (~2 m / min). Farmed ballan wrasse for trial 1 were reared at Otter Ferry Seafish Ltd. (Tighnabruaich, Argyll, Scotland), where they were hatched in 2013 from wild-caught broodstock. Fish were reared in 2.8 m^3 circular flow-through tanks (salinity 33–34 ppt) under ambient temperature, 24 h light, and fed with pelleted feed (BioMar Symbio 2 mm). Fifty fish were transported in a tank via road to the Loch Leven site and retained in a 300L perforated plastic barrel submerged below a floating jetty prior to tag implantation.

Prior to the start of trial 2, the experimental cages were stocked in June 2016 with Q1 2016 Atlantic salmon, and when the first acclimatisation trial commenced, the two cages contained approximately 56,700 and 41,600 salmon with mean weights of 461.5 g and 453.9 g. Farmed ballan wrasse for trial 2 originated from Otter Ferry Seafish Ltd., where they were hatched in 2014 from wild-caught broodstock. For the first acclimatisation trial (2a), 1,620 wrasse were maintained in standard rearing conditions (non-acclimatised group, 24 h light regime, BioMar Symbio 2 mm pelleted feed, no tank furniture), and 1,950 wrasse were acclimatised for around one month (11^{th} May – 19^{th} June, 2016), both in 2,000 L tanks.

The hatchery acclimatisation involved changing the environmental rearing conditions: artificial kelp hides were present in the tank, a simulated natural photoperiod was provided via skylights in the roof of the tank room, and supplementary feed blocks were provided in the tanks (Leclercq et al., 2015) in addition to pelleted feed (Biomar Symbio 2.0 mm). After two weeks, the pelleted feed was withdrawn. The mean water temperature during this period was 11.5 ± 0.5 °C, and the mean weight of the fish was 38 g at the start of the acclimatisation period. Following the hatchery acclimatisation, both groups of fish were transported in tanks via road to the Loch Leven site. Acclimatised fish were stocked into one cage (n = 1,950; 3.4 % of salmon stock) and non-acclimatised fish were stocked into another (n = 1,620; 3.9 % of salmon stock) on 11th June 2015. At the time of stocking 50 fish per group were retained in 300L perforated plastic barrels submerged below a floating jetty for subsequent acoustic tag implantation.

For the second acclimatisation trial (2b), 200 wrasse from the same cohort of fish used in trial 2a were retained at the hatchery under standard rearing conditions as before. Six weeks prior to the start of the trial, half of the wrasse were acclimatised for around one month (5th–30th August, 2016) using the same conditions as for trial 2a. The mean water temperature during this period was 12 ± 0.5 °C, and the mean weight of the fish was 40 g at the start of the acclimatisation period. Two weeks prior to the start of the trial (30th August 2016), these fish were transported to the Loch Leven site as before and introduced to a 2m x 2m x 4m keep net within the sea cage. The keep net contained artificial kelp hides, and supplementary feed blocks were offered. For tag implantation, these fish were captured using a hand net. Two days prior to the start of the trial (11th September 2016), the 100 remaining non-acclimatised

wrasse were transported to the Loch Leven site and retained in submerged, perforated 300L plastic barrels ready for tag implantation and stocking into the cages.

Water temperature, salinity and dissolved oxygen were measured at 30 min intervals at 1, 4, 8 and 12 m depth in 2015 (trial 1) and 1, 2, 4 and 12 m depth in 2016 (trials 2a and 2b) over the study duration (see supplementary data) using data loggers (HOBO U24-002C; HOBO U26-001; Onset Computer Corporation, Bourne, MA, USA) attached to a weighted line deployed between the experimental cages.

2.4 Surgical procedure and tagged fish deployment

Before each trial, each acoustic tag was programmed with a unique PRI ranging from 6,275 to 9,957 msec using an acoustic tag programmer (490-LP, HTI-Vemco (USA) Inc., Seattle, WA, USA) connected to a Windows laptop running TagProg software (v6.0, HTI-Vemco (USA) Inc., Seattle, WA, USA) and stored in a mild antiseptic solution (0.5g/L, Presept; Johnson & Johnson, CA, USA). Tags were implanted into the coelemic cavity of the fish following the surgical procedure described in Leclercq et al. (2018). Following recovery, fish were isolated at sea in 300L perforated barrels for 48 h with any spare fish not tagged, then examined for survival and suture integrity prior to release in their designated sea cage along with any spare fish. No mortalities occurred during the recovery period before deployment in the sea cages. Once deployed, tag signals from tagged fish were recorded continuously until the tag batteries expired after several months. Hide tags (n = 4; Model 795 LG; 11.0 x 25.0 mm) were programmed at 9,313–15,235 msec and one was deployed within each cleaner-fish hide to track the movements of the hides resulting from tidal currents. All experiments were carried out in accordance with the Animal (Scientific Procedures) Act 1986 UK and were approved by the University of Stirling animal welfare ethical review board.

2.5 Data processing

Raw acoustic data were processed to identify tags and calculate their positions using MarkTags (v6.10) and AcousticTag (v6.10) software (HTI-Vemco (USA) Inc., Seattle, WA, USA), which were saved as hourly Microsoft Access (.mdb) database files consisting of a list of tag number and Coordinated Universal Time (UTC) stamp with three-dimensional Cartesian coordinates (x, y, z). Specifically, a noise filter was used to extract individual tag signals according to their PRIs, and then a 3D algorithm was used to calculate the position of each individual tag pulse within the study coordinate system based on simultaneous detections from at least four hydrophones. Up to 16,023 positions fish/day were recorded but where fish remained in hides or on the bottom of the sea cage, many signals were blocked and the number of detected positions was as low as 1,082 fish/day. The hourly position files were converted to comma separated values (.csv) files, and all further analyses were conducted in R (R Foundation for Statistical Computing, www.R-project.org/).

Hourly files were merged into daily files, which were further processed and filtered as follows: the time between detections was used to calculate the minimum swimming speed (BL (body lengths)/sec) between successive detections based on the length of each fish at the time of tag implantation; headings (degrees) were calculated based on each successive set of detections; spurious tag detections resulting from attenuation or reflection of the tag signal were removed by filtering out all subsequent detections with a time delay < 5 sec (all tag PRIs were > 5 sec) and using a moving average fish location filter to eliminate false detections; each individual fish track was visualised and analysed to identify any moribund or dead fish (date and time of mortality was noted), and tag detections emitted from dead fish were removed from the dataset.

The length of the datasets from each trial were selected based on numbers of tagged fish mortalities and spent tags (due to tag batteries being drained). Fish were selected for inclusion in the final datasets based on tags emitting signals for the entire period of the dataset and fish remaining alive for at least 10 days after the final day of the selected length of each dataset.

Solar and tidal status were assigned to each tag detection based on their time stamp as follows: solar status (dawn, day, dusk, night) was based on sunrise and sunset times at Fort William, Scotland (http://www.timeanddate.com/sun/uk/fort-william, 9 miles north of study site) with a 2-h dawn/dusk period centred on sunrise/sunset and night/day starting/ending 2 h before/after sunrise/sunset; tidal status was based on tidal charts for Loch Leven Head, Scotland (http://www.tidetimes.co.uk/loch-leven-head-tide-times, 5.6 miles east of study site) (high- and low-tides (slack tide) were defined as a 20-min time period centred at each predicted tidal maximum/minimum, and similarly, mid-tides (flood and ebb tides) were defined as a 20-min time period centred between successive high and low tides); tag detections during dawn and dusk periods were excluded from analyses as they are transition periods between light and dark.

Based on their Cartesian coordinates, each tag detection was categorised into one of five locations within each cage: bottom (below 15 m), hide corner (6 × 6 m, 0–15 m depth at each cage corner where hides were present), empty corner (6 × 6 m, 0–15 m depth at each cage corner where no hides were present), edges (outside the theoretical cage volume or within 6 m inside the cage edges, corners excluded, 0–15 m depth), centre (13 × 13 m at the cage centre; 0–15 m depth) and hides (2 m diameter × 3 m depth cylinder centred to each shelter

location using hide tag positions). A degree of net-bag distortion from tidal flow occurred, which resulted in some tag detections outside the theoretical cage volume.

Home ranges for each fish were estimated from bivariate normal fixed kernel utilisation distributions (KUDs), which were calculated over a 0.5 × 0.5 m resolution grid using the *adehabitatHR* package in R, and the 95% KUD and 50% KUD areas were termed home range and core area, respectively (March et al., 2010). Changes in home ranges were investigated by plotting the daily cumulative KUD_{95} for each fish over the period of the study. The home range of each fish is established when the asymptote is reached, which was defined as the day that the change in KUD_{95} between two consecutive days was less than 5% (Rechisky and Wetherbee, 2003).

2.6 Statistical analysis

Due to the large-scale nature of the study conducted at a commercial salmon farm, it was not possible to use replicate treatment groups (cages). However, individual fish were treated as pseudo replicates for all analyses. Means of individual units (fish) were checked for normality using the Anderson-Darling test and for homogeneity of variance using Levene's test and observations of residual plots. Log transformations were used where necessary to normalise data where possible. A one-way analysis of variance (ANOVA) was used to compare differences in means between groups, and a repeated-measures ANOVA was used to investigate the effect of daily changes in depth or activity according to the time of day with Tukey post-hoc tests used for pairwise comparisons. The Chi-squared goodness-of-fit test was used for nominal frequency data (i.e. fish headings), but due to the very large datasets, all comparisons were highly significant ($P < 0.001$) even where differences were not biologically important (Anderson et al., 2000). Consequently, Cramer's V-test (*rcompanion*

294 package in R) was used to measure effect size with magnitudes defined as small = > 0.042,
295 medium = > 0.127 and large = > 0.212 (Cohen, 1988) where the number of categories $k = 8$
296 (45° per category). To compare trends in depth over time between groups of fish, general
297 linear models were fitted to daily means for each group using least-squares regression, and
298 significant differences between slopes (trends) were estimated using pairwise comparisons
299 (*lsmean*s package in R).
300
301 **3 RESULTS**
302 The datasets used for analyses all commenced on the deployment of the tagged fish and
303 ended 43, 30 and 30 days after deployment for trial 1, trial 2a and trial 2b, respectively.
304 During trial 1, no data was collected for a total of six days due to temporary network failures.
305 Water quality data are summarised for each trial in Table 2, and time-series plots are
306 provided as supplementary data. On day 7 of trial 1, a hydrogen peroxide bath treatment was
307 administered to treat against amoebic gill disease, which affected the behaviour of the wrasse
308 for several days.
309
310 3.1 Mortality
311 Mortality in trial 1 was 11.1% for wild wrasse (2 mortalities) and 33.3% (7 mortalities) for
312 farmed wrasse over 43 days (Fig. 2). In addition, a further one farmed wrasse and two wild
313 wrasse tags ceased emitting during the study (presumed batteries expired) meaning that 14
314 wild wrasse and 10 farmed wrasse were included in the analyses of trial 1.
315
316 Mortality in trial 2a was 15% for acclimatised wrasse (3 mortalities) and 10% for non-
317 acclimatised wrasse (2 mortalities) over 30 days (Fig. 2). In addition, a further four tags from

each group ceased emitting during the study (presumed batteries expired) meaning that 13 acclimatised wrasse and 14 non-acclimatised wrasse were included in the analyses of trial 2a.

Mortality in trial 2b was 5.9% (1 mortality) in acclimatised wrasse and 0% in non-acclimatised wrasse over 30 days (Fig. 2). However, a further four mortalities in the acclimatised fish and two mortalities in the non-acclimatised fish were seen in the 10 days following the 30 days that were analysed, so these fish were also removed from the dataset. In addition, two tags in acclimatised fish and one tag in a non-acclimatised fish ceased emitting during the study period, meaning that 10 acclimatised fish and 14 non-acclimatised fish were included in the final dataset for trial 2b.

3.2 Sea lice numbers

Sea lice numbers on the salmon in the experimental cage remained low throughout trial 1, with the maximum mean numbers recorded being 0.32 lice/fish for all motile lice stages and 0.2 lice/fish for gravid females (data not shown). As both groups of fish (wild and farmed) were deployed into the same sea cage, it was not possible to determine the level of delousing of either group of fish, although the low lice numbers suggest that delousing did occur.

During trial 2a, lice numbers increased from 0.2 and 0.1 lice/fish (all motile stages) to 1.65 and 3.4 lice/fish at the beginning of July 2016 (day 17 of the trial) for acclimatised and non-acclimatised cages, respectively (data not shown). The mean number of gravid female lice was very low at 0.05 lice/fish or lower throughout the trial in both cages. Following the administration of medicated feed on 12–16th July, the number of lice decreased to zero.

342 During trial 2b, the lice numbers fluctuated between 0.65 and 3.2 lice/fish in the acclimatised
343 wrasse cage and 2.2 and 5.2 lice/fish in the non-acclimatised wrasse cage (all motile stages)
344 (data not shown). The number of gravid female lice was consistently 0.1 or less in the
345 acclimatised wrasse cage and 0.5 or less in the non-acclimatised wrasse cage.
346
347 3.3 Depth
348 In trial 1, the mean depth of wild wrasse for the duration of the study was significantly
349 shallower than farmed wrasse (13.3 ± 2.4 m vs. 18.2 ± 1.7 m, respectively, $F = 173.6$, $P = 0$,
350 Fig. 3a), although there were no significant differences between daily daytime and night time
351 mean depths in either group (Fig. 3b & 3c). In the night following the bath treatment, the
352 mean depth of the wild fish increased dramatically to 19.8 ± 0.6 m, but decreased gradually
353 to pre-treatment levels in the following days, whereas the farmed fish remained deep
354 throughout the study. Over the course of the trial, the daytime mean depth of wild wrasse
355 decreased from 14.03 ± 1.04 m on day 1 to 11.91 ± 1.44 m on day 43 (Fig. 3b) whereas the
356 daytime mean depth of farmed wrasse increased from 14.02 ± 0.97 m on day 1 to 18.71 ±
357 1.17 m on day 43 (Fig. 3c); slopes of fitted linear regressions for wild and farmed wrasse
358 depth over time were significantly different (t-ratio = -3.718, $P = 0.0004$).
359
360 In trial 2a, there was no significant difference in depth preferences between both hatchery-
361 acclimatised and non-acclimatised fish (13.8 ± 1.7 m vs. 13.3 ± 1.8 m, respectively, $F =$
362 2.061, $P = 0.15$, Fig. 3a), and there were no significant differences between daytime and night
363 time daily mean depths (Fig. 3d & 3e). Although the mean depths of both groups of fish
364 decreased slightly during the study, the difference in mean depths between the start and end
365 of the trial and the slopes of fitted linear regressions were not significantly different (t-ratio =
366 1.577, $P = 0.12$).

At the start of trial 2b (day 1), both acclimatised and non-acclimatised fish remained deep (15.2 ± 2.3 m vs. 19.1 ± 0.4 m, respectively) (Fig. 3f & 3g). However, the acclimatised fish rapidly decreased their depth; by day 7 their mean daytime depth was 9.08 ± 2.05 m, and they remained relatively high (>11m) in the water column for the rest of the trial. In comparison, the non-acclimatised fish were slower to swim up in the water column and the change in depth was less, although the slopes of fitted linear regressions for acclimatised and non-acclimatised fish were not significantly different from each other (t-ratio = 1.577, P = 0.12). Overall, however, non-acclimatised fish were significantly deeper than acclimatised fish (9.8 ± 2.0 m vs. 13.7 ± 1.9 m, respectively, F = 188.6, P = 0, Fig. 3a), although there were no significant differences in either group between daytime and night time daily mean depths.

In all trials, there was a large variation in the mean depths of individual fish although variations in the daily means of individual fish were generally low. In all trials, only two wild fish and one hatchery-and-cage-acclimatised fish showed a significant difference between daytime and night time mean daily depths (S4a & S4e).

3.4 Activity

In trial 1, the mean daytime activity of wild fish was significantly higher than their mean night time activity (0.39 ± 0.08 BL/s vs. 0.26 ± 0.04 BL/s, respectively, F = 159.7, P = 0, Fig. 4a), whereas the same was not significantly different in farmed fish (F = 3.119, P = 0.08). Furthermore, the mean daytime activity of wild fish was significantly higher than mean daytime and night time activity in farmed fish (F = 41.88, P = 0 and F = 47.02, P = 0, respectively, Fig. 4a). When comparing daily means, wild fish daytime activity was

391 significantly higher than night time activity on 68% of observed days, as opposed to 16% of
392 observed days in farmed fish (Fig. 4b, 4c).
393
394 In trial 2a, the hatchery acclimatisation had no significant effect on swimming activity (Fig.
395 4a). When comparing daily means, daytime and night time activity was significantly different
396 in only one day in each group (Fig. 4d, 4e).
397
398 In trial 2b, mean daytime activity was significantly higher than mean night time activity in
399 hatchery-and-cage-acclimatised fish (0.65 ± 0.09 BL/s vs. 0.48 ± 0.06 BL/s, respectively, $F = 63.47$, $P = 0$, Fig. 4a), but not in non-acclimatised fish ($F = 3.39$, $P = 0.07$). Due to the wide
401 variation of daytime activity between fish in hatchery-and-cage-acclimatised fish, their mean
402 daytime activity was not significantly different from non-acclimatised fish in trial 2b (Fig.
403 5a). Furthermore, the large variability between fish means that daily daytime activity was
404 only significantly different to daily night time activity in 23% of observed days ($P < 0.05$–
405 0.01, Fig. 4f).
406
407 In all trials, there was a clear distinction between individual fish with a significantly higher
408 mean daytime activity than mean night time activity and those with very similar activity at
409 different times of day. In trial 1, 86% of wild fish had significantly higher swimming activity
410 during the day compared to the night ($P < 0.001$, Fig. 5a) with the increase ranging from 0.07
411 to 0.23 BL/s. Conversely, mean activities were low in trial 1 farmed fish (0.27 ± 0.01 – 0.39
412 ± 0.05 BL/s) and only 30% exhibited a significant difference between mean daytime and
413 night time activity, and this increase was notably lower at 0.04 BL/s (Fig. 5b). In trial 2a,
414 swimming activity was higher during the day compared to the night in only two hatchery-
415 acclimatised fish (Fig. 5c), whereas 70% of hatchery-and-cage-acclimatised fish (trial 2b) had

significantly elevated daytime activity compared to 15% in non-acclimatised fish (trial 2b) with the increase in activity ranging from 0.06 to 0.39 BL/s and 0.12 to 0.26 BL/s, respectively (Fig. 5e, 5f).

3.5 Cage locations

During the first week of trial 1, wild wrasse spent approximately 50% of their time below 15m, and this increased to 82% on day 8 following a hydrogen peroxide bath treatment administered on day 7 (Fig. 6a). On the day of the treatment, tagged fish spent a high proportion of their time in the centre of the cages compared to all other days (14.7% and 14.8% for wild and farmed wrasse, respectively) due to the reduction in the volume of the sea cages for the bath treatment. For wild wrasse, the daily time spent below 15m decreased after day 8 and then remained at approximately 30–40% for the rest of the study. The edges and corners were also preferred locations, with more time spent in hide corners than empty corners, although the hides were very seldom used (data not shown). Edges and corners together accounted for approximately 50–70% of wild wrasse daily time from day 19. Visits to the cage centre were infrequent (0.38–3.52% of daily time). In comparison, farmed wrasse in trial 1 spent 60–90% of their time below 15m throughout the trial (Fig. 6b). Other preferred locations of the farmed wrasse were edges and corners with very little time spent in the cage centre.

In trial 2a, the behaviour of the hatchery-acclimatised fish and non-acclimatised fish were similar, and the acclimatisation did not appear to have a significant impact on their preferred cage locations, with the fish spending the majority of the time in the corners, particularly the hide corners (data not shown).

In trial 2b, the hatchery-and-cage-acclimatised fish spent increasingly less time below 15m during the day, from 67.3% on day 1 to 27.4% on day 5 (Fig. 6c), a pattern also reflected in their mean depths (Fig. 3e). As in the wild fish, corners and edges were preferred locations, with hide corners being preferred over empty corners, and an increasing proportion of time was spent in the centre of the cage towards the end of the trial (maximum of 12.8% on day 25). In contrast, non-acclimatised fish in trial 2b spent more time during the day below 15m at the start of the trial (90.9% on day 1), which decreased gradually to 28.2% on day 11 (Fig. 6d). As with the acclimatised fish, edges and corners were the preferred locations, with hide corners being preferred over empty corners.

Night time locations in all trials were similar to daytime locations, except for in wild fish and hatchery-and-cage-acclimatised fish, which regularly spent more time in the corners during the night (S5).

3.6 Orientation

Tidal flow in the sea cages at the study site is on an ESE-WNW axis, and farmed wrasse strongly oriented to this axis whereas wild wrasse showed a weak orientation with headings distributed more evenly (Fig. 7a, 7b). While both wild and farmed wrasse headings were significantly different from a uniform distribution of headings due to the large sample sizes ($P = 0$), there was no sizeable effect in wild wrasse ($V < 0.042$), whereas a medium-size effect was seen in farmed wrasse ($V > 0.127$). In trial 2b, non-acclimatised fish were strongly oriented on an ESE-WNW axis with a small effect size ($V > 0.042$, Fig. 7d), whereas in hatchery-and-cage-acclimatised fish, fish headings were more evenly distributed with no sizeable difference from a uniform distribution ($V < 0.042$, Fig. 7c).

3.7 Home ranges and core areas

There was considerable variation in the home ranges and core areas of individual fish (Table 3). Wild fish had the largest home ranges and core areas, and in most fish their home ranges covered the majority of the cage area (Fig. 8a). In contrast, farmed fish in trial 1 had the smallest home ranges and core areas, and their ranges were primarily at the centre of the cage (comparison with depths and locations indicates that these fish were below 15m). Both home ranges and core areas were significantly larger in wild fish than in farmed fish ($F = 11.81$, $P = 0.00002$).

The home ranges and core areas of hatchery-and-cage-acclimatised fish in trial 2b were statistically similar to those in wild fish ($F = 11.81$, $P = 0.17$), and the core areas were mostly in the corners and hides (Fig. 8c). Although the mean home ranges and core areas of non-acclimatised fish in trial 2b were smaller than in acclimatised fish (404.6 and 46.1 vs. 514.3 and 78.3, respectively), the populations were not significantly different ($F = 11.81$, $P = 0.15$).

The calculation of cumulative home ranges for individual fish shows that the home ranges of wild fish in trial 1 were larger than in farmed fish, and they were established over two days earlier on average (8.07 ± 3.83 d vs. 10.5 ± 5.4 d for wild and farmed fish, respectively, Fig. 9a, 9b). In trial 2, hatchery-and-cage-acclimatised fish rapidly established their home ranges in 8.1 ± 4.28 d compared to 10.9 ± 5.02 d in non-acclimatised fish (Fig. 9c, 9d).

4 DISCUSSION

Passive-acoustic telemetry has been proven as a useful technique for observing the fine-scale behaviour of individual cleaner fish in salmon sea cages (Leclercq et al., 2018), and this study successfully used PAT in commercial salmon sea cages to compare the behaviour of

wild and farmed ballan wrasse and investigate the effect of acclimatisation to sea-cage conditions. Hatchery acclimatisation alone had limited impact on the behaviour of the fish once deployed at sea, whereas a combination of hatchery-and-cage acclimatisation caused the fish to rapidly decrease their depth once deployed, develop diurnal rhythms in activity and establish home ranges earlier than non-acclimatised fish. These behaviours may be a proxy for delousing behaviour.

Although sea lice numbers were recorded weekly for farm records during the trials, due to the low numbers sampled, chemical treatments, natural fluctuations and the aggregation of some wrasse treatment groups within the same cage, it is difficult to draw any conclusions on the delousing performance of the wrasse from this data. Nonetheless, lice numbers in the acclimatised wrasse cage in trials 2a and 2b were generally lower than in the non-acclimatised wrasse cage, which may indicate a higher level of delousing in the acclimatised wrasse. Underwater cameras used for monitoring stocks and feeding rates may be used to corroborate acoustic data and records of lice numbers. However, consultation with the farm workers revealed that delousing behaviour had not been observed through the cameras suggesting that there is a low frequency of delousing behaviour and/or delousing behaviour does not occur near the cameras at the centre of the pens.

4.1 Survival

The low survival of cleaner fish in commercial salmon sea cages is a key bottleneck that needs to be addressed (Brooker et al., 2018b) and more data is required from commercial farms to better understand the multifactorial causes of these mortalities (Powell et al., 2018). While only a relatively small number of fish were tagged in this study, it provides an estimation of survival rates in a commercial sea-cage environment. Fish mortalities are

516 collected routinely in salmon farms, although some of the tagged fish in these studies were
517 not collected after death suggesting that actual mortality rates may be higher than predicted.
518 Mortality was low to moderate in all trials (0.26–0.5% per day) and relatively consistent for
519 the duration of the trials, except for farmed wrasse in trial 1, where mortality was 33% over
520 43 days or 0.78% per day. This high mortality may be due to the smaller size of the farmed
521 fish when deployed, which was further confounded by the bath treatment seven days post-
522 deployment. It is not possible to identify the causes of mortality, and the tagging procedure
523 may have caused some, especially in the period following surgery and release of the fish into
524 the sea cages. In all three trials, however, no mortalities were seen in the 48 h following
525 surgery before they were released into the sea cages, and there was no peak in the rates of
526 mortality after the surgery, suggesting that few, if any, mortalities were due to the tagging
527 procedure. The two mortalities in wild wrasse were caused by the fish being trapped in the
528 net during a net change, although this did not occur in the 2016 trials, suggesting that this
529 problem was identified and eliminated. However, it highlights the importance of careful
530 observation during net changes to avoid unnecessary cleaner fish mortalities.
531
532 4.2 Wild vs. farmed wrasse behaviour
533 Wild ballan wrasse are effective salmon delousers in salmon sea cages (Treasurer, 2002,
534 2013; Brooker et al., 2018b). Although farmed ballan wrasse are proven to be very efficient
535 delousers in tank trials (Leclercq et al., 2014a), it has been suggested from farm observations
536 that they may not always perform effectively in sea cages, which could be due to their
537 hatchery rearing and sea-cage deployment environments being very different. Skiftesvik et al.
538 (2013) found that farmed wrasse were as effective as wild wrasse at delousing in sea cages,
539 but these were in small experimental cages, which are different to full-size commercial sea
540 cages. Therefore, if the behaviour of the wild wrasse in the current study is typical of wild

wrasse behaviour in sea cages following a suitable period of acclimatisation, it can be used as a reference for ballan wrasse behaviour in salmon sea cages, with similar behaviour emulated in farmed wrasse considered desirable.

Wild ballan wrasse showed a strong diurnal rhythm in behaviour in both depth and activity with a preference for shallower depths at night and increased activity during the day, a pattern similar to wild wrasse in a previous sea-cage study (Leclercq et al., 2018). This increased activity during the day suggests that active foraging and delousing behaviour occur during the day. Furthermore, although cage edges and corners were preferred locations at all times, they were used more at night than during the day, suggesting nocturnal quiescence similar to ballan wrasse in the wild (Costello, 1991; Villegas- Ríos et al., 2013). Cleaner fish hides were very seldom used by wild wrasse, as also previously reported by Leclercq et al. (2018), although corners with hides were preferred over empty corners. Underwater structures are known to be an attraction for many pelagic and demersal fish species (Pickering and Whitmarsh, 1997) suggesting that proximity to a structure may attract ballan wrasse in sea cages despite the fish rarely being resident within the hides. By stationing in open water close to the hides, these fish may be optimising feeding opportunities while remaining close enough to be able to seek shelter in or around the hide if threatened, and these areas may be where delousing occurs. Hides are considered essential for wrasse maintenance in salmon sea cages (Treasurer, 2013), and although they were used very little by the fish in this study, they do seem to have a role in providing suitable structures to attract the wrasse. As this study was conducted during the summer, it may be that hides are used more at low winter temperatures when ballan wrasse are known to enter a state of torpor (Morel et al., 2013), although hide use was also relatively low in a similar study conducted at lower temperatures in March–May (Leclercq et al., 2018). Wild wrasse spent very little time

566 in the centre of the cage where the majority of the salmon biomass can be found, and core
567 areas of the wild wrasses' ranges (KUD_{50}) nearly always incorporated hide corners (with
568 some in empty corners). The attraction of cage edges and corners may also be due to the
569 substrate-grazing habits of ballan wrasse (Deady et al., 1995; Skiftesvik et al., 2013), and
570 while the nets were air-dried fortnightly to avoid biofouling, ballan wrasse were often
571 observed grazing on the nets.
572
573 In contrast to the wild wrasse, the farmed wrasse in trial 1 remained deep (>15m) throughout
574 the trial and showed no diurnal variation in depth or activity (except in activity towards the
575 end of the trial). In addition, their home ranges were smaller than for wild wrasse and were
576 focussed at the centre of the cage with their core areas primarily in the centre at the deepest
577 part of the cage. This behaviour is very different to the behaviour patterns exhibited by the
578 wild wrasse in trial 1 and is unlikely to be conducive to desirable behaviour, i.e. delousing.
579 Considering their hatchery rearing conditions in small circular tanks with constant lighting,
580 temperature and feeding, it is not surprising that such a dramatic change in environmental
581 conditions, in addition to the stress of transport to the grow-out site (Leclercq et al., 2014b),
582 resulted in the fish remaining deep at the bottom of the sea cage throughout the study
583 possibly reflecting difficulties in coping with the change. However, it should be reiterated
584 that the wild wrasse in trial 1 were already resident in the sea cage for several months prior to
585 tagging and were already acclimatised to the farm conditions at the start of the trial.
586
587 A further effect of tank rearing can be seen in the strong orientation of the farmed wrasse to
588 tidal currents in the sea cage. While the wild wrasse in trial 1 showed a relatively even
589 distribution of headings, the farmed wrasse showed a strong orientation to the predominant
590 tidal currents at the sea-cage site. This is likely due to the farmed wrasse becoming

591 acclimatised to the uniform circular current present in the rearing tanks, and they commonly
592 orientate towards this current. In comparison, wild wrasse are accustomed to the swirling
593 currents and eddies of natural rocky reefs. The domestication of fish is a strong selection
594 pressure and results in the development of specific behavioural syndromes (Sih et al., 2004;
595 Huntingford and Adam, 2005) as seen in the farmed wrasse in this study, which may not be
596 desirable traits for ballan wrasse used as cleaner fish.
597
598 While the comparison of different groups of fish allows differing trends in behaviour to be
599 identified, a significant benefit of PAT is the ability to quantify the behaviour of individual
600 fish. Despite fish in the same group being treated the same, there was large variation amongst
601 individual fish behaviours, and consistent individual differences in behaviour result in
602 various behavioural phenotypes, or personalities, within a population (Huntingford, 2004;
603 Nilsson et al., 2014). In wild wrasse in trial 1, some fish remained deep (>15m), whereas
604 others preferred shallower depths (<10m). Furthermore, some fish showed no diurnal
605 variation in depth, where others preferred shallower depths at night than during the day.
606 While there was less variation between the activities of individual fish, all but one wild
607 wrasse had significantly higher activity during the day than at night. This suggests that the
608 wild wrasse were nocturnally quiescent with resting activity rates at night generally <0.3
609 BL/s and actively foraging during the day with activity rates of 3–6 BL/s although it remains
610 to be proven whether increased swimming activity translates into increased delousing
611 activity.
612
613 4.3 Effect of acclimatisation to sea-cage conditions
614 Due to the consistently deep mean depths, low activity and lack of diurnal behaviour patterns
615 observed in the farmed wrasse studied in trial 1, the acclimatisation trials aimed to explore

methods of improving the behaviour of farmed ballan wrasse following deployment. The acclimatisation protocol was implemented as a two-step process in two separate trials to determine the relative importance of acclimatisation in the hatchery and acclimatisation in the sea cage.

Trial 1 and trial 2 were conducted in different years (2015 and 2016) with different stocks of farmed wrasse, albeit from the same hatchery, so it is difficult to draw conclusions regarding differences in behaviour between the two trials. Ballan wrasse culture is a new and rapidly evolving industry (Brooker et al., 2018b), and culture techniques are likely to have changed between the two cohorts of fish being produced. Indeed, the fish used in the first trial in 2015 were some of the first farmed ballan wrasse to be deployed in salmon cages in Scotland. This may have been a contributing factor explaining the higher mortalities in the farmed wrasse in trial 1 and differences in behaviour between these fish and the non-acclimatised farmed wrasse in trials 2a and 2b. Furthermore, although study 1 and study 2a were conducted at approximately the same time of year with similar water temperatures, salinity was lower in study 1, especially near the surface, due to high rainfall and freshwater runoff during the study. This may partially explain differences in the depth of the fish between trials 1 and 2a. Territorial competition between the wild and farmed wrasse present in the same cage also cannot be discounted.

The hatchery acclimatisation using artificial kelp hides, natural photoperiod and supplementary feed blocks (trial 2a), had no apparent significant impact on depth and just one fish developed diurnal rhythms in activity. Conversely, hatchery acclimatisation followed by acclimatisation in the sea cage where fish were retained in keep nets within the sea cages with artificial kelp hides and supplementary feed blocks (trial 2b) had a significant impact on

641 behaviour, especially for depth and activity and the development of diurnal activity patterns.
642 However, study 2b was conducted later in the summer when water temperatures were higher,
643 and this may partially account for the higher rates of activity and shallower swimming depths
644 in this study. There was a broad range in the mean activities of individual hatchery-and-cage-
645 acclimatised wrasse, and not all fish developed diurnal activity patterns. It seems that this
646 diurnal pattern in activity is an indicator of a positive response to acclimatisation and the
647 development of daily rhythms in behaviour, similar to those of wild wrasse in trial 1. The
648 different responses of individual fish may be due to differences in their behavioural plasticity
649 (Dingemanse and Wolf, 2013) with some fish able to adapt to the sea-cage environment more
650 effectively than others. Villegas-Ríos et al. (2018) found that the response of wild cod
651 (*Gadus morhua*) to environmental fluctuations can be partially explained by their different
652 personalities on a reactive-proactive axis, and this may contribute to the different responses
653 of acclimatised fish in this study. However, genetics and environmental fluctuations can only
654 partially explain differences in individual fish behaviour, and even in consistent and identical
655 rearing conditions, as in farmed wrasse in this study, behavioural individuality has been
656 demonstrated in clonal fish, and individuality may be an inevitable outcome of early
657 development (Bierbach et al., 2017). Nonetheless, while a range of behavioural phenotypes
658 was observed in the hatchery-and-cage-acclimatised wrasse, the acclimatisation process
659 appears to have shifted the overall population behaviour structure towards that of wild
660 wrasse.
661
662 The positive effect of hatchery-and-sea-cage acclimatisation is further evidenced by cage
663 locations. Cage edges and corners were preferred by the hatchery-and-cage-acclimatised
664 wrasse during the daytime and night time, similar to the preferences of wild wrasse seen in
665 trial 1. Hatchery-and-cage acclimatisation also had a positive effect on reducing orientation to

prevailing currents, which appears to be a result of being reared in tanks with consistent directional currents. While trial 2b non-acclimatised wrasse were strongly oriented to the prevailing ESE-WNW tidal currents at the site, the headings of hatchery-and-cage-acclimatised wrasse were more evenly distributed, as also seen in the wild wrasse. Although the sizes and cage coverage of the home ranges and core areas were similar for both groups of fish in trial 2b, the estimation of cumulative home ranges highlights a clear difference between acclimatised and non-acclimatised wrasse. The establishment of home ranges was rapid in hatchery-and-cage-acclimatised wrasse (mean 8.1 ± 4.3 d), while non-acclimatised wrasse gradually expanded their home ranges over a longer period (mean 10.9 ± 5.02 d), which provides further evidence that the hatchery-and-cage acclimatisation promoted the rapid acclimatisation of the fish to the sea-cage environment.

5 CONCLUSIONS

Ballan wrasse are proven to be effective at delousing salmon infected with sea lice in commercial sea cages, although the origin of the fish, wild or farmed, appears to impact on delousing efficiency. In this study, PAT was used effectively to visualise the behaviour of individual cleaner fish in commercial salmon sea cages and compare wild and farmed wrasse and investigate the effect of acclimatisation. Clear differences were found between the behaviour of wild and farmed ballan wrasse. Wild wrasse frequented shallower depths, were more active during the day and covered more of the cage area. A combination of hatchery-and-cage acclimatisation to sea-cage conditions had a positive effect on farmed wrasse, with these fish exhibiting behaviours similar to those of wild origin and more rapidly acclimatising to the sea-cage environment. The development of diurnal rhythms in behaviour, particularly in activity, appears to be a key indicator of a positive response to acclimatisation in farmed wrasse. While most hatchery-and-cage-acclimatised fish developed diurnal rhythms in

activity in this study, some did not, and it may be that the response of individual fish to acclimatisation is a function of time, with some fish requiring longer acclimatisation periods than others. Extending the acclimatisation period may further shift their overall behaviour towards that of wild wrasse, although further investigation is required. Nonetheless, a combination of hatchery-and-cage acclimatisation is recommended prior to deployment to improve farmed ballan wrasse delousing efficacy.

Acknowledgements

The authors would like to thank staff at the Mowi Loch Leven sea site and HTI-Vemco (USA) Inc. for their technical support.

Funding

This work was supported by a Sainsbury's Agriculture R&D Grant and a Scottish Aquaculture Innovation Centre project in collaboration with Mowi Scotland, Scottish Seafarms, BioMar and Pharmaq.

References

Anderson, D., Burnham, K., Thompson, W., 2000. Null hypothesis testing: problems, prevalence, and an alternative. J. Wildlife Manage. 64, 912–923.

Brooker, A.J., Skern-Mauritzen, R., Bron, J.E., 2018a. Production, mortality and infectivity of planktonic larval sea lice, *Lepeophtheirus salmonis* (Krøyer, 1837): current knowledge and implications for epidemiological modelling. ICES J. Mar. Sci. 75, 1214–1234.

714 Brooker, A.J., Papadopoulou, A., Gutierrez, C., Rey, S., Davie, A., Migaud, H., 2018b.
715 Sustainable production and use of cleaner fish for the biological control of sea lice: recent
716 advances and current challenges. Vet Rec. 183, 383.

717 Brown, C., Davidson, T., Laland, K., 2003. Environmental enrichment and prior experience
718 of live prey improve foraging behaviour in hatchery-reared Atlantic salmon. J. Fish Biol. 63
719 (Supplement A), 187–196.

720 Bierbach, D., Laskowski, K.L., Wolf, M., 2017. Behavioural individuality in clonal fish
721 arises despite near-identical rearing conditions. Nat. Commun. 8, 1–7.

722 Brown, C., Laland, K., 2002. Social enhancement and social inhibition of foraging behaviour
723 in hatchery-reared Atlantic salmon. J. Fish Biol. 61, 987–998.

724 Cohen, J., 1988. Statistical power analysis for the behavioral sciences, second ed. New
725 Lawrence Erlbaum Associates, York.

726 Costello, M,, 1991. Review of the biology of wrasse (Labridae: Pisces) in Northern Europe.
727 Prog. Underwater Sci. 16, 29–51.

728 Deady, S., Varian, S.J.A., Fives, J.M., 1995. The use of cleaner-fish to control sea lice on two
729 Irish salmon (*Salmo salar*) farms with particular reference to wrasse behaviour in salmon
730 cages. Aquaculture. 131, 73–90.

731 Dingemanse, N.J., Wolf, M., 2013. Between-individual differences in behavioural plasticity
732 within populations: causes and consequences. Anim. Behav. 85, 1031–1039.

733 Ehrenberg, J.E., Steig, T.W., 2009. A study of the relationship between tag-signal
734 characteristics and achievable performances in acoustic fish-tag studies, ICES J. Mar. Sci. 66,
735 1278–1283.

736 Fenderson, O.C., Carpenter, M.R., 1971. Effects of crowding on the behaviour of juvenile
737 hatchery and wild landlocked Atlantic salmon (*Salmo salar* L.). Anim. Behav. 19, 439–447.

738 Huntingford, F.A., Adams, C., 2005. Behavioural syndromes in farmed fish: Implications for
739 production and welfare. Behaviour. 142, 1207–1221.

740 Huntingford, F.A., 2004. Implications of domestication and rearing conditions for the
741 behaviour of cultivated fishes. J. Fish Biol. 65 (Supplement A), 122–142.

742 Jackson, C.D., Brown, G.E., 2011. Differences in antipredator behaviour between wild and
743 hatchery-reared juvenile Atlantic salmon (*Salmo salar*) under seminatural conditions. Can. J.
744 Fish. Aquat. Sci. 2165, 2157–2165.

745 Jarvi, T., Uglem, I., 1993. Predator training improves the anti-predator behaviour of hatchery
746 reared Atlantic salmon (*Salmo salar*) smolt. Nordic J. Freshw. Res. 68, 63–71.

747 Komyakova, V., Swearer, S.E., 2018. Contrasting patterns in habitat selection and
748 recruitment of temperate reef fishes among natural and artificial reefs. Mar. Environ. Res.
749 143, 71–81.

750 Leclercq, E., Zerafa, B., Brooker, A.J., Davie, A., Migaud, H., 2018. Application of passive-
751 acoustic telemetry to explore the behaviour of ballan wrasse (*Labrus bergylta*) and lumpfish
752 (*Cyclopterus lumpus*) in commercial Scottish salmon sea-pens. Aquaculture. 495, 1–12.

753 Leclercq, E., Graham, P., Migaud, H., 2015. Development of a water-stable agar-based diet
754 for the supplementary feeding of cleaner fish ballan wrasse (*Labrus bergylta*) deployed
755 within commercial Atlantic salmon (*Salmon salar*) net-pens. Anim. Feed Sci. Tech. 208, 98–
756 106.

Leclercq, E., Davie, A., Migaud, H., 2014a. Delousing efficiency of farmed ballan wrasse (*Labrus bergylta*) against *Lepeophtheirus salmonis* infecting Atlantic salmon (*Salmo salar*) post-smolts. Pest Manag. Sci. 70, 1274–1282.

Leclercq, E., Davie, A., Migaud, H., 2014b. The physiological response of farmed ballan wrasse (*Labrus bergylta*) exposed to an acute stressor. Aquaculture, 434, 1–4.

March, D., Palmer, M., Alós, J., Grau, A., Cardona, F., 2010. Short-term residence, home range size and diel patterns of the painted comber *Serranus scriba* in a temperate marine reserve. Mar. Ecol. Prog. Ser. 400, 195–206.

Morel, G.M., Shrives, J., Bossy, S.F., Meyer, C.G., 2013. Residency and behavioural rhythmicity of ballan wrasse (*Labrus bergylta*) and rays (*Raja* spp.) captured in Portelet Bay, Jersey: implications for Marine Protected Area design. J. Mar. Biol. Ass. UK. 93, 1407–1414.

Munro, L.A., Wallace, I.S., 2019. Scottish Fish Farm Production Survey 2018. Marine Scotland Science, Edinburgh, 55 pp.

Näslund, J., Rosengren, M., Villar, D.D., Gansel, L., Norrgård, J.R., Persson, L., Winkowski, J.J., Kvingedal, E., 2013. Hatchery tank enrichment affects cortisol levels and shelter-seeking in Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 70, 585–590.

Nilsson, J., Brönmark, C., Hansson, L., Chapman, B.B., 2014. Individuality in movement: the role of animal personality, in Animal movement across scales ed. by Hansson LA and Akesson S, Oxford University Press, Oxford, pp. 90–109.

Pickering, H., Whitmarsh, D., 1997. Artificial reefs and fisheries exploitation: a review of the 'attraction versus production' debate, the influence of design and its significance for policy. Fish. Res. 31:39–59.

779 Powell, A., Treasurer, J.W., Pooley, C.L., Keay, A.J., Lloyd, R., Imsland, A.K., Garcia de
780 Leaniz, C., 2018. Use of lumpfish for sea-lice control in salmon farming: Challenges and
781 opportunities. Rev. Aquacult. 10, 683–702.

782 Rechisky, E.L., Wetherbee, B.M., 2003. Short-term movements of juvenile and neonate
783 sandbar sharks, *Carcharhinus plumbeus*, on their nursery grounds in Delaware Bay. Environ.
784 Biol. Fish. 68, 113–128.

785 Sih, A., Bell, A., Johnson, J.C., 2004. Behavioral syndromes: an ecological and evolutionary
786 overview. Trends Ecol. Evol. 19, 372–378.

787 Skiftesvik, A.B., Bjelland, R.M., Durif, C.M.F., Johansen, I.S., Browman, H.I., 2013.
788 Delousing of Atlantic salmon (*Salmo salar*) by cultured vs. wild ballan wrasse (*Labrus*
789 *bergylta*). Aquaculture. 402–403, 113–118.

790 Treasurer, J.W., 2002. A review of potential pathogens of sea lice and the application of
791 cleaner fish in biological control. Pest Manag. Sci. 58, 546–558.

792 Treasurer, J.W., 2013. Use of wrasse in sea lice control. Scottish Aquaculture Research
793 Forum, 31pp.

794 Villegas-Ríos, D., Alós, J., March, D., Palmer, M., Mucientes, G., Saborido-rey, F., 2013.
795 Home range and diel behavior of the ballan wrasse, *Labrus bergylta*, determined by acoustic
796 telemetry. J. Sea Res. 80, 61–71.

797 Villegas-Ríos, D., Olsen, E.M., Réale, D., Freitas, C., Moland, E., 2018. Personalities
798 influence spatial responses to environmental fluctuations in wild fish. J. Anim. Ecol. 87,
799 1309–1319.

800

Table 1. Summary of the three acoustic tagging trials.

	Trial 1	**Trial 2a**	**Trial 2b**
Comparison	Wild *vs.* non-acclimatised farmed ballan wrasse	Hatchery-acclimatised *vs*. non-acclimatised farmed ballan wrasse	Hatchery-and-cage-acclimatised *vs.* non-acclimatised farmed ballan wrasse
Hatchery acclimatisation	–	11th May – 19th June 2016	5th August – 30th August 2016
Sea-cage acclimatisation	–	–	30th August – 12th September 2016
Transport to sea cage	Wild: October 2014, Farmed: 31st May 2015	11th June 2016	Acclimatised: 30th August 2016, non-acclimatised: 11th September 2016
Tagging surgery	2nd June 2015	13th June 2016	12th September 2016
No. tagged wrasse	18 per group	20 per group	17 per group
Weight at surgery	Wild: 66.27 ± 12.21 g Farmed: 43.57 ± 6.49 g	Acclimatised: 45.08 ± 5.39 g, non-acclimatised: 46.38 ± 4.92 g	Acclimatised: 50.43 ± 6.23 g, non-acclimatised: 63.70 ± 11.73 g
Length at surgery (TL)	Wild: 16.83 ± 1.01 cm Farmed: 13.97 ± 0.60 cm	Acclimatised: 13.38 ± 0.57 cm, non-acclimatised: 13.59 ± 0.42 cm	Acclimatised: 14.35 ± 0.67 cm, non-acclimatised: 14.79 ± 0.73 cm
Deployment date	5th June 2015	15th June 2016	14th September 2016
Data acquisition	124 days	60 days	77 days

Table 2. Summary of water quality parameters at 4m depth during the three acoustic trials recorded at 30 min intervals and averaged over 12 h. (mean ± standard deviation, range in parentheses).

	Trial 1	**Trial 2a**	**Trial 2b**
Temperature (°C)	11.59 ± 0.97 (9.01–13.20)	11.68 ± 0.42 (10.59–12.82)	13.66 ± 0.29 (12.92–14.18)
Salinity (PSU)	18.83 ± 6.04 (9.53–26.92)	32.49 ± 0.57 (31.16–33.54)	29.38 ± 4.37 (21.29–36.88)
Dissolved oxygen (mg/L)	9.70 ± 1.60 (4.64–13.11)	10.36 ± 0.42 (9.40–11.48)	7.11 ± 0.67 (4.67–8.85)

Table 3. Core areas (CA) and home ranges (HR) of individual fish in each trial. All values are m^2.

	Trial 1				Trial 2b			
	Wild		Farmed		Acclimatised		Non-acclimatised	
Fish ID	CA	HR	CA	HR	CA	HR	CA	HR
1	95	680	23	237	95	564	40	425
2	148	733	70	364	118	599	28	194
3	123	664	14	194	14	142	65	440
4	37	407	24	339	82	611	75	562
5	121	566	108	648	75	572	62	563
6	83	627	10	185	76	474	80	576
7	26	546	85	457	68	553	24	303
8	113	583	43	355	117	676	35	347
9	138	709	29	314	84	481	25	412
10	85	642	22	369	55	472	11	138
11	140	674	-	-	-	-	43	398
12	98	589	-	-	-	-	55	421
13	101	637	-	-	-	-	65	439
14	63	580	-	-	-	-	40	449
Mean ± SD	97.8 ± 36.8	616.8 ± 110.1	42.9 ± 33.4	346.0 ± 136.1	78.3 ± 30.2	514.3 ± 146.6	46.1 ± 20.9	404.6 ± 128.2

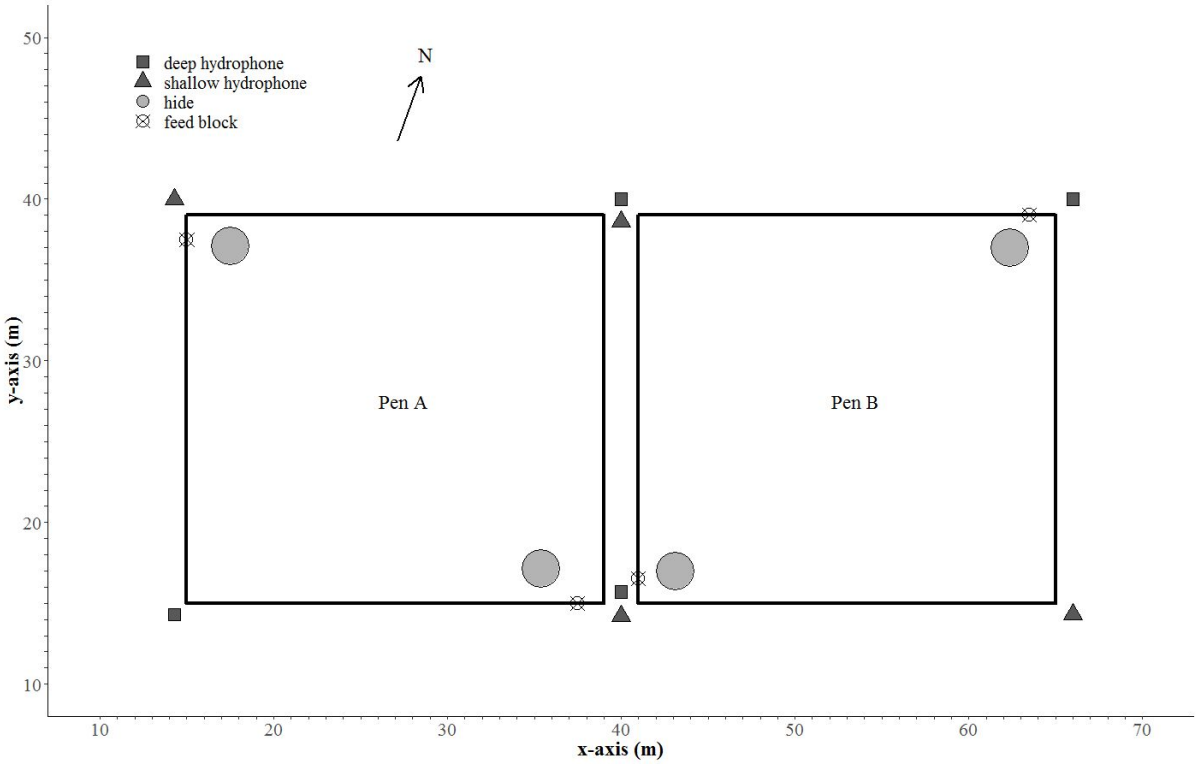


Figure 1. Plan-view schematic of 24 × 24 m square cages in the local Cartesian coordinate system showing the positioning of the cleaner-fish hide areas (2 m diameter grey circles, mean location during study), the hydrophone array deployed across two horizontal planes at 1 m (shallow) and 20 m (deep) depth and wrasse feed blocks deployed weekly adjacent to the hides.

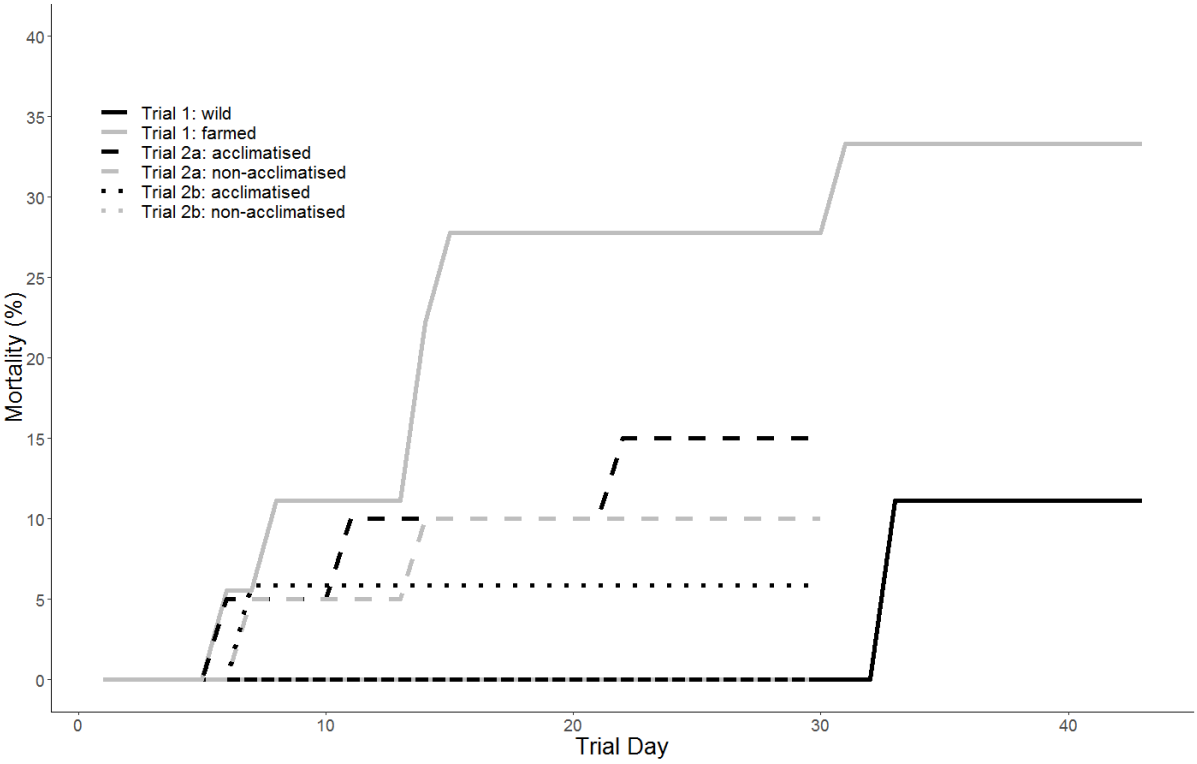


Figure 2. Ballan wrasse mortality in all trials and experimental groups during the periods used for analysis.

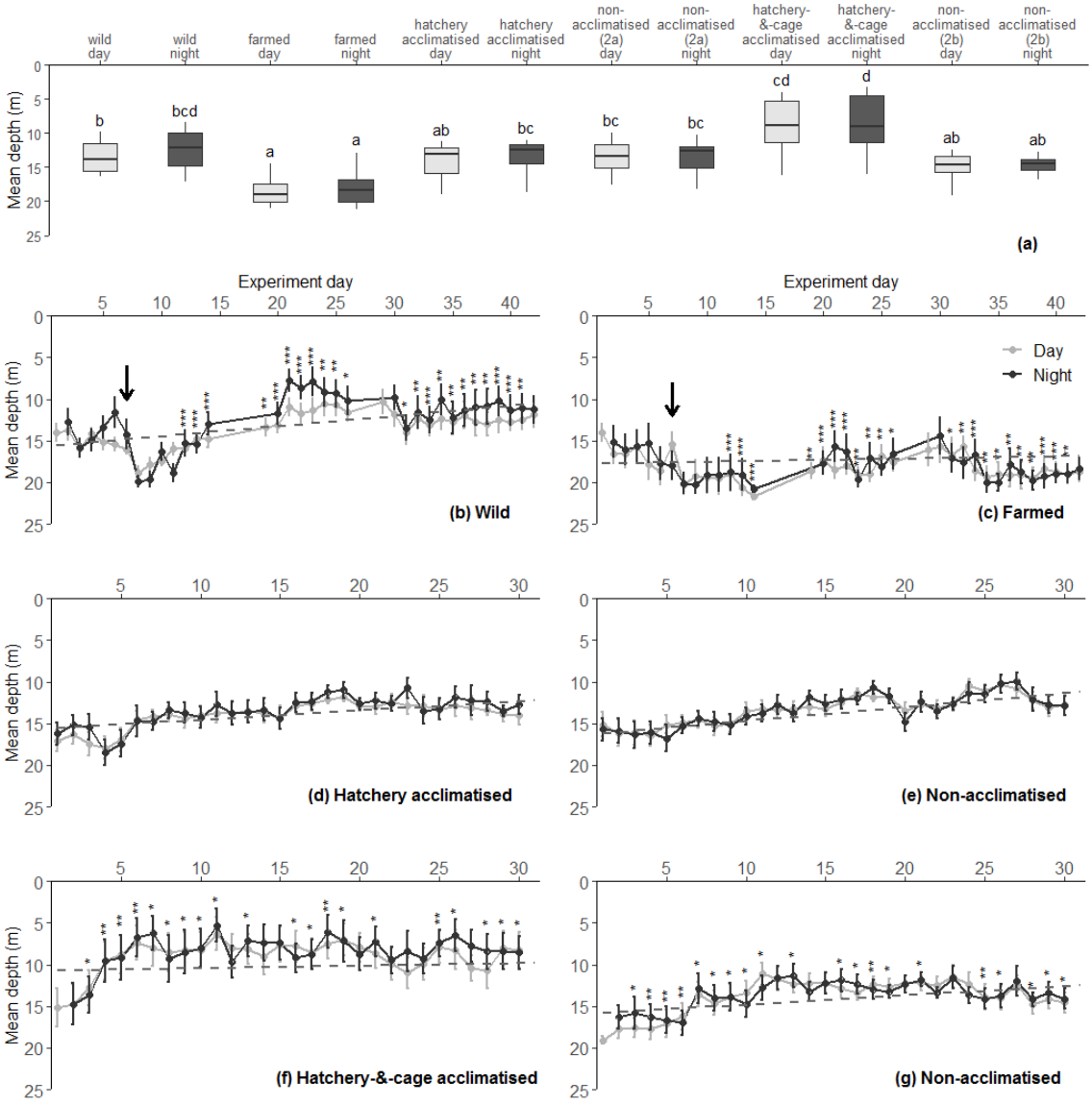


Figure 3. (a) Boxplot of group depth for each trial (letters represent significance with different letters denoting significant differences from other groups, $P < 0.05$). Comparison of daytime and night time mean daily depth for (b) trial 1 wild wrasse, (c) trial 1 farmed wrasse, (d) trial 2a hatchery-acclimatised wrasse, (e) trial 2a non-acclimatised wrasse, (f) trial 2b hatchery-and-cage-acclimatised wrasse and (g) trial 2b non-acclimatised wrasse (mean ± SEM, n = 10–14 fish,. Asterisks show significant differences between daily mean depths of corresponding treatment groups (* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$). Dotted lines are fitted linear regressions of daily mean activity. Gaps between points in (b) and (c) are due to temporary system failures. Arrows indicate day of bath treatment.

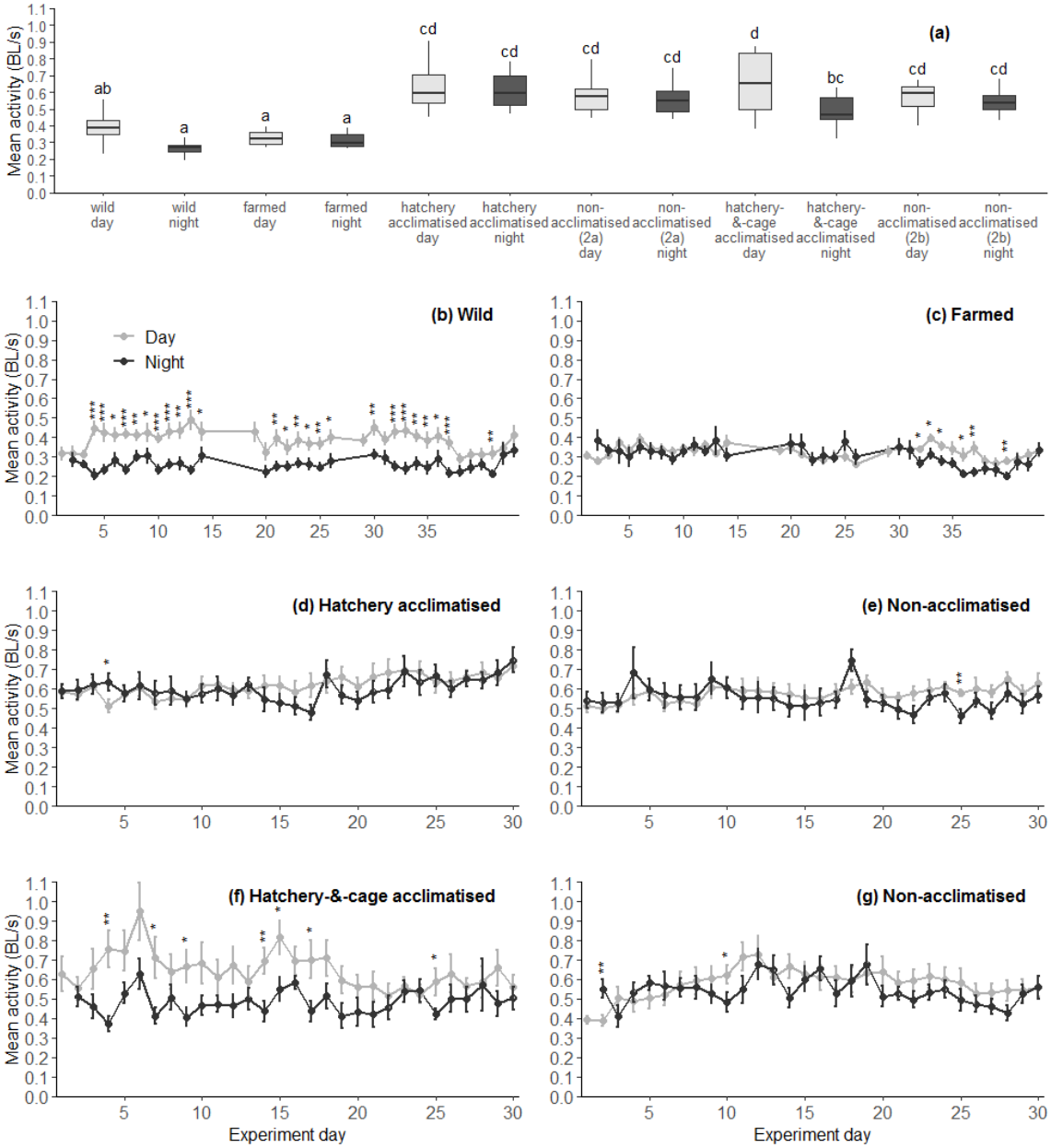


Figure 4. (a) Boxplot of group activity for each trial (letters represent significance groups with different letters denoting significant differences from other groups, $P < 0.05$). Comparison of daytime and night time mean daily activity for (b) trial 1 wild wrasse, (c) trial 1 farmed wrasse, (d) trial 2a hatchery-acclimatised wrasse, (e) trial 2a non-acclimatised wrasse, (f) trial 2b hatchery-and-cage-acclimatised wrasse and (g) trial 2b non-acclimatised wrasse (mean ± SEM, n = 10–14 fish. Asterisks show significant differences between daytime and night time activity (* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$). Gaps between points in (b) and (c) are due to temporary network failures.

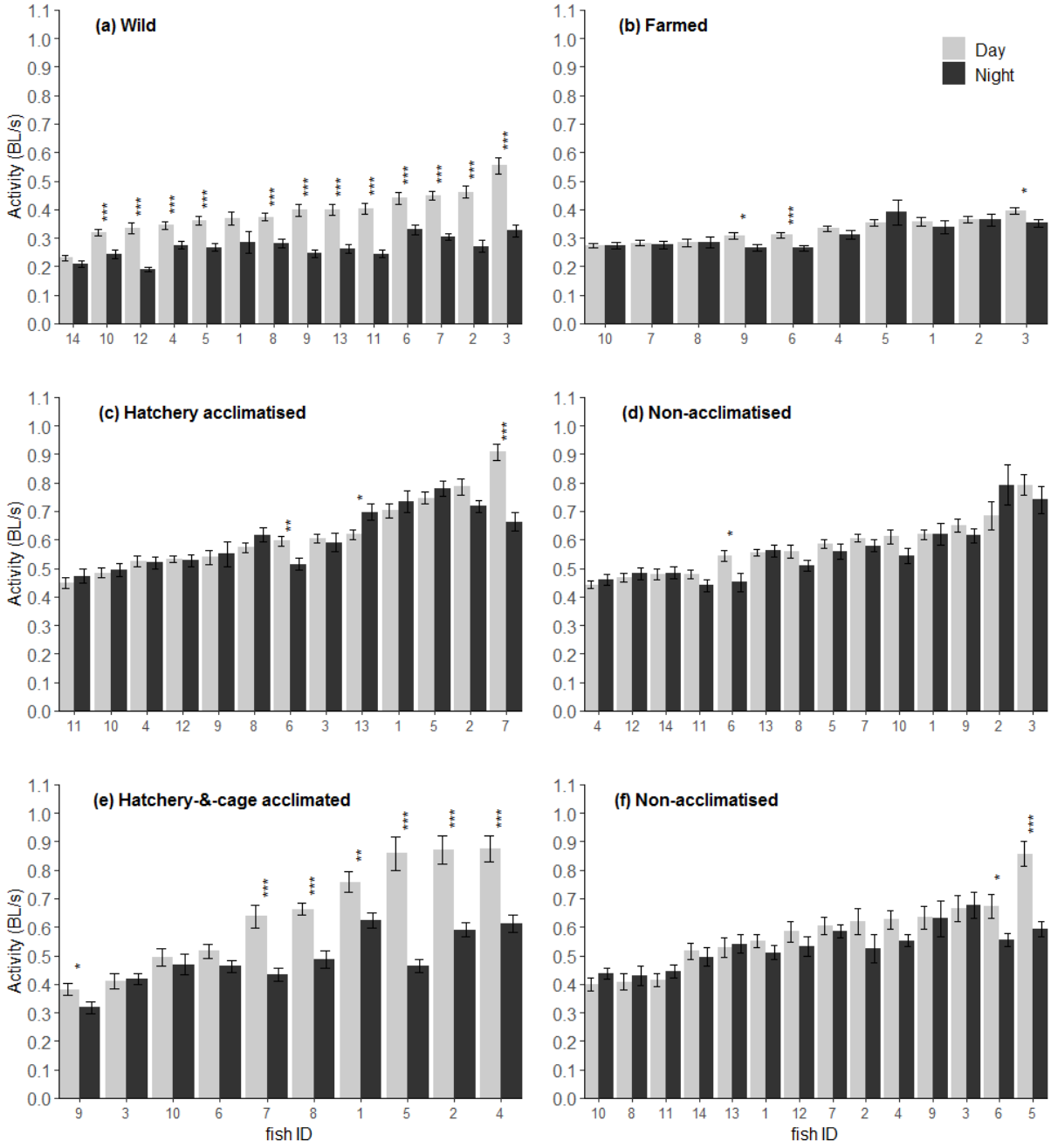


Figure 5. Comparison of daytime and night time mean activity of individual fish for (a) trial 1 wild wrasse, (b) trial 1 farmed wrasse, (c) trial 2a hatchery-acclimatised wrasse, (d) trial 2a non-acclimatised wrasse, (e) trial 2b hatchery-and-cage-acclimatised wrasse, (f) trial 2b non-acclimatised wrasse (mean ± SEM, n = 30–43 days). Asterisks show significant differences between daytime and night time activity (* = P <0.05, ** = P < 0.01, *** = P <0.001).

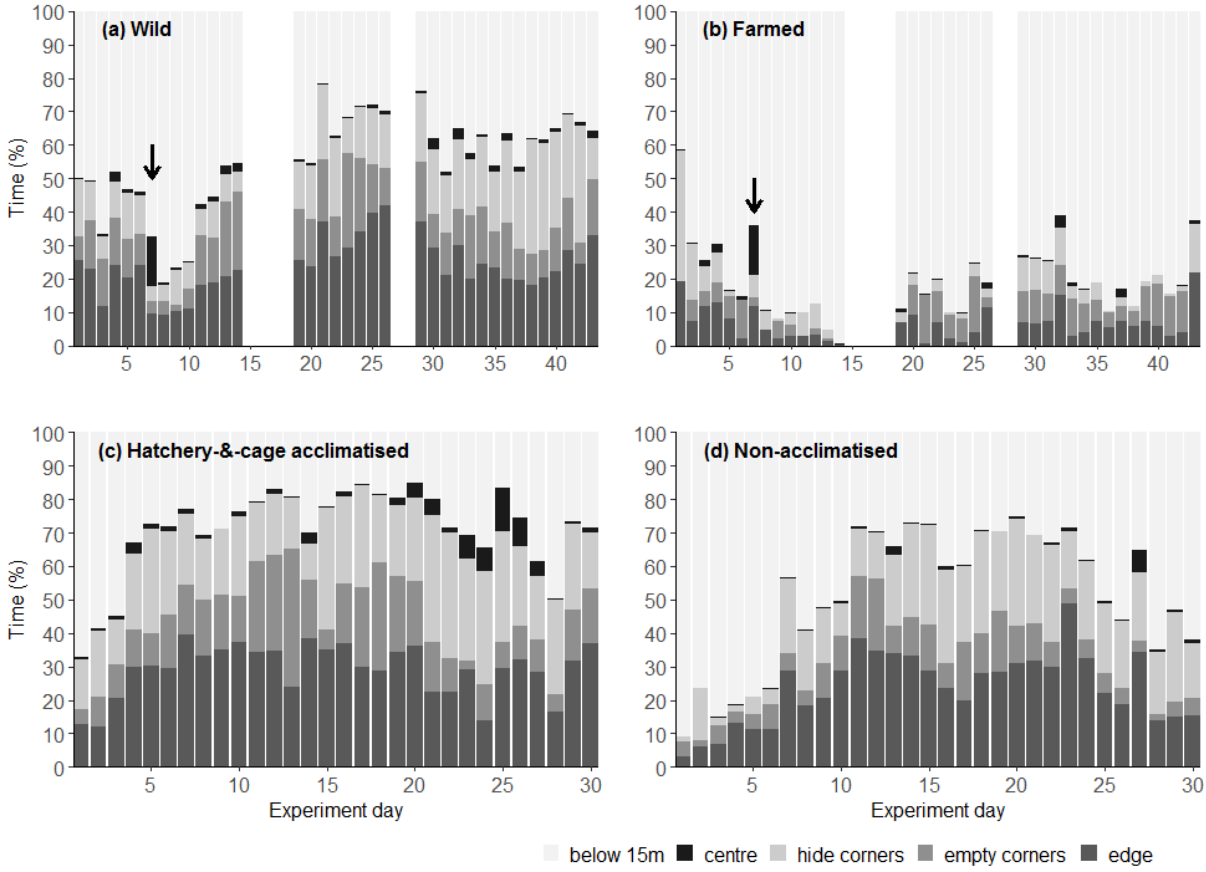


Figure 6. Proportion of time spent in different cage locations during the daytime for (a) trial 1 wild wrasse, (b) trial 1 farmed wrasse, (c) trial 2b hatchery-and-cage-acclimatised wrasse, (d) trial 2b non-acclimatised wrasse. Gaps in (a) and (b) are due to temporary system failures. Arrows indicate day of bath treatment.

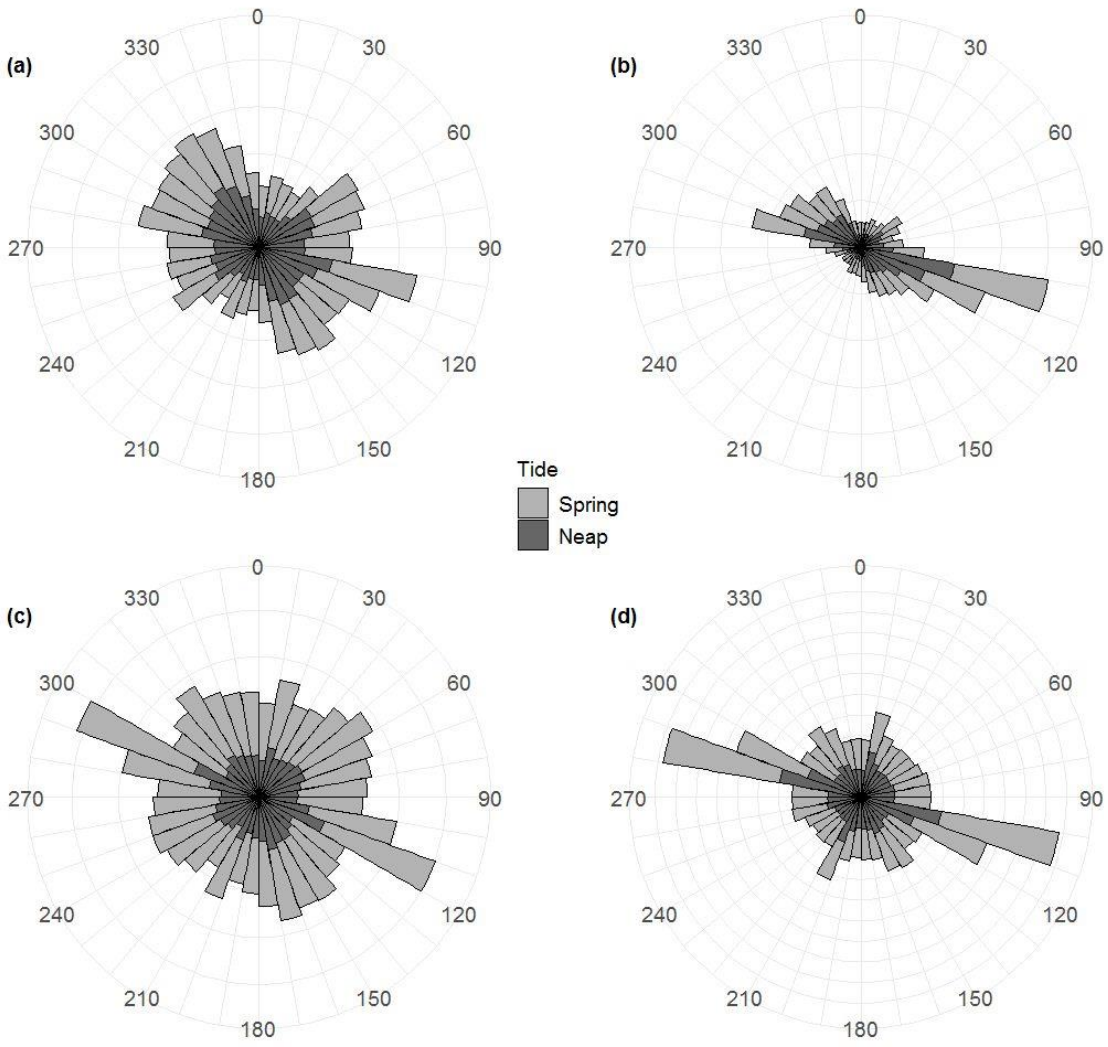


Figure 7. Polar distribution of ballan wrasse headings during spring and neap tides where swimming speed > 1 BL/s; (a) trial 1 wild wrasse, (b) trial 1 farmed wrasse, (c) trial 2b acclimatised wrasse and (d) trial 2b non-acclimatised wrasse (y-axis gridlines = 2,500 observations).

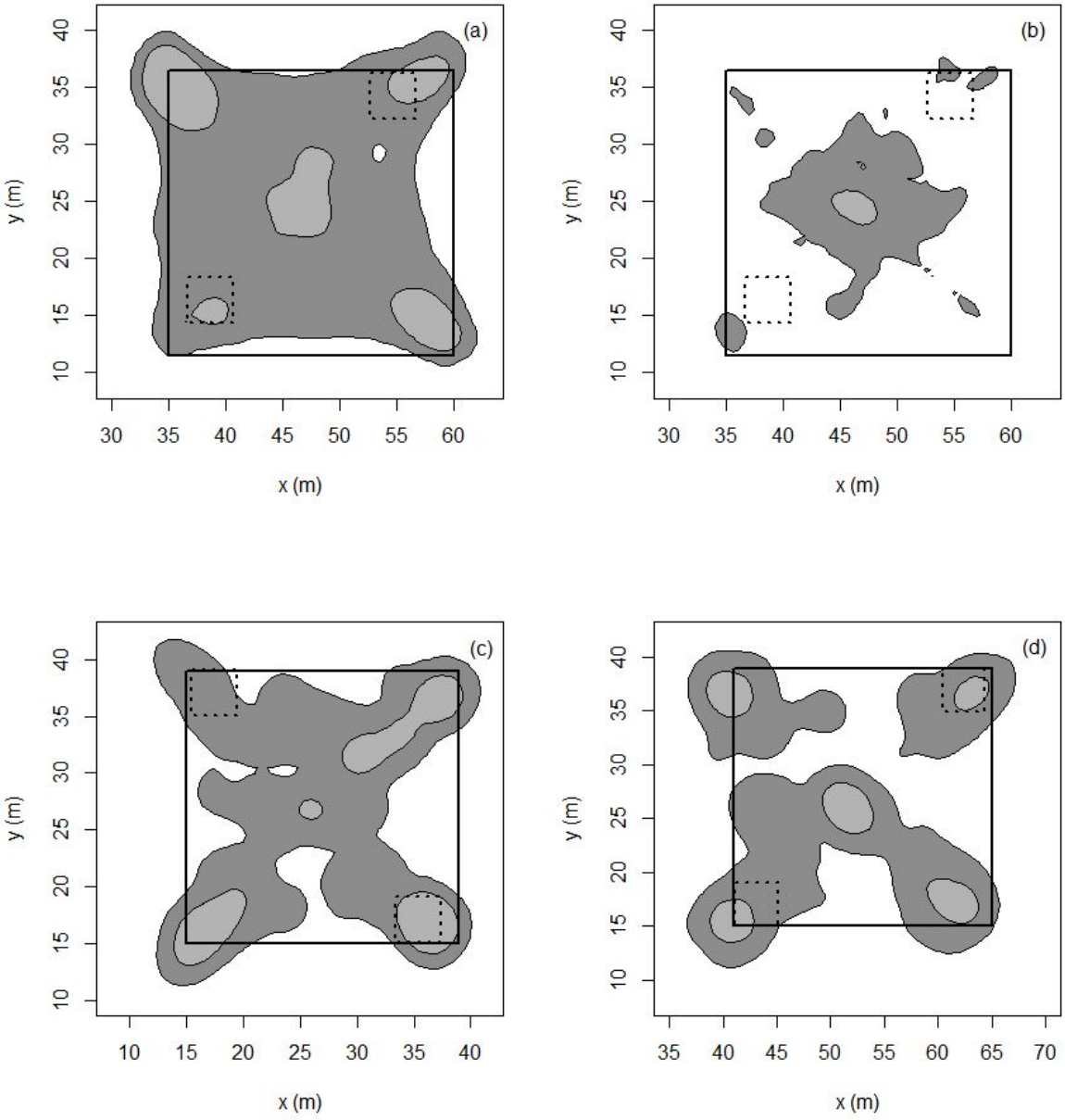


Figure 8. Examples of kernel utilisation distributions (home ranges) of individual fish for (a) wild wrasse #11, (b) farmed wrasse #3, (c) hatchery-and-cage-acclimatised wrasse #9 and (d) non-acclimatised wrasse #3. Light grey = core area (KUD_{50}), dark grey = home range (KUD_{95}), solid line = cage boundary and dotted lines = approximate location of hides.

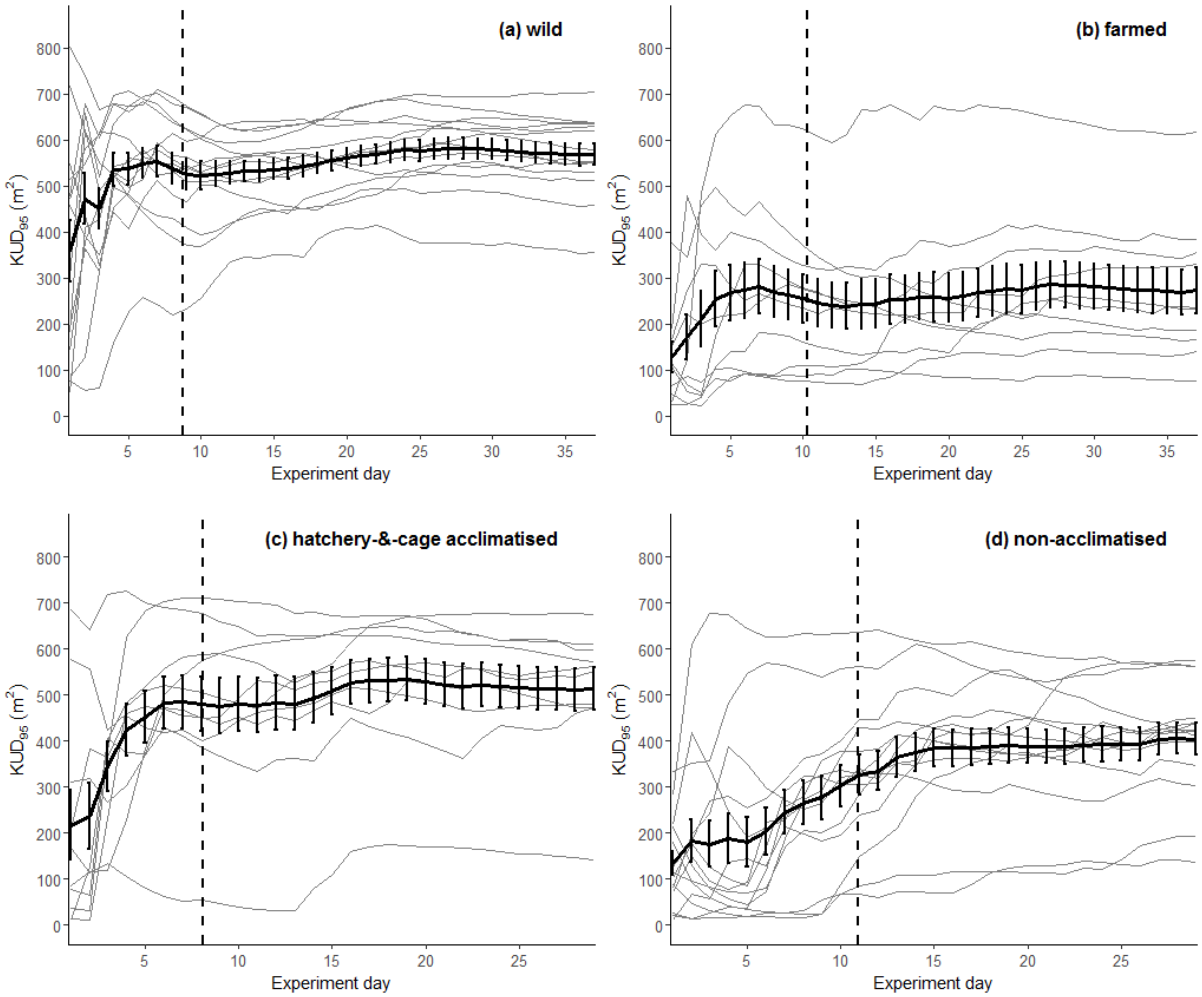
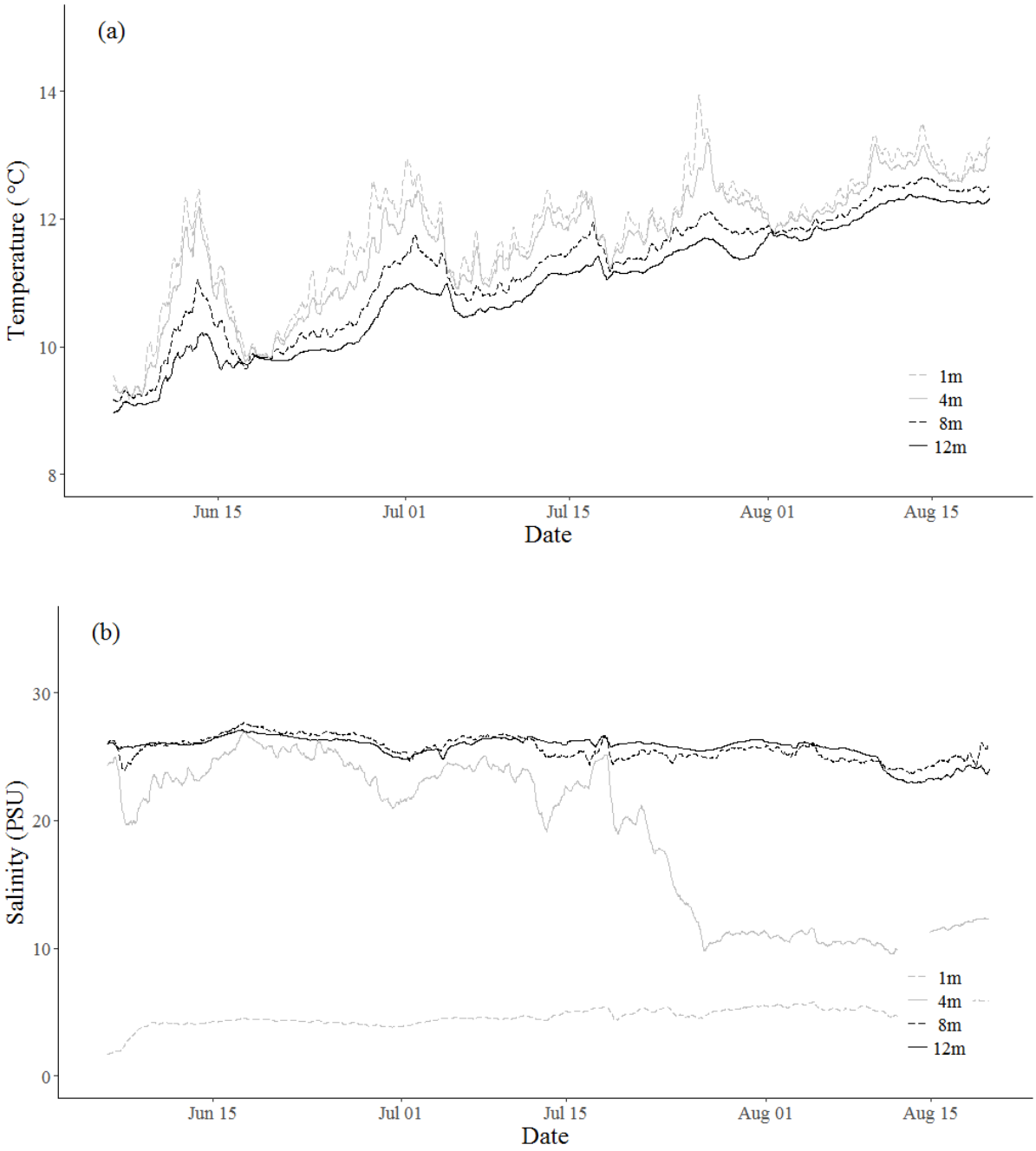
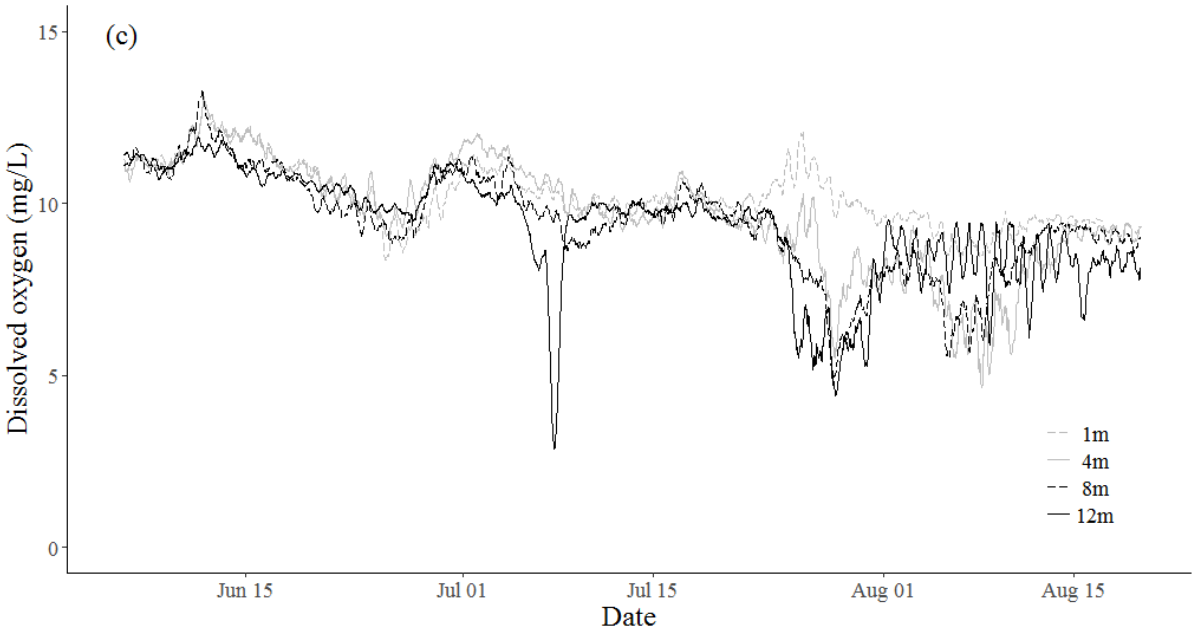


Figure 9. Cumulative 95% kernel utilisation distributions (KUD_{95}) for (a) wild wrasse, (b) farmed wrasse, (c) hatchery-and-cage-acclimatised wrasse and (d) non-acclimatised wrasse. Grey lines = cumulative KUD_{95} for individual fish, black lines = mean cumulative KUD_{95} ± SEM, dotted lines = mean asymptote (time taken to establish home range).

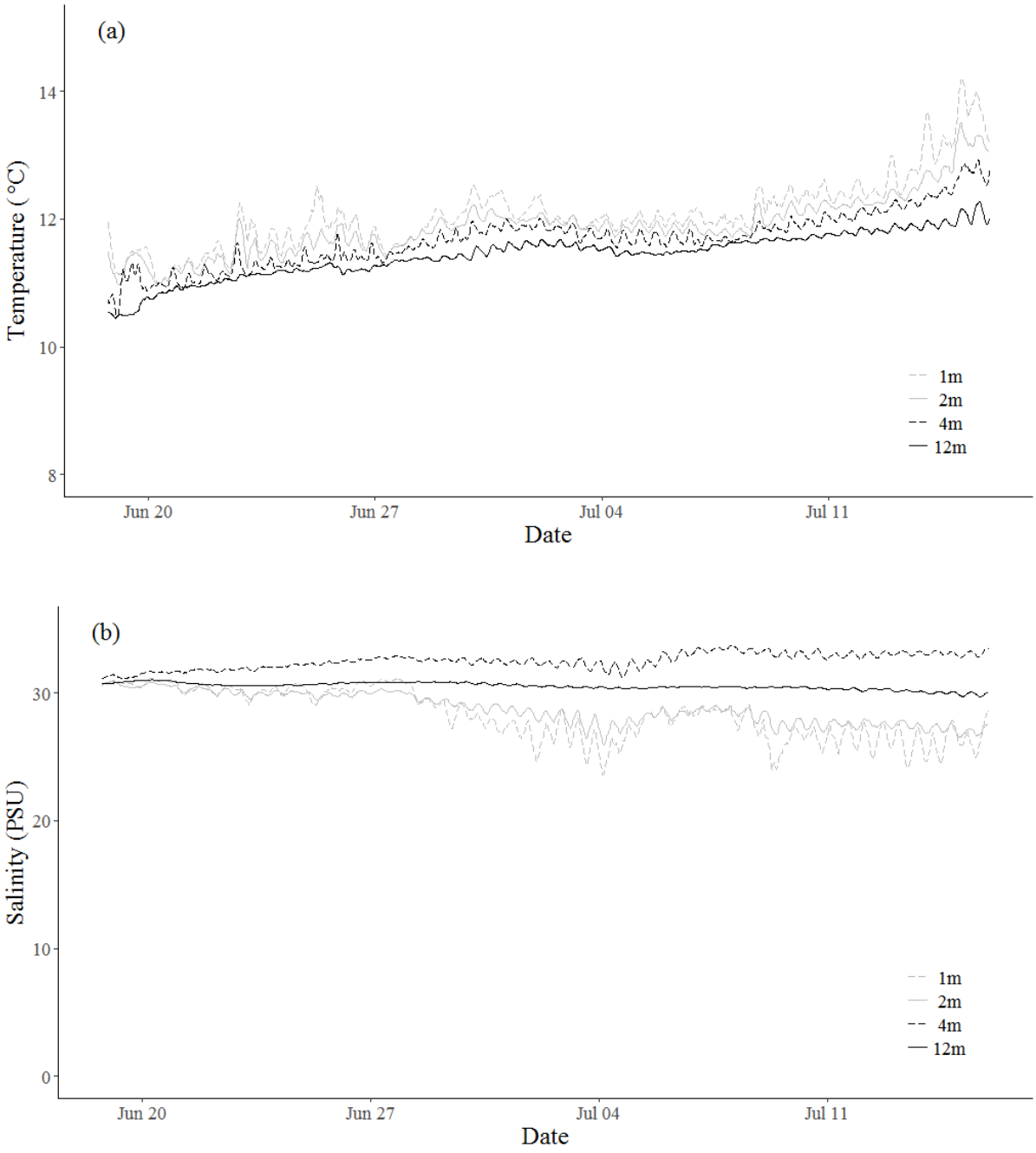
Supplementary data

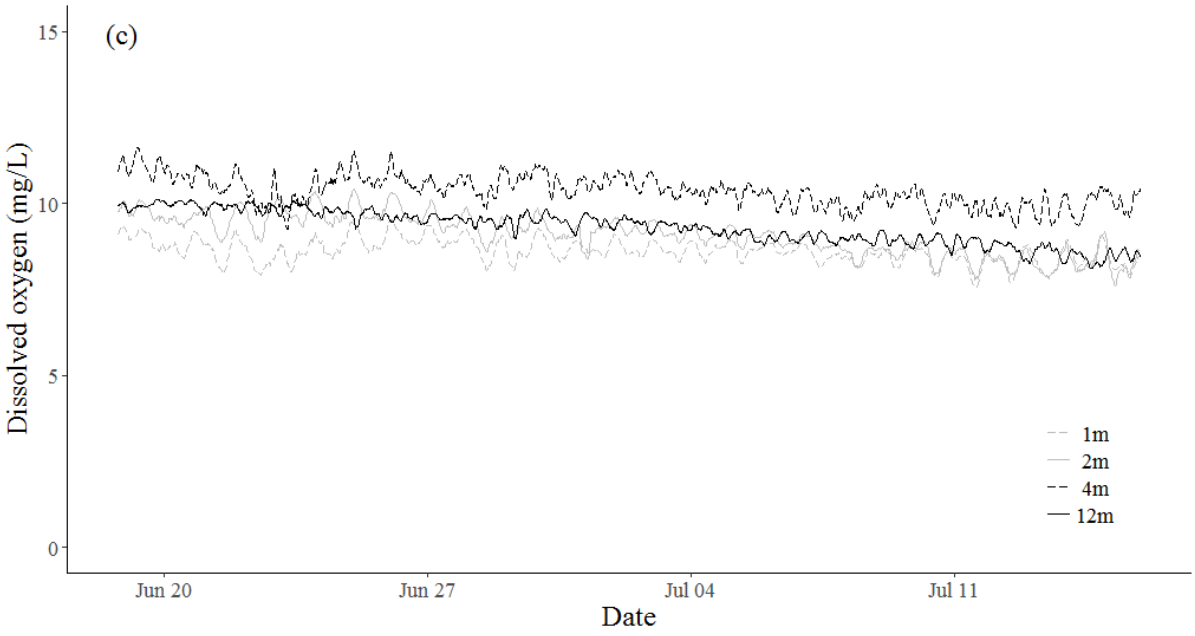
S1. (a) temperature, (b) salinity and (c) dissolved oxygen during trial 1 measured at 1, 4, 8 and 12m depth and 30 min intervals over the study period and averaged over 12 h.



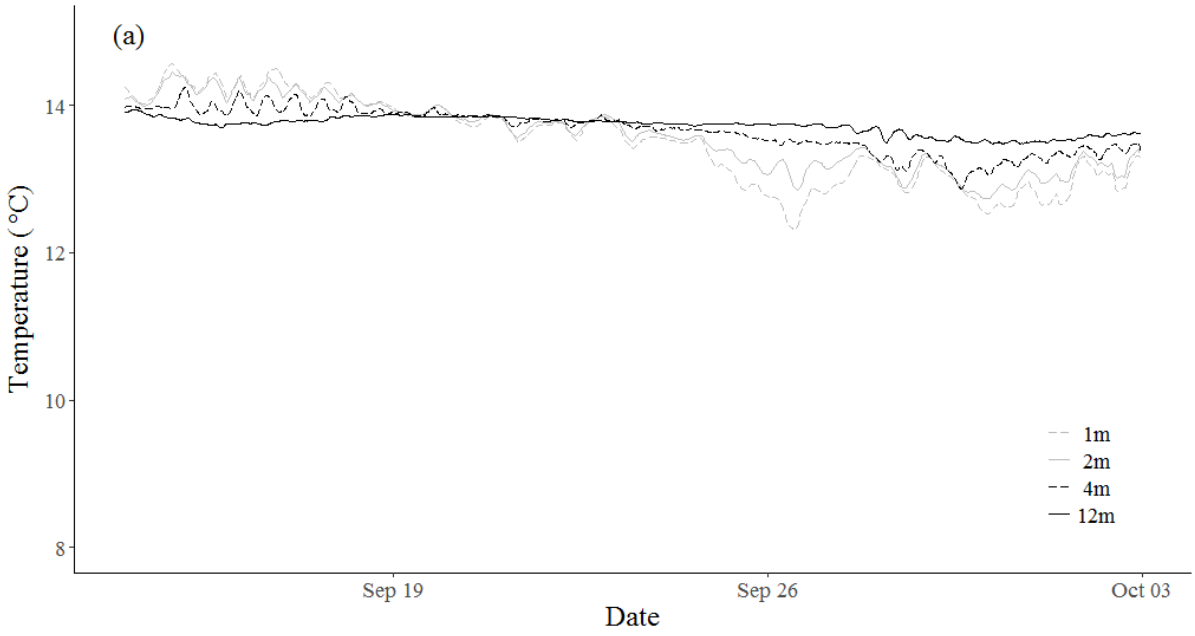

(c)
15
10
5
0
Dissolved oxygen (mg/L)
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Date
1m
4m
8m
12m

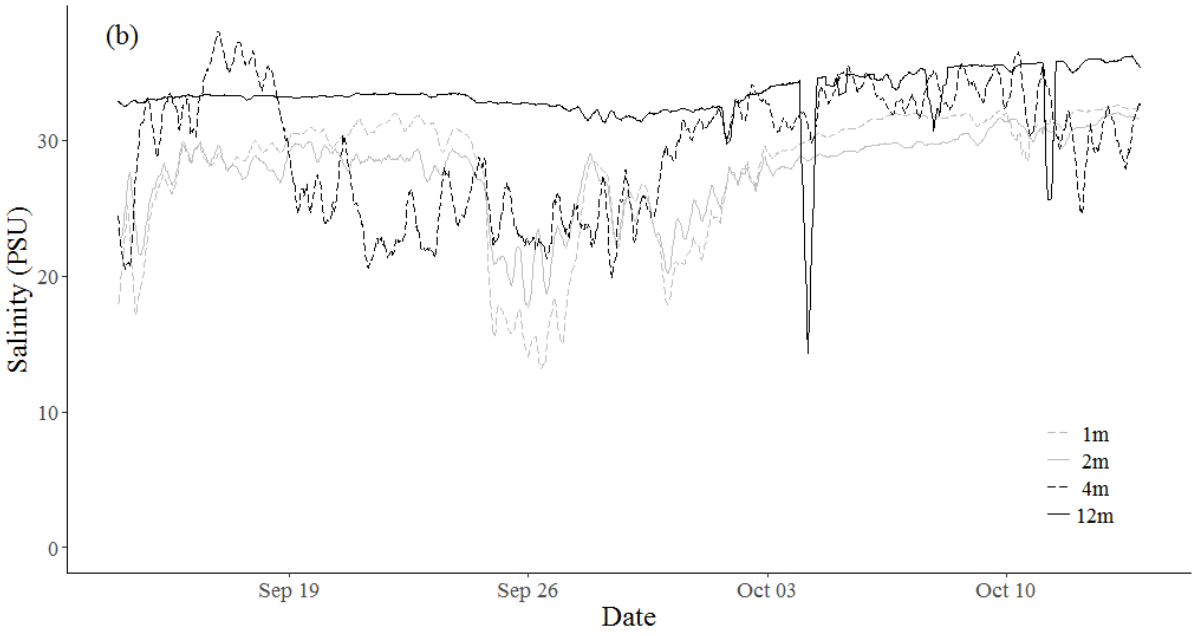
S2. (a) temperature, (b) salinity and (c) dissolved oxygen during trial 2a measured at 1, 2, 4 and 12m depth and 30 min intervals over the study period and averaged over 12 h.

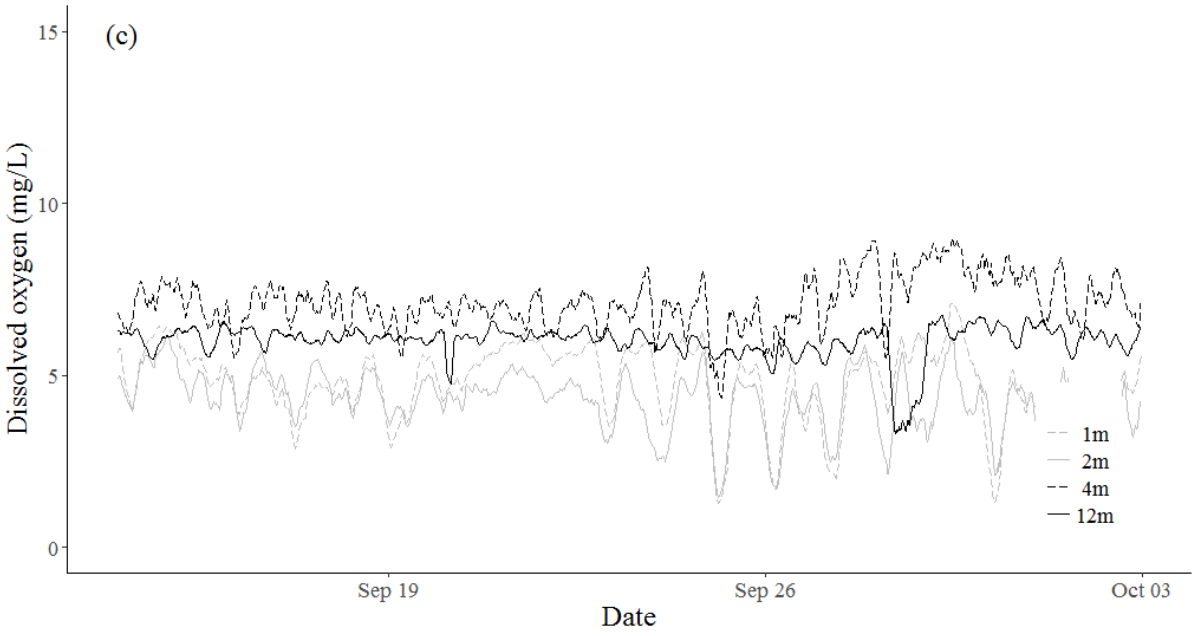



(c)
15
10
5
0
Dissolved oxygen (mg/L)
1m
2m
4m
12m
Jun 20
Jun 27
Jul 04
Jul 11
Date

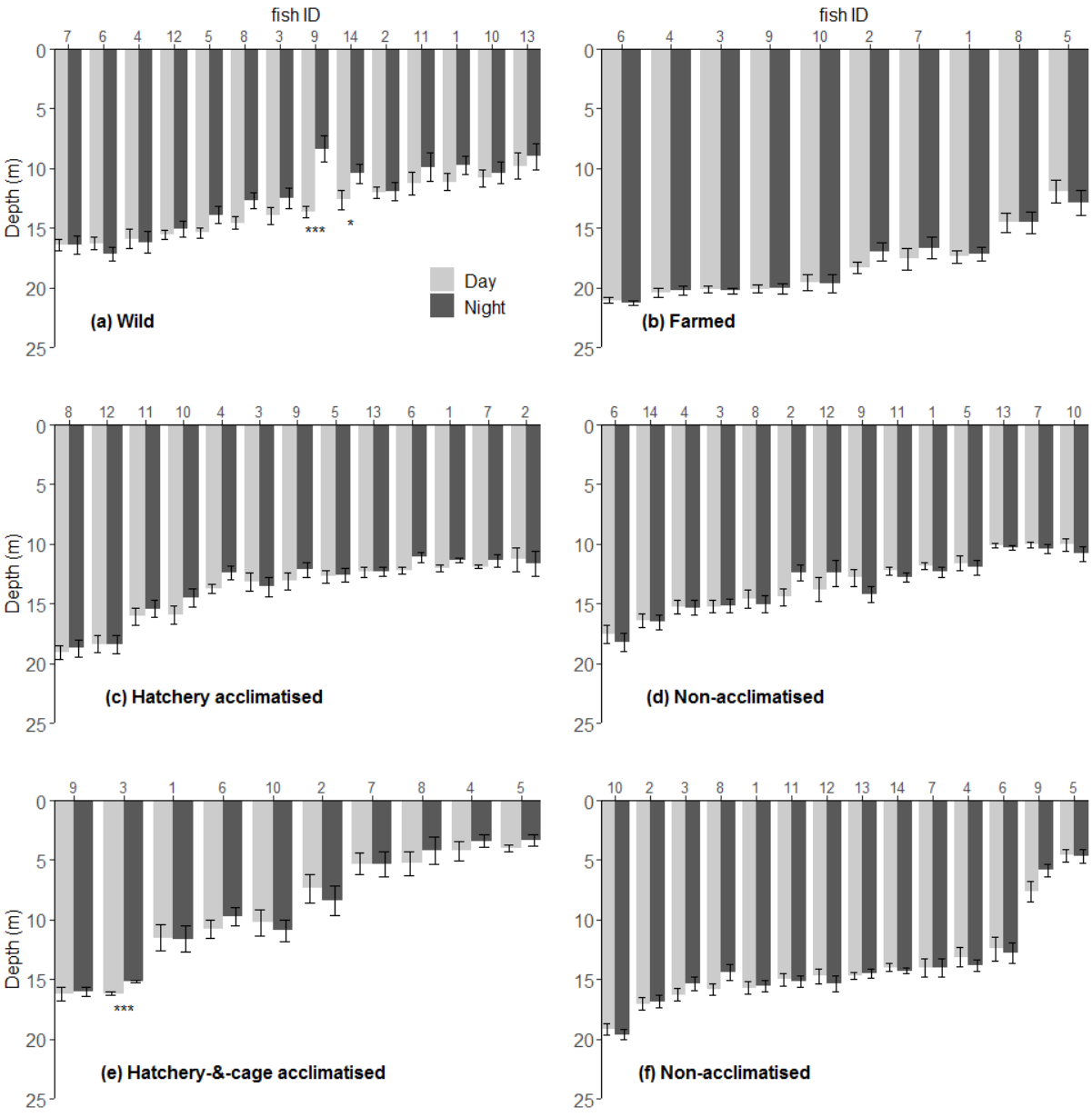
S3. (a) temperature, (b) salinity and (c) dissolved oxygen during trial 2b measured at 1, 2, 4 and 12m depth and 30 min intervals over the study period and averaged over 12 h.






(c)
15
10
5
0
Dissolved oxygen (mg/L)
1m
2m
4m
12m
Sep 19
Sep 26
Oct 03
Date

S4. Comparison of daytime and night time mean depth of individual fish for (a) trial 1 wild wrasse, (b) trial 1 farmed wrasse, (c) trial 2a hatchery-acclimatised wrasse, (d) trial 2a non-acclimatised wrasse, (e) trial 2b hatchery-and-cage-acclimatised wrasse, (f) trial 2b non-acclimatised wrasse (mean ± SEM, n = 30–43 days). Asterisks show significant differences between daytime and night time depths (* = P <0.05, *** = P <0.001).



S5. Proportion of daily time spent in different cage locations during the night time for (a) trial 1 wild wrasse, (b) trial 1 farmed wrasse, (c) trial 2b hatchery-and-cage-acclimatised wrasse (d) trial 2b non-acclimatised wrasse. Gaps in (a) and (b) are due to temporary system failures. Arrows indicate the night following the bath treatment.