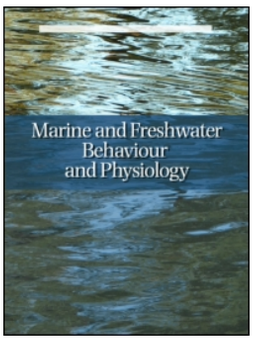

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A second site occupied by *Octopus tetricus* at high densities, with notes on their ecology and behavior

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ABSTRACT

We report wild octopuses (*Octopus tetricus*) living at high density at a rock outcrop, the second such site known. *O. tetricus* are often observed as solitary individuals, with the species known to exist at similar densities and exhibiting complex social behaviors at only one site other than that described here. The present site was occupied by 10–15 octopuses on eight different days. We recorded frequent interactions, signaling, mating, mate defense, eviction of octopuses from dens, and attempts to exclude individuals from the site. These observations demonstrate that high-density occupation and complex social behaviors are not unique to the earlier described site, which had been affected to some extent by remains of human activity. Behavior at this second site confirms that complex social interactions also occur in association with natural substrate, and suggest that social interactions are more wide spread among octopuses than previously recognized.

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Introduction

A growing number of studies show that some species of octopuses are not as habitually solitary and asocial as previously supposed. Recent studies have documented aspects of social behavior, such as aggregation, interaction, and signaling, in several octopus species (e.g. *Abdopus aculeatus*, Huffard 2007; Larger Pacific Striped Octopus, Caldwell et al. 2015; *Octopus tetricus*, Scheel et al. 2016). Much of this change in the perceptions of octopuses has happened over the past decade: Boal (2006) in a review of social recognition in cephalopods listed only three species (*Octopus joubini*, *O. briareus*, *O. bimaculoides*) reported to occur at high densities in the wild as exceptions to the description of octopuses as "generally solitary." Ten years later, Scheel et al. (2016) included 14 species as exceptions to the "predominant view that octopuses are solitary and asocial."

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Among the species recently recognized as exceptions is the gloomy octopus, *Octopus tetricus* Gould, 1852. This species commonly can be observed as solitary individuals (Anderson 1997), but Godfrey-Smith and Lawrence (2012) described a single site at which *O. tetricus* occurs in high density, interacts, and mates – the only such site known to exist at the time. Their observations were from a field site in Jervis Bay on the east coast of Australia at a depth of 17 m. The site was discovered by Matthew Lawrence in 2009 and comprised an extended midden forming a bed of shell hash around what is probably a single human artifact, of unknown origin (Godfrey-Smith & Lawrence 2012; Scheel et al. 2014). The artifact is a single flat object about 30 cm long, heavily encrusted but possibly made of metal, that we have not identified. The site has been observed occupied by 2 to 16 octopuses since its discovery through December 2016 (Scheel et al. 2014, 2016).

Shelters have important roles in octopus ecology (e.g. *Octopus bimaculatus*, Ambrose 1982; *O. tehuelchus*, Iribarne 1990), and remarkably so at this site. Godfrey-Smith and Lawrence (2012) hypothesized that the artifact provided a locus for initial settlement. Octopuses carry prey items back to their dens for consumption and discard the hard remains in a midden pile, leading to the formation of the extended shell bed of discarded remains. As the shell bed expanded and stabilized surrounding soft sediment, additional octopuses were able to excavate dens. Scheel et al. (2014) have further argued that the expanding shell bed provides resources for other organisms, and thus that the octopuses were acting as ecosystem engineers. The key role of a human artifact in this scenario raises the question whether the behavioral interactions at this site could occur without the anthropogenic object providing hard shelter in a soft-sediment environment.

In this note, we report the discovery of a second site where *O. tetricus* is found at high densities, and interacts in similar ways to those described at the original site. The second site was discovered by Martin Hing and Kylie Brown in December 2016, at 10–15 m depth a few hundred meters distant from the first site. Hing reported the site to researchers working at the original site nearby. Subsequently, divers David Scheel and Stephanie Chancellor surveyed the second site and left cameras to record octopus behavior. We also include in this report observations made informally during recreational dives on several subsequent days. Video recorded at this site is still being analyzed, and more detailed analyses of the behavior will be forthcoming.

The second site extends about 18 m in length along a southwest to northeast axis, and is approximately 4 m wide (Figure 1). Within this area are three patches of rock, the only rock emerging from otherwise soft sediment observed in the vicinity. Matthew Lawrence, who dives extensively in this area, has not seen other patches of emergent rock anywhere in this area. The largest patch of rock is at the west end of the site, and consists of two smooth rocks separated by a crevice of approximately 1.5 m length and 10 cm width, in which there were two or three octopuses, each in dens in the unconsolidated substrate and shell hash between the rocks (Figure 1). We found signs of excavation surrounding the dens, including sediment and aged and eroded shells among fresh shell hash. We found additional dens (up to nine others) in the shell bed along the rock edge, or in an extension of shell bed out from the rock. To the east of this in the middle of the site, across about 5 m of soft sediment, there is a second extended midden around three boulders that emerge from the substrate. This shell bed contains up to seven dens in unconsolidated sediment. At the east end of the site, after a further 1.2 m of intervening soft sediment, we found an additional three dens around a small boulder just beneath the substrate.

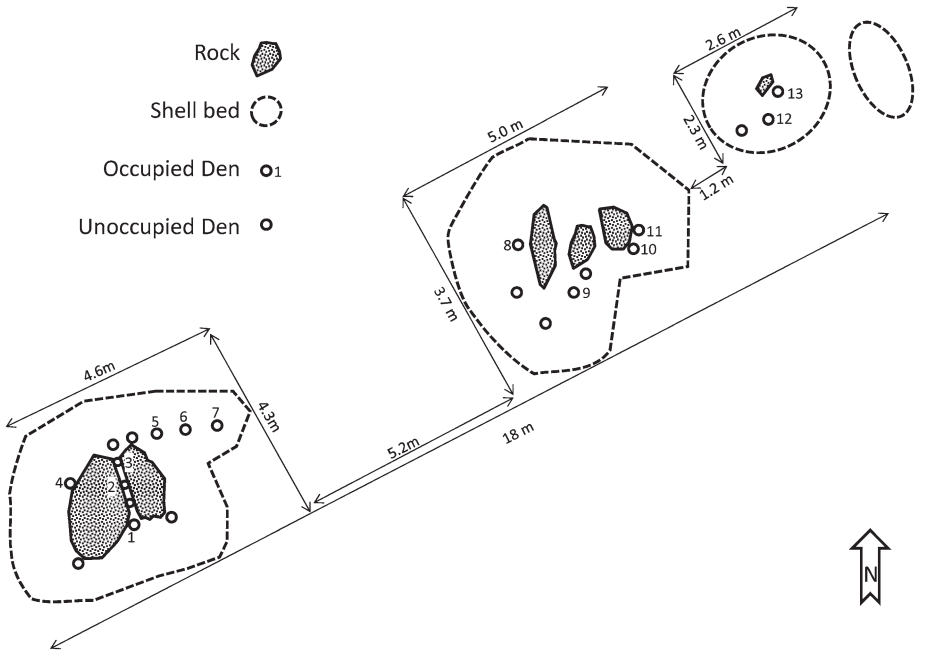

Figure 1. A sketch of the second site occupied by *Octopus tetricus* at high densities. Numbers indicate inhabited dens during a single dive when the sketch was first made.

On the soft sediment surrounding this site, particularly to the northwest, is a bed of doughboy scallops, *Mimachlamys asperrima* (Lamarck, 1819). The scallop bed has an estimated density of 39 scallops per square meter, based on a count of 201 scallops from a single photograph taken about 20 m from the high-density octopus site. This compares with approximately 60 scallops per square meter at a distance of 20 m from the original site (Scheel et al. 2014), counted in quadrats by divers. Note that counts from a photograph may be lower than counts by dive survey due to inability in photographs to distinguish each individual scallop when they occur in clumps. In addition, upslope from the site is a second bed of mud arks *Anadara trapezia* (Deshayes, 1840) (density not estimated). Divers also saw the king scallop *Pecten fumatus* Reeve, 1852 in the area.

Prey items that had been recently added to the midden were identified by clean inner surfaces without epifauna or algae growth. The most common items of recent prey in the middens were remains of *A. trapezia*, *M. asperrima*, and the razor clam, *Pinna bicolor* Gmelin, 1791. In addition, other bivalve prey remains were present less commonly in the midden, including *P. fumatus*, and the Tasmanian scallop *Notochlamys hexactes* (Péron [in Lamarck], 1819). Octopuses had also accumulated beer bottles and lead fishing lures into the midden piles (e.g. Figure 2 top).

Divers visited the second site on eight different days between 17 December 2016 and 14 January 2017. The count of octopuses at the site varied from a low of 10 to a high of 15 individuals. Octopuses in neighboring dens were often within arms' reach of one another (Figure 2, top). Interactions between octopuses included behaviors like those at the original site. Mating between individuals in adjacent dens was noted three times on two different days, at both the west end of the site and the middle cluster of dens. Attempted mating,

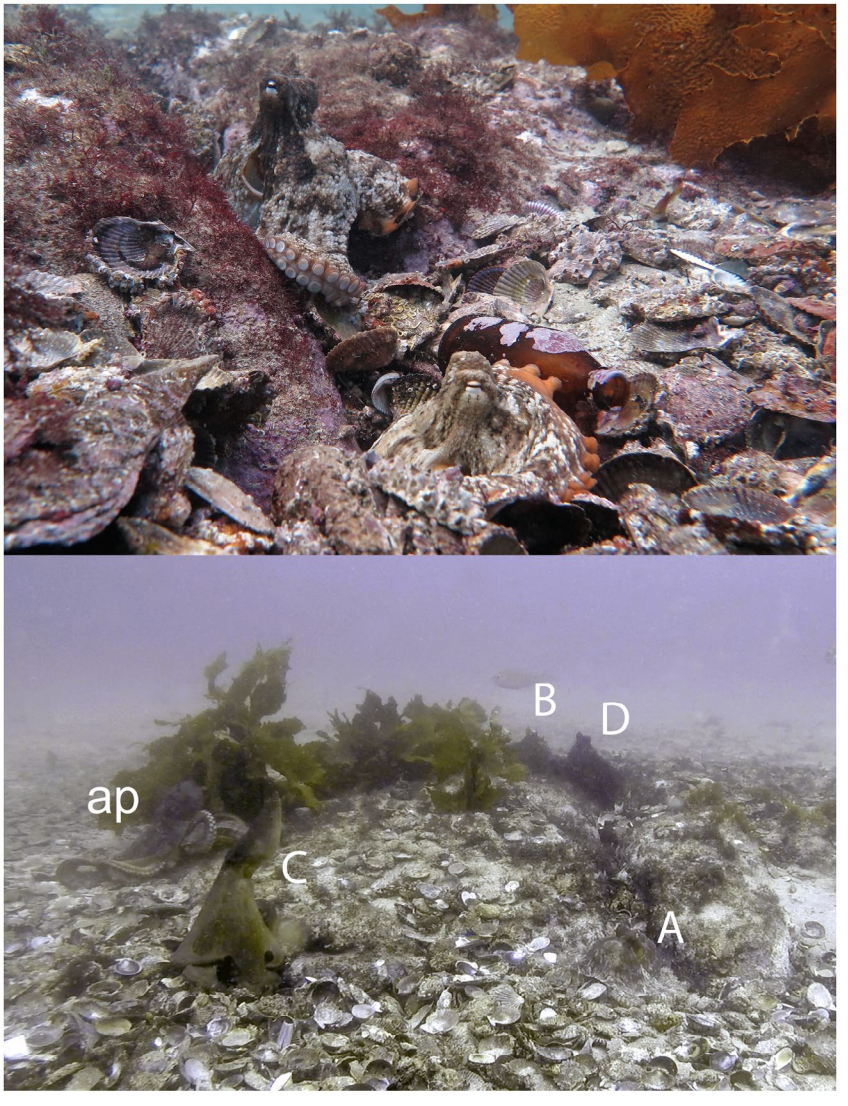

Figure 2. Octopus interactions.
Notes: Top – adjacent dens were often within arms' reach of each other. Bottom – octopuses engaged in complex interactions. Each octopus is indicated with a letter just above it corresponding to their description in the text. The approaching octopus (ap) is at the upper left, at the edge of a clump of kelp. Octopus A in this image is in the den numbered 1 (Figure 1). Contrast and color balance have been adjusted from the original video files, and some debris removed from the images.

reaching, displays, and signals (Godfrey-Smith and Lawrence 2012; Scheel et al. 2016) were all recorded. For example, an octopus (octopus ap) approaching the site was observed by four other octopuses (octopuses A to D, Figure 2 bottom). Each of these moved from their dens toward the octopus approaching the site. Octopus A partially emerged from a den and reached with its first right arm. Octopus B left its den moving toward the octopus approaching the site, and A quickly returned to its den. Octopuses C and D turned dark, stood tall with web spread, and raised their mantles while moving toward the approaching octopus, a signal that mediates agonistic encounters (Scheel et al. 2016). As the octopus ap

began to retreat, observing octopuses A, B, and C returned toward their dens, while octopus D reached out to the now retreating octopus ap until it (octopus ap) fled just before contact with octopus D.

In another example, a diver with a hand-held camera filmed an octopus entering the middle den cluster. This octopus reached into a den and evicted its occupant (Figure 3 top), who was previously not visible within the den. The evicted octopus fled to the den cluster at the east end of the site and settled into a den there adjacent to another octopus. Within a few minutes, the evicting octopus then departed the middle cluster of dens to the northwest

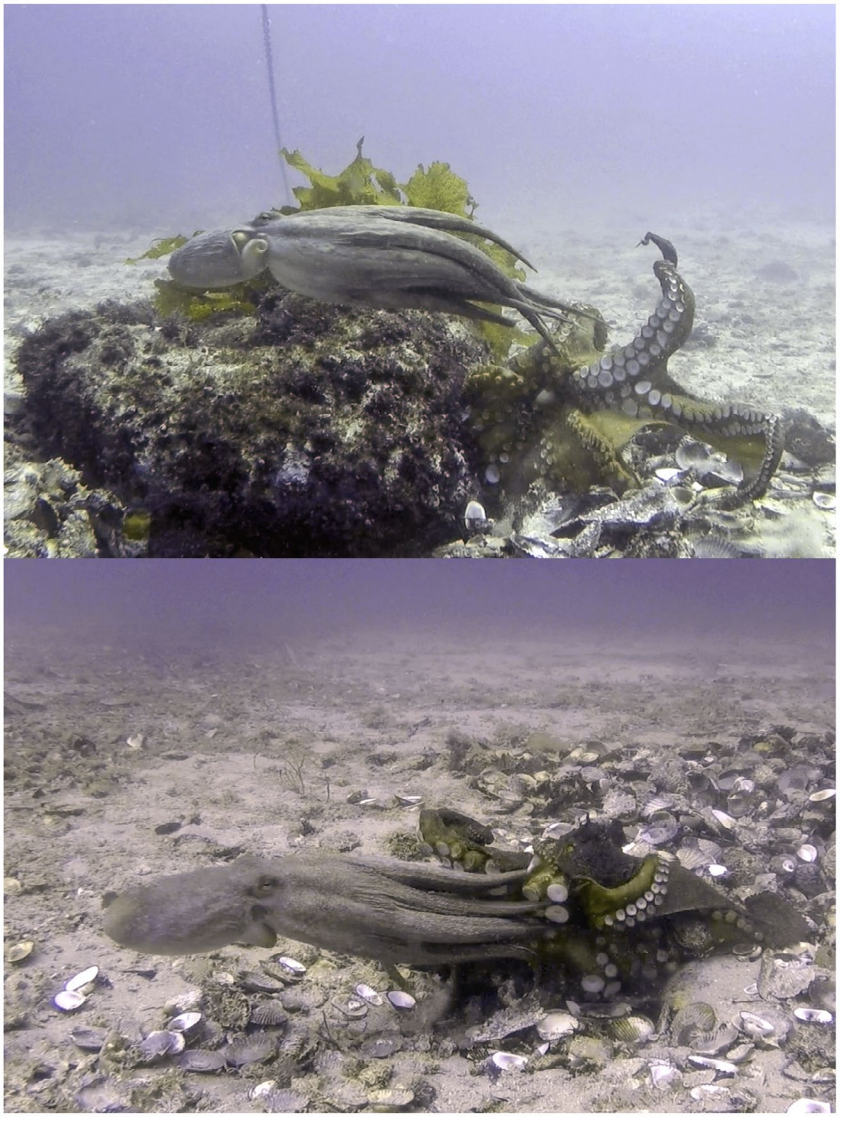

Figure 3. One octopus evicted another from its den (frames captured from video).
Notes: Top – at den numbered 11 (Figure 1), the evicting octopus (arms spread, lower right) has just pulled the evicted octopus (swimming, center) from its den, now occupied by the evicting octopus. Bottom – at den numbered 13 (Figure 1), the same evicting octopus (right) has again pulled the same evicted octopus (left) from the den where it had retreated after being pulled from den 11. Enlarged suckers are visible on the evicting octopus. See text for details. Images adjusted as in Figure 2.

of the site into the scallop bed briefly, before departing the scallop bed directly back to the east end of the site. The evicting octopus went directly to the east end den occupied by the previously evicted octopus, and again evicted it from its den (Figure 3 bottom). Both of these octopuses were presumed to be males based on the presence of enlarged suckers on the first two pair of arms (Figure 3), and neither appeared to respond to the diver in any obvious way.

The video recorded when divers were not present shows that these behaviors occur frequently at the second location, as has been recorded at the original site. Such interactions take a substantial investment of time. Octopus D from the example above (Figure 2 bottom) evicted octopus C who retreated off-screen. Octopus D, who remained on-screen continuously, then prevented octopuses entering from off-screen (possibly octopus C repeatedly attempting to return) from occupying this den on the site for at least 40 min. This activity kept octopus D out of its den for much of that time. This prolonged interaction, and others (Figure 3), escalated to physical contact and grappling.

In addition to substantial time investment, energy expenditure, and risk of injury, activity outside of their dens also exposes octopuses to risks from predators. A wobbegong shark arrived at the site after the interactions described above between octopus ap and octopus D. The wobbegong settled behind the kelp from which octopus ap had first attempted to enter the site (Figure 2 bottom). The shark entered stealthily, and none of the octopuses visibly reacted to its arrival. At the original site described in earlier work, octopuses remained inactive in their dens when a wobbegong shark was conspicuously present at the site, and that shark investigated an octopus that attempted to depart from its den (Scheel et al. 2014). Other fish were also recorded at the second site that might attack octopuses themselves (e.g. leatherjacket, *Nalusetta ayraud*), or attract larger predators such as the wobbegong (e.g. bream, *Pagrus auratus*). Presumably, the agonistic interactions among octopuses represent costly investments in energy and risk of predation. Relative to the more typical solitary life, the costs and benefits of living in aggregations and investing in interactions remain to be documented.

Conclusion

The gloomy octopus, *Octopus tetricus*, has been observed living in close proximity and high density at two sites in Jervis Bay, Australia. At both sites, the octopuses engage in frequent and complex social behaviors that are unusual for many species of octopus. The discovery reported here of the second site underscores that the first site was not a unique result of a human artifact that apparently provided the nucleus for the formation of the original site. However, the finding does support the contention that limited den opportunities amidst abundant food availability leads to high density and complex interactions (Scheel et al. 2016). At both sites, octopuses have formed a shell bed surrounding a hard structure. Shelter availability occurring in clusters has been found in several species (*O. joubini*, Mather 1982; *O. vulgaris*, Mather and O'Dor 1991; *Abdopus aculeatus*, Huffard 2007; *Octopus insularis*, Leite et al. 2009; Huffard et al. 2010). Clustered shelter sites in combination with abundant local food supplies may be a recipe for heightened social interaction in other octopus species as well.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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