"This is the peer reviewed version of the following article: [Booth, D. J. (2016), Ability to home in small site-attached coral reef fishes. J Fish Biol, 89: 1501–1506 ] which has been published in final form at [http://dx.doi.org/10.1111/jfb.13043]. This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Self-Archiving."
BRIEF COMMUNICATION

Ability to home in small site-attached coral reef fishes

D. J. Booth*

School of Life Sciences, University of Technology Sydney, PO Box 123, Broadway, NSW, 2007, Australia

(Received 1 December 2015, Accepted 20 April 2016)

The ability of two common, site-attached coral-reef fishes to return to their home corals after displacement was investigated in a series of field experiments at One Tree Island, southern Great Barrier Reef. The humbug Dascyllus aruanus was displaced up to 250 m, with 42% of individuals returning home, irrespective of body size, displacement, direction (up or across currents) and route complexity, while for the lemon damselfish Pomacentrus moluccensis 35% of individuals returned overall, with 33% from the greatest displacement, 100 m along a reef edge. Given that the home range of both species is <1 m², over their 10+ year life span, the mechanisms and motivations for such homing ability are unclear but it may allow resilience if fishes are displaced by storm events, allowing rapid return to home corals.

Key words: body size; coral-reef fish movement; Dascyllus aruanus; habitat complexity; homing; Pomacentrus moluccensis.

Movement is a key demographic parameter used to describe and model dynamics of natural populations. For coral-reef fishes, dispersal of pelagic larvae drives large scale distribution patterns in space and time (recruitment limitation: Doherty, 1981), however these patterns are modified by post-settlement growth, mortality, reproduction and movement (Forrester, 1990; Booth, 1995). Small-scale post-settlement movement patterns of site-attached coral reef fishes are poorly understood. In some taxa, such as cardinalfishes, nocturnal foraging forays from reef bases can extend 100s of metres, and such species are able to navigate home when displaced experimentally up to 2 km (Marnane, 2000). Larger reef fishes long been known to possess strong abilities to home (Ogden & Buckman, 1973). Most small reef fishes, however, are highly site-attached with very small home ranges and when displaced have only limited ability to return to home [e.g. Gobiodon histrio (Valenciennes 1837), only 20% returned from 4 m: Wall & Herler (2009)]. Intertidal rockpool species may have strong homing ability, for example over 50% of fishes displaced up to 30 m returned to home pools within 42 days (White & Brown, 2013). Shima et al. (2012) showed ontogenetic differences in homing abilities in a temperate reef species, the common triplefin Forsterygion.

© 2016 The Fisheries Society of the British Isles

Author to whom correspondence should be addressed. Tel.: +61 2 9514 4053; email: david.booth@uts.edu.au

© 2016 The Fisheries Society of the British Isles
lapillum Hardy 1989, with overall 30% of F. lapillum displaced over 200 m returning home, mostly larger adults.

In this study, the homing abilities of two common reef damselfishes, the humbug Dascyllus aruanus (L. 1758) and the lemon damsel Pomacentrus moluccensis Bleeker 1855, were investigated by displacements of individuals to distances up to two orders of magnitude greater than their presumed home range, and assessing the influence of body size, habitat complexity and direction of displacement on the homing response. Dascyllus aruanus and P. moluccensis are common and well-studied damselfishes on the Great Barrier Reef and are widely distributed in the Indo-Pacific region. Dascyllus aruanus lives in tight-knit groups of up to 20 individuals on small live branching corals and has a very limited home range (Sale, 1971; Forrester, 1990; D.J. Booth pers. obs.). Larger individuals are competitively dominant and may venture several metres among corals, while smaller D. aruanus generally stay closer to the coral while foraging. Pomacentrus moluccensis also prefer small branching coral heads (Booth & Beretta, 2004) but are more common along the edges of discrete reefs, in contrast to D. aruanus, which is common on corals across the flat inter-reef bottom (Sale, 1971). New recruits of P. moluccensis remain in close proximity to corals while larger and older individuals may have a larger home range, up to 2 m from a home coral (D.J. Booth, unpubl. data), and so would not be predicted to possess any strong ability to navigate beyond several metres. Sometimes these small P. moluccensis are seen singly occupying marginal habitat, possibly displaced due to storm events. Whether individuals were more likely to home from up-current v. down-current locations was also tested, to indicate whether water-borne chemical cues may be involved. While these small site-attached reef fishes rarely venture from coral shelter, such displacements may occur during times of strong wave action and high turbidity. Lewis (1997) noted that 29% of P. moluccensis and 77% of D. aruanus that arrived at experimental patch reefs were post-settlement, indicating that both species are capable of across-sand movement, but their return to home corals was not tested. Whether homing was facilitated by the substratum while the individual was in transit was also tested. A more complex route (more live hard substratum) may either enhance homing (less open sand to cross, so lower predation) or inhibit it (more aggressive fishes to encounter).

The experimental area was located in One Tree Island Lagoon on the southern Great Barrier Reef (23° 30′ S; 152° 06′ E). For D. aruanus, an experimental site was selected on sandy bottom in the lagoon in c. 0.5 m water depth. Individual branching corals (mostly Pocillopora damicornis or Acropora spp.) were scattered across this sand area, about one third of which were occupied by groups of D. aruanus. In July 2011, 10 individual corals, supporting no D. aruanus, were tagged at each of the following distances: 10, 25, 50, 100 and 250 m (n = 50 corals total) from the origin, a 1 × 1 m natural matrix of fine-branching Acropora sp. surrounded by several metres of bare sand. Corals at each distance were separated radially as much as possible (i.e. 10 corals each spread by c. 35°). All individuals were captured by a snorkeller from the origin, spraying a clove oil mixture (1:4 clove oil:ethanol solution) and netting the anaesthetised fishes. Fishes were measured (total length, L_T, and standard length, L_s) then individually tagged while anaesthetised using Visible Implant Elastomer (VIE: Bruyndoncx et al., 2002; www.mnt.us/products/vie/vie.shtml). Each D. aruanus was randomly assigned to a displacement distance (n = 10 individuals total at each displacement distance) and carefully relocated singly in sea water in Ziploc bags in opaque buckets (i.e. there were no visual or chemical cues on displacement). Individuals were observed on release (just
before dusk, when any aggression by resident fishes is minimal (Booth & Beretta, 2004) and behaviours (e.g. aggression, movement and feeding) were recorded for 10 min. Twice per day, for the following week, careful searches were made for tagged individuals up to 300 m from the origin. If found, they were identified and their location (GPS) and behaviour were recorded. Four individuals (25–60 mm $L_T$) were captured as above but replaced on the origin coral matrix as a control to check for movement over the study period. Habitat complexity was assessed along the direct route from each tagged coral to the origin. A belt transect 2 m wide was swum and the number of small suitable coral heads en route counted as an index of habitat availability as stepping stones.

For $P$. moluccensis, the experiment was conducted along a continuous reef edge. Individuals were captured in the same way by a snorkeller with clove oil from a single matrix of branching corals ($Porites$ sp.) on the reef edge in One Tree Lagoon, measured ($L_T$ and $L_s$) and individually tagged using VIE. Each individual was assigned to one displacement distance (25, 50 or 100 m) in one of two directions from the central coral matrix, and carefully relocated singly in sea water in a Ziploc bag in an opaque bucket on the reef edge. The reef edge was c. 2 m in height and it was possible to allocate six fish to each distance, separated by at least 2 m. Along-reef homing at distances over 100 m was not tested since larger reefs were not available for testing. Individuals were observed on release (just before dusk) for 10 min and notes made on behaviours, such as aggression, movement and feeding, as for $D$. aruanus. Four individuals (25–55 mm $L_T$) were captured as above but replaced on the origin coral matrix to check for movement over the study period.

Binary logistic regression (SPSS Ver. 20; www-01.ibm.com/software/au/analytics/spss) was used to examine the relationship between independent variables [continuous: fish size, habitat complexity (number of corals per metre); categorical: distance, direction ($D$. aruanus: in quadrants of 0–90°, etc.), for $P$. moluccensis: along reef edge in one direction v. another] and the response variable (arrived home, yes or no, within 1 week). Individuals of both species were observed immediately after release to seek shelter deep within coral branches, with only a few ($n = 3$ for $D$. aruanus, $n = 3$ for $P$. moluccensis) attacked by residents (these were encouraged back onto the coral until settled). Surprisingly, 42% of displaced $D$. aruanus and 35% of $P$. moluccensis returned to their original location within 1 week, most arriving within 24 h after release. Ten per cent were found elsewhere for $D$. aruanus and 15% for $P$. moluccensis, taking up residence on a range of small coral heads with and without residents, while 48% disappeared for $D$. aruanus and 50% for $P$. moluccensis. For $D$. aruanus there was no significant difference in proportion of displaced individuals homing among displacement distances (up to 250 m), direction, body size (28–68 mm $L_T$) or among path complexities (binary logistic regression, Table I, $P > 0.05$). Control fishes ($n = 4$ fish for both species) did not move away during the experimental duration, reinforcing that handling was unlikely to be a cause of disappearance.

For $P$. moluccensis, homing was related to both body size (larger individuals were more likely to return home; Fig. 1 and Table I; binary regression, Wald statistic = 7.80, d.f. = 3, $P < 0.05$) and less likely with greater displacement distances (Fig. 1 and Table I; binary regression, Wald statistic = 6.45, d.f. = 3, $P < 0.05$). No clear mechanism for low rates of homing by $P$. moluccensis displaced the intermediate (50 m) distance was seen.

Table I. Binary regression models for homing in two species of coral reef fish

<table>
<thead>
<tr>
<th>Source</th>
<th>$B$</th>
<th>s.e.</th>
<th>Wald</th>
<th>d.f.</th>
<th>$P$-value</th>
<th>Exp($B$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Dascyllus aruanus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body size</td>
<td>0.008</td>
<td>0.018</td>
<td>0.193</td>
<td>1</td>
<td>0.660</td>
<td>1.008</td>
</tr>
<tr>
<td>Distance</td>
<td>1.673</td>
<td>3</td>
<td>0.643</td>
<td>0.994</td>
<td>0.464</td>
<td>0.664</td>
</tr>
<tr>
<td>Complexity</td>
<td>0.395</td>
<td>2</td>
<td>0.821</td>
<td>1</td>
<td>0.009</td>
<td>0.009</td>
</tr>
<tr>
<td>Direction</td>
<td>3.968</td>
<td>3</td>
<td>0.265</td>
<td>0.464</td>
<td>0.008</td>
<td>0.008</td>
</tr>
<tr>
<td>Constant</td>
<td>0.560</td>
<td>1.485</td>
<td>0.142</td>
<td>1</td>
<td>0.008</td>
<td>0.008</td>
</tr>
<tr>
<td>(b) Pomacentrus moluccensis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body size</td>
<td>7.801</td>
<td>3</td>
<td>0.048</td>
<td></td>
<td>0.048</td>
<td>0.048</td>
</tr>
<tr>
<td>Distance</td>
<td>6.452</td>
<td>2</td>
<td>0.964</td>
<td>1</td>
<td>0.326</td>
<td>2.067</td>
</tr>
<tr>
<td>Direction</td>
<td>0.726</td>
<td>0.740</td>
<td>0.664</td>
<td>1</td>
<td>0.664</td>
<td>0.664</td>
</tr>
<tr>
<td>Constant</td>
<td>0.320</td>
<td>0.737</td>
<td>0.189</td>
<td>1</td>
<td>0.008</td>
<td>0.008</td>
</tr>
</tbody>
</table>

The direction of displacement (up- v. down-current) was not significant, $P < 0.05$, which suggests that long distance chemical cues such as sun compass, polarized light, olfaction and sound (Sweatman, 1988; Huijbers et al., 2012) may not be used. Homing success dropped with distance displaced, which may reflect the loss of cues or more likely that when a greater distance along the reef edge is travelled, the individual encounters more aggressive residents. Displaced fishes were sometimes chased by residents including a wide variety of small conspecifics and heterospecifics. For $P$. moluccensis, larger individuals were overall more likely to home, possibly given the lower levels of aggression towards them, or reduced sensory abilities of younger and smaller individuals (Lecchini et al., 2007).

Unexpectedly for $D$. aruanus, individuals displaced the furthest, 250 m, were just as likely to return home, and smaller individuals were not less likely to return home, despite the known strong size-based dominance hierarchies in this species (Forrester, 1990). Mann et al. (2014) investigated $D$. aruanus movement between habitats in aquaria and concluded that individuals use ‘stable’ information such as conspecific

![Percentage of displaced Pomacentrus moluccensis (n = 60 total) returning home and (a) total length ($L_T$) and (b) displacement distance (n = 12).](image-url)
group size as cues to move to new habitat, and loss of group members in the field may prompt individuals to undertake larger journeys than are normally observed.

Reef fishes possess impressive abilities to home once displaced, with distances of over 2 km (Marnane, 2000). These abilities were interpreted as adaptive for foraging forays in more mobile reef fish species. This is the first documentation of homing at 100 m+ scales of coral reef fishes that are not known to normally venture beyond several metres from their home coral. So why does this behaviour exist and by what mechanisms? Cues used for navigation are unknown but the lack of significance of direction home and path complexity suggests that odour and chemosensory cues are not primarily responsible. Path complexity, while not significant, was measured in a very basic manner and this parameter could usefully incorporate a measure of coral clumping or fish residency (aggression towards homing fishes) en route in future. Possibly, the behaviour occurs as a remnant of a previously-adaptive response, or is occasionally useful if the individual is displaced by storm events. If the latter, it may enhance the resilience of these fish species. Both species studied here are from the family Pomacentridae (damselfishes) so a next step would be to examine homing ability across a range of sedentary reef-fish families.

Many thanks for field support to H. Beck and the UTS Coral Reef Ecosystems classes, and to One Tree Island Research Station. I thank anonymous reviewers for their useful suggestions.

References


Queries from the Copyeditor:

AQ1. Please confirm that given names (red) and surnames/family names (green) have been identified correctly.

AQ2. Please check if the page no. provided for the reference 'Mann et al., 2014' is appropriate.
**Using e-Annotation Tools for Electronic Proof Correction**

Required software to e-Annotate PDFs: Adobe Acrobat Professional or Adobe Reader (version 7.0 or above). (Note that this document uses screenshots from Adobe Reader X)

The latest version of Acrobat Reader can be downloaded for free at: [http://get.adobe.com/uk/reader/](http://get.adobe.com/uk/reader/)

Once you have Acrobat Reader open on your computer, click on the Comment tab at the right of the toolbar:

This will open up a panel down the right side of the document. The majority of tools you will use for annotating your proof will be in the Annotations section, pictured opposite. We've picked out some of these tools below:

1. **Replace (Ins) Tool** — for replacing text.
   - Strikes a line through text and opens up a text box where replacement text can be entered.
   - **How to use it**
     - Highlight a word or sentence.
     - Click on the Replace (Ins) icon in the Annotations section.
     - Type the replacement text into the blue box that appears.

2. **Strikethrough (Del) Tool** — for deleting text.
   - Strikes a red line through text that is to be deleted.
   - **How to use it**
     - Highlight a word or sentence.
     - Click on the Strikethrough (Del) icon in the Annotations section.

3. **Add note to text Tool** — for highlighting a section to be changed to bold or italic.
   - Highlights text in yellow and opens up a text box where comments can be entered.
   - **How to use it**
     - Highlight the relevant section of text.
     - Click on the Add note to text icon in the Annotations section.
     - Type instruction on what should be changed regarding the text into the yellow box that appears.

4. **Add sticky note Tool** — for making notes at specific points in the text.
   - Marks a point in the proof where a comment needs to be highlighted.
   - **How to use it**
     - Click on the Add sticky note icon in the Annotations section.
     - Click at the point in the proof where the comment should be inserted.
     - Type the comment into the yellow box that appears.
5. Attach File Tool – for inserting large amounts of text or replacement figures.

How to use it
- Click on the Attach File icon in the Annotations section.
- Click on the proof to where you’d like the attached file to be linked.
- Select the file to be attached from your computer or network.
- Select the colour and type of icon that will appear in the proof. Click OK.

END

6. Add stamp Tool – for approving a proof if no corrections are required.

How to use it
- Click on the Add stamp icon in the Annotations section.
- Select the stamp you want to use. (The Approved stamp is usually available directly in the menu that appears).
- Click on the proof where you’d like the stamp to appear. (Where a proof is to be approved as it is, this would normally be on the first page).

7. Drawing Markups Tools – for drawing shapes, lines and freeform annotations on proofs and commenting on these marks.

How to use it
- Click on one of the shapes in the Drawing Markups section.
- Click on the proof at the relevant point and draw the selected shape with the cursor.
- To add a comment to the drawn shape, move the cursor over the shape until an arrowhead appears.
- Double click on the shape and type any text in the red box that appears.

For further information on how to annotate proofs, click on the Help menu to reveal a list of further options: