Supplement

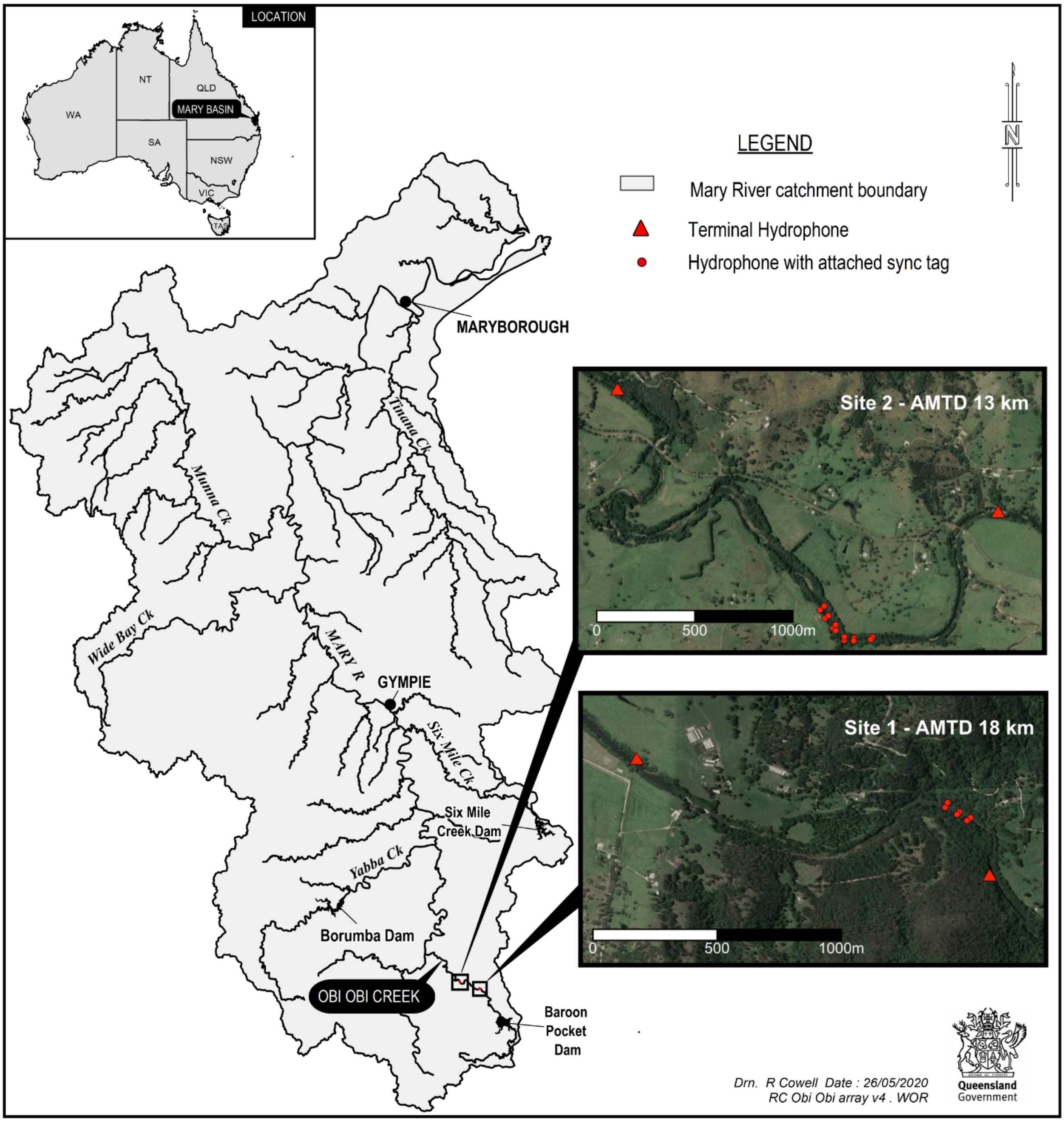

Figure S1. Map showing location of Obi Obi Creek study sites within Mary River catchment. Insets show Site 1 - AMTD 18 km (bottom) and Site 2 - AMTD 13 km (top) hydrophone arrays including hydrophones with attached sync tags (red dots ●). Terminal receivers are shown upstream and downstream of the VPS arrays and are denoted by red triangles ▲.

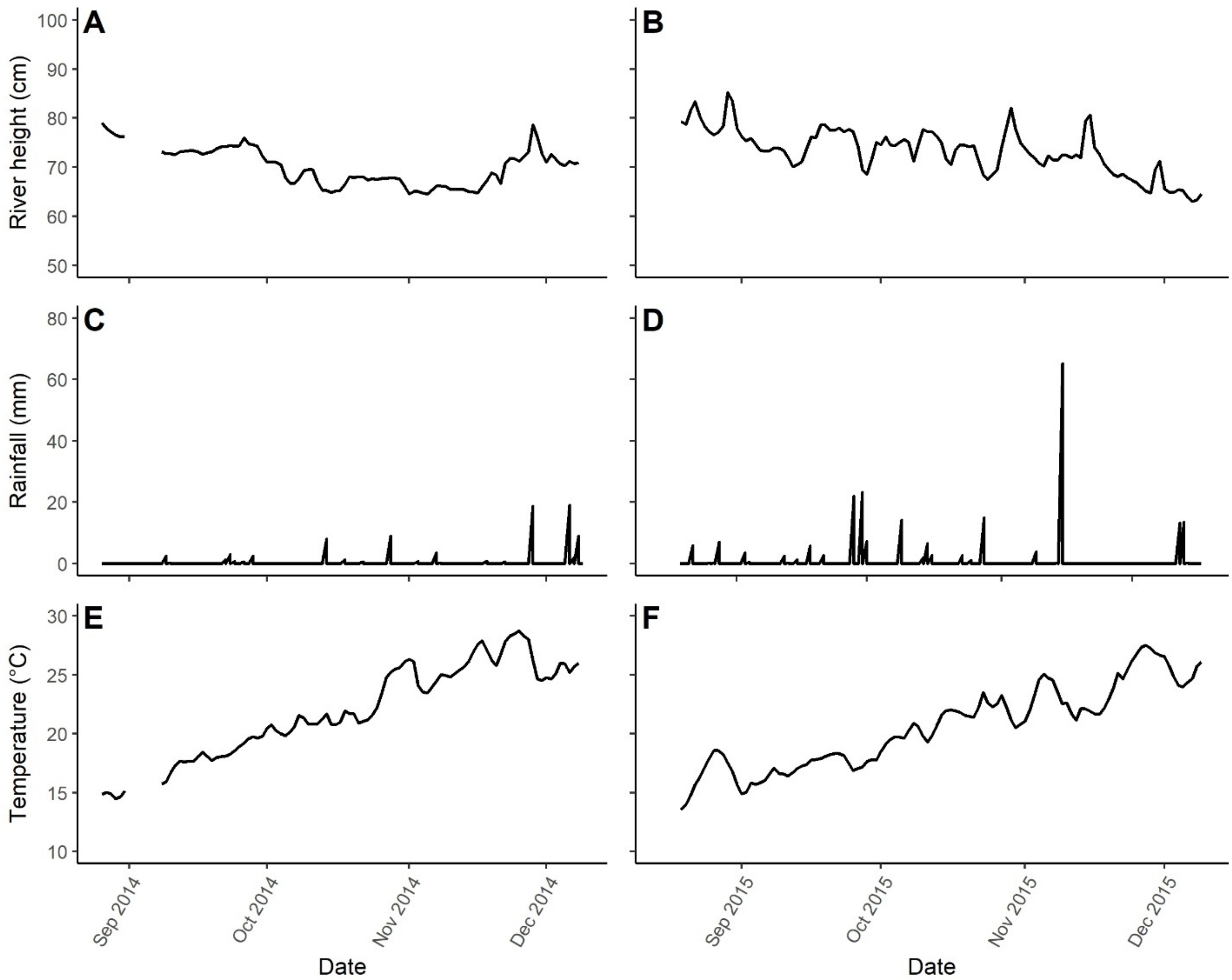

Figure S2. Variation in river height (A and B), rainfall (C and D) and temperature (E and F) for Site 1 (left) and Site 2 (right).

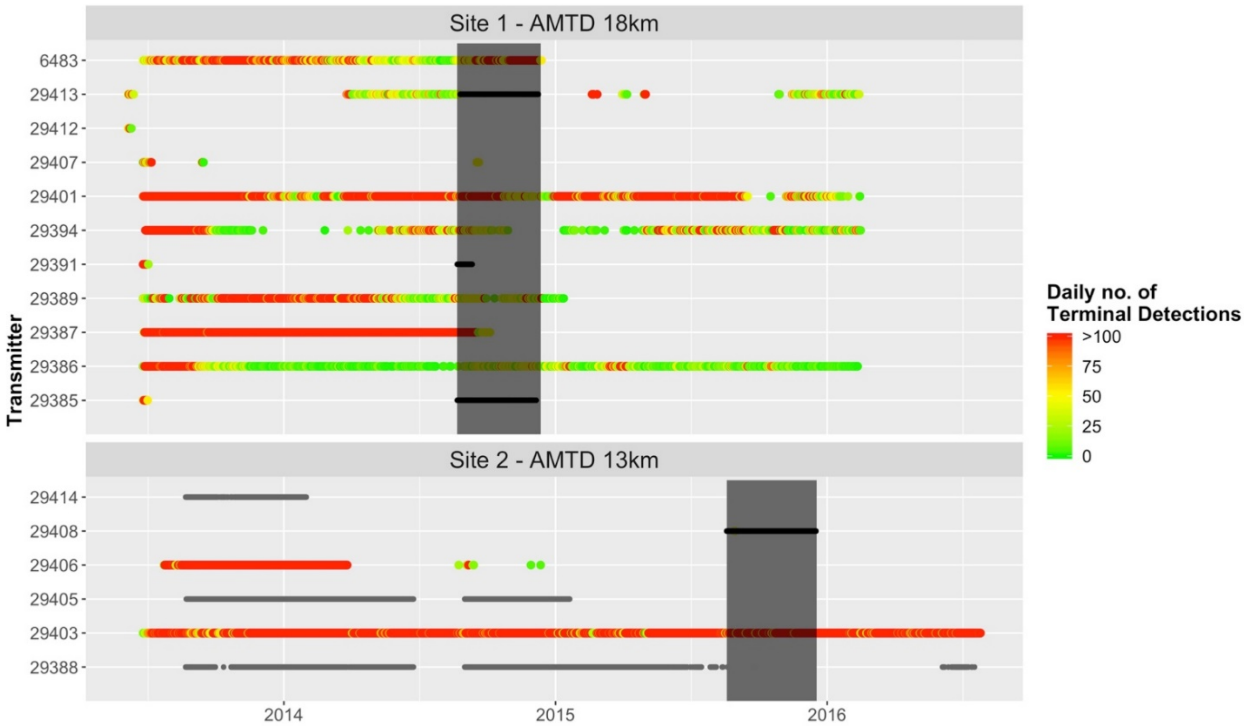

Figure S3. Daily detections of Mary River cod within hydrophone arrays at sites 1 and 2. Period of fine-scale array deployment at each site is indicated by shaded areas. Daily detections at terminal hydrophones situated upstream and downstream of sites 1 and 2 are indicated with coloured dots. Colour gradient for detections by terminal hydrophones ranges from green ● for a low number of detections, to red ● for a high number of detections on a given day. Black dots ● denote fine-scale array detections. Grey dots ● in Site 2 denote fish ID detections within the VPS array area during periods the VPS array was not deployed.

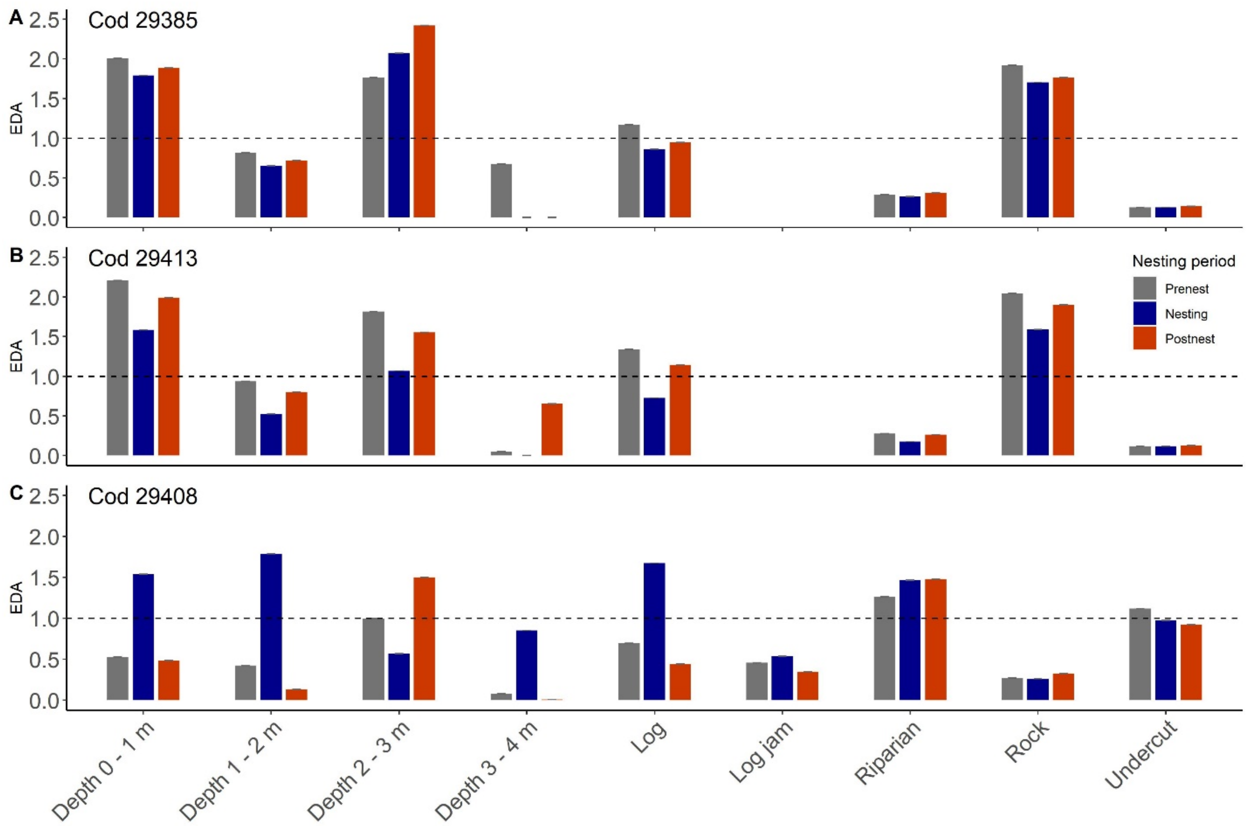

Figure S4. Habitat type selection (mean ± s.d.) for each cod during pre-nesting, nesting and post-nesting periods (bottom), as shown by Euclidean distance analysis (EDA). Values < 1 indicate increased use relative to availability, while values > 1 indicate avoidance. Scores of 1 indicate random selection.

Text S1 Materials and Methods

Mary River cod collection and tagging

Twenty-four Mary River cod were captured from Obi Obi Creek in June 2013 using a boat-mounted electrofisher unit (2.5 GPP; Smith Root, Inc., Vancouver, WA, USA), backpack electrofishing unit (LR-24 Smith-Root, Inc., Vancouver, WA, USA), and by angling (lure). Electrofisher voltage (500–1000 V), frequency (15–120 pulses s-1) and duty cycle (0–100%) were adjusted depending on site conditions to minimize harm to fish and other biota. Once collected, fish were held in a 250 L tank filled with river water and were sedated with AQUI-S® (50 mg L-1 - AQUI-S New Zealand Ltd) prior to surgery. During surgery, fish were held in a V-shaped cradle, and 25 mg L-1 of AQUI-S® solution was irrigated continuously over the fish's gills using a battery-operated circulatory pump system to maintain sedation.

Mary River cod (490 – 850 mm total length, mean 560 mm ± 166 mm SD) were surgically implanted with Vemco™ V13-1x transmitters (length = 36mm, weight = 11g) set to a 60 - 180 second roving ping rate (battery life approximately 36 months). Tag sizes ensured the weight ratio was kept under 2.25% of total fish body weight (Butler et al. 2009). Transmitters were inserted into the gut cavity through a 15 - 30 mm incision behind the left pectoral fin. The incision was closed with absorbable sutures and tissue adhesive (Vetbond; Provet, Brisbane Qld, Australia). All 24 fish were allowed to recover in aerated freshwater holding tanks until normal swimming behaviour was observed before release back into the creek, at the point of capture.

Fine-scale acoustic telemetry

Fine-scale movements of Mary River cod were quantified using hydrophone (Vemco™ VR2W - Vemco Amirix Systems Inc, NS Canada) arrays established at two sites (Site 1 at 18 km AMTD and Site 2 at 13 km AMTD; Figure S1) over two consecutive years (2014 and 2015, respectively). Prior to hydrophone installations, range tests were conducted at each site using a reference tag to determine in situ detection ranges of transmitters. Due to high complexity of submerged physical structures (e.g. logs, rocks), range tests were optimal at distances less than 100 m, therefore adjacent hydrophones were conservatively deployed at 50 m intervals. Final configurations of hydrophones aimed to maximise detection of transmitters within the array. Stationary transmitters (synchronising tags) were deployed with all hydrophones to calibrate temporal positions, and stand-alone reference tags were deployed within the Site 2 array to calibrate spatial positions over the study period (Smith 2013). All hydrophones were deployed ~0.5 m above the riverbed using concrete weights and rope secured to overhanging riparian vegetation.

For Site 1, six hydrophones were deployed in a grid pattern over a 150 m reach of Obi Obi Creek (Figure S1). The Site 1 array was deployed from 22/08/14 – 9/12/14, within a large deep pool where a spawning aggregation of up to 20 adult cod had been previously observed in 2012 (T. Espinoza, personal observation). Using a Vemco™ VR100 manual tracking receiver, two tagged cod were located within Site 1, and up to 13 cod were located in the adjacent downstream pool during the 14-month period before array installation. It was assumed these cod would move upstream into the array for the 2014 and 2015 spawning seasons, as had previously been observed. For Site 2, 13 hydrophones were deployed in an array over a 350 m reach of the creek. The array at Site 2 was deployed in a large pool from 19/08/15 – 17/12/15 where three tagged cod had been located with the VR100 prior to installation of the hydrophone array. In addition, a further three tagged cod had utilized habitat within this reach over the previous 18-months and were believed to be residing in pools adjacent to the study site. Hydrophones located upstream and downstream of each fine-scale array (hereafter termed “terminal hydrophones”) (Figure S1) were also used to determine presence of Mary River cod in areas immediately surrounding (i.e. within 2.5km) each array over the study period.

Environmental data and habitat mapping

TD-Diver dataloggers (Van Essen Instruments™) were installed in Obi Obi Creek at AMTD 7 km and AMTD 17 km to monitor water levels and water temperature over the study period (Figure S2). Rainfall observations were sourced from the Bureau of Meteorology’s ‘Climate Data Online’ website (http://www.bom.gov.au/climate/data/) for the closest station at Kenilworth Township (Station 040106). Diel period was calculated using the insol package in R (Corripio 2014).

Bathymetry and habitat data for Site 2 was collected using a 3.25 m aluminium punt mounted with a Brookhouse NMEA 0183 datalogger coupled to a Garmin® GPS and depth sounder. Water depth and habitat features were recorded along bank-to-bank cross-sections (5 – 10m intervals) for the entire array area. Habitat features including logs (single), log jams (clusters), boulders, macrophytes, overhanging riparian vegetation and undercut banks were recorded at the time of survey. Bathymetry and habitat data for Site 1 was collected using a Leica™ TCR1205+ total station and corner cube prism attached to a levelling staff, due to lack of GPS reception at this site. Waterhole and habitat feature elevations were established by total station traverse, height transfer and connection to datum using static and RTK Trimble™ R10 GNSS receivers.

Data analysis

Detections of Mary River cod within hydrophone arrays, and at terminal hydrophones, were compared to determine occupancy of individuals within the fine-scale arrays, and in the immediate surrounding areas. Raw acoustic telemetry data downloaded from hydrophone arrays were provided to Vemco™ for processing with the Vemco Positioning System (VPS) algorithm (Espinoza et al. 2011). The VPS measures time differences in arrival of tag detections between at least three time-synchronized receivers to triangulate tag positions within hydrophone arrays (Smith 2013). VPS data were filtered by horizontal position error (HPE), a unit-less measure of relative error for VPS data generated through assessment of static reference tags. Only positions with HPE values corresponding to < 5 m error were included in analyses for Site 1 and Site 2. Only positions with an HPE < 14 and < 8 were included in analyses for site 1 and site 2, respectively. These HPE thresholds corresponded to positional errors of < 5 m (Site 2: 4.8 m, Site 1: 3.4 m, 95th percentiles) when examining errors of sync tags placed within the array, similar to other VPS studies (Espinoza et al. 2011).

Rate of movement (ROM - m/min) was calculated for each individual fish as a measure of activity within the arrays using the adehabitatLT package (Calenge 2006) in R version 3.6.0 (www.r-project.org). ROM responses to environmental factors including river height, water temperature and diel period, were assessed using a mixed-effects linear regression model, using the lme4 package in R (Bates et al. 2015). Fish ID was included as a random effect (intercept) in the model. Following the protocol of Zuur et al. (2010), we checked for statistical outliers and collinearity among predictor variables using variance inflation factors (VIF). The ROM response variable was log transformed [log(x + 1)] to satisfy the assumption of normality for linear regression models. Using Akaike information criterion (AIC), all possible combinations of fixed effects and interactions were checked, and the best model was selected. Model residuals were checked for normality and model fit was assessed by comparing model residuals and fitted values.

Spatial occupancy of Mary River cod was examined using kernel utilization distributions (KUD) in the adehabitatHR package (Calenge 2006) in R. For each cod, a 95% and 50% KUD was produced from VPS positions, after HPE filtering, and was visually inspected for spatial and temporal trends. Data was displayed for three time periods related to potential cod nesting behaviour defined based on prior knowledge of the timing and temperature required for onset of nesting, and inspection of changes in movement activity of the tagged fish. The reproductive cycle of Mary River cod begins in late winter – early spring, when water temperatures approach 20°C, with paternal nest establishment followed by a brief courtship period where females will seek a suitable male and nest site to spawn (Simpson & Jackson 2000). Males then fertilise, guard and maintain eggs until they hatch and become freeswimming larvae, which takes approximately 21 days. Over the duration of our study, the three time periods were specified as: pre-nesting (22/08/2014 – 25/09/2014 and 19/08/2015 – 02/10/2015), nesting (25/09/2014 – 14/10/2014 and 02/10/2015 – 21/10/2015), and post-nesting (14/10/2014 – 21/12/2014 and 21/10/2015 – 18/12/2015).

Variation in habitat selection before, during and after the potential nesting period was assessed using Euclidean distance-based analysis (EDA) (Conner & Plowman 2001). Discrete habitat features within fine-scale arrays were interpolated using universal kriging from sampled transect points within ArcGIS™ 10.4 Geospatial Analyst extension (ESRI, California), then 1000 random points were generated and distances between each habitat type and each random point enabled a vector of mean distances to each habitat type to be created. For each VPS position, the distance to all habitat types was determined in the same way (distance to the habitat occupied by the fish at the time of detection was 0). EDA ratios were calculated as the mean observed distance (from VPS positions) divided by the mean expected distance (from random points) to each habitat type. A unique EDA ratio was calculated for each habitat type for each fish, retaining the individual as the experimental unit. If habitat use is random, all EDA ratios should equal one, with values >1 indicating positions farther from a habitat type than expected (avoidance) and values <1 indicating positions closer to a habitat type than expected (preference).

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