Seahorse Hotels: Use of artificial habitats to support populations of the endangered White’s seahorse Hippocampus whitei

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ABSTRACT
The provision of temporary, specially designed artificial habitat may help support populations of the Endangered Whites’ seahorse Hippocampus whitei in the face of rapid coastal urbanisation and declining natural habitats. Three designs of artificial habitat (Seahorse Hotels) were installed in Port Stephens, New South Wales, Australia, where natural habitats had significantly declined. Mark recapture surveys were used to assess seahorse site fidelity and population parameters, and the effect of Seahorse Hotel design on seahorse abundance, epibiotic growth and mobile epifauna seahorse prey was determined. The Seahorse Hotels sustained a substantial population of seahorses (64; 57–72 95% confidence intervals) in comparison to recent local population estimates. There were no significant differences in seahorse abundance, mobile epifauna or epibiotic growth among the three different hotel designs. This research demonstrated that H. whitei will inhabit Seahorse Hotels in absence of natural habitat, and additional complexity in these artificial structures was not necessary to support seahorse populations. Temporary structures such as Seahorse Hotels will be a valuable tool in supporting H. whitei and other Syngnathid populations through infrastructure maintenance or habitat modification.

1. Introduction

One of the key contributors to general habitat loss is widespread urbanisation, and as a result a substantial number of animals have suffered significant population declines, with many species facing extinction (Mace and Lande, 1991; Airoldi et al., 2008; Waycott et al., 2009). An increasing percentage of the world’s population lives in coastal cities (Creel, 2003), and as coastal urbanisation accelerates, as do the impacts on natural marine habitats (Airoldi and Beck, 2007; Bulleri and Chapman, 2010). One impact of rapid coastal development is the replacement of natural coastline with artificial structures (largely referred to as ocean sprawl (Firth et al., 2016)); these artificial structures support human services such as coastal defence (e.g., seawalls, breakwaters) and recreation (e.g., protective swimming nets, jetties). Many studies have explored the potential ecological effects of artificial structures, and they are often associated with declines in biodiversity and increases in habitat homogeneity (Bulleri and Chapman, 2010; Gittman et al., 2016). Additionally, artificial structures have been associated with the spread of invasive species (Glasby et al., 2007; Dafforn et al., 2009). There exists a need for modern conservation tools and approaches to deal with this problem and whilst tools such as marine protected areas and conservation of habitats can make a substantial positive impact at a broad scale (McClanahan and Mangi, 2006; Russ and Alcala, 2004), smaller scale actions focused on target habitats or taxa can make significant contributions to the conservation of specific threatened species (Martins et al., 2010).

Artificial structures can be engineered and modified to increase complexity and enhance biodiversity in a process called ecological engineering (Chapman and Underwood, 2011), a term coined to describe the combination of engineering principles and ecology to reduce the environmental impacts of artificial structures (Bergen et al., 2001). The addition of complex microhabitats (e.g. crevices, holes, water-retaining features) to structures such as seawalls often have positive effects on the richness of invertebrate and fish species (Chapman and Blockley, 2009; Strain et al., 2018). Specially designed artificial reefs have been implemented to create habitat and increase biodiversity in areas where natural habitat has declined, with some studies showing that fish assemblages on these structures are similar to those on natural habitats (Wen et al., 2010; Burt et al., 2013), but not others (Burt et al., 2009). While the majority of custom-built artificial habitats to date have been
designed to enhance an assemblage of species, there is also strong argument for designs that target specific taxa (Correia et al., 2013). In particular for fish assemblages, as different species or functional groups often have complex responses to alterations in habitat complexity (Morris et al., 2018).

Fourteen seahorse species (Syngnathidae, *Hippocampus* spp.) are currently listed as Vulnerable or Endangered (IUCN, 2018), due to declines in natural habitat as well as pressure from overfishing (Vincent et al., 2011). Seahorses inhabit shallow coastal waters that are often heavily urbanised, and due to unique biological and behavioural traits documented in multiple seahorse life history and ecology reviews (Paster and Vincent, 2004; Vincent et al., 2011) (e.g. weak swimming ability, small home range, monogamous breeding partners), they can be susceptible to population fluctuations and collapse (Correia et al., 2015a). *Hippocampus whitei* (Bleeker, 1855) is endemic to the east coast of Australia (Short et al., 2019) and over the past decade has experienced population declines across its range (Harasti and Pollom, 2017; IUCN, 2018). In Port Stephens, New South Wales (NSW), Australia, it was shown that significant declines in abundance of *H. whitei* were linked to loss of their preferred natural habitats of sponges and soft corals (*Dendronephthya australis*). A distinct characteristic of these naturally preferred habitats is a complex topography for seahorses to grasp using their prehensile tail while resting and feeding (James and Heck, 1994), termed a ‘holdfast’. Variations in the density of holdfasts, as well as their relative size and complexity are important for seahorses as holdfasts are critical for anchoring and providing camouflage (Correia et al., 2013; Manning et al., 2018).

When artificial structures are present, seahorses are known to inhabit them, and in some cases the presence of artificial structures has been beneficial for seahorses (Correia et al., 2015b; Claassens, 2016). In Sydney Harbour, NSW, Australia, *H. whitei* have been found in elevated numbers on protective swimming nets compared to natural habitats around the harbour (Harasti et al., 2010). Seahorses, including *H. whitei*, have been shown to preferentially select artificial structures or custom-built habitats over natural ones when in proximity (Claassens et al., 2018; Simpson et al., 2019), although conversely, artificial structures have had limited seahorse recruitment when placed in proximity to high quality, complex natural habitats (Correia et al., 2015b). Increasing the complexity of artificial structures (e.g. through adding new material or holdfasts) can enhance the abundance of seahorses that use those structures (Hellyer et al., 2011; Correia et al., 2013, 2015b). Seahorse numbers are further increased when artificial structures are fouled by epibiota, which adds complexity, in addition to supporting an abundance of mobile epifauna as potential seahorse prey (Clynick, 2008; Harasti et al., 2010).

The affiliation of seahorses with artificial structures has led to the trialling of specially designed habitats as a potential conservation tool for *Hippocampus* spp. that are threatened by natural habitat loss, such as *Hippocampus guttulatus* in Portugal (Correia et al., 2013, 2015b). As artificial structures that support populations of seahorses may be regularly disturbed (such as protective swimming nets, that are seasonally cleaned or repaired (Harasti et al., 2010)), specially designed artificial habitats may be implemented as a temporary replacement habitat. They may also be used to support populations of seahorses while natural habitats undergoing regeneration after being lost. There is no evidence of such temporary habitats being utilised to help the Endangered seahorse *H. whitei* in Australia, and there are no tests whether such habitats can support a population of *H. whitei* in areas where natural habitat has been lost.

Here, we tested the hypothesis that temporary purpose-designed artificial structures “Seahorse Hotels” could provide habitat for the Endangered seahorse species *H. whitei* in areas where they have had decreases in abundance as a result of natural habitat loss. The population size of seahorses on the Seahorse Hotels was estimated, as well as calculations of site fidelity. Additionally, we tested the hypothesis that differences in Seahorse Hotel complexity and materials would be associated with variations in (a) seahorse abundance, (b) epibiotic growth and (c) associated mobile epifauna. This study helps explore how artificial habitats may be utilised to assist in the conservation of an Endangered seahorse species.

### 2. Methods

#### 2.1. Study sites

This study was done at two sites approximately 700 m apart in Nelson Bay, Port Stephens, New South Wales, Australia. The eastern basin of the Port Stephens estuary is an important location for the Endangered *H. whitei* which has been subject to several previous studies (Harasti et al., 2012, 2014a, 2014b; Harasti, 2016). Seahorse Hotels were installed at the Pipeline (32°43′02.1″S 152°08′28.4″E) and Seahorse Gardens (32°42′55.1″S 152°09′01.2″E) sites (Fig. 1), which are both approximately 6000 m² and located within the Port Stephens-Great-Lakes Marine Park. These sites are within a habitat protection zone where high-impact activities such as commercial trawling are prohibited, and contain a number of benthic habitat-providing taxa such as sponges, soft coral (*Dendronephthya australis*) and seagrass (*Posidonia australis*) (Davis et al., 2015). Both are popular recreational dive spots due to the marine life present, however, the abundance of habitat-providing species (as described above) at these sites has been in significant decline in recent years (Harasti, 2016), with a concomitant reduction in abundance of *H. whitei* seahorses at these sites. Longer-term monitoring at Pipeline and Seahorse Gardens has shown that these sites have supported large *H. whitei* populations as recently as 2009 (mark-recapture estimates of approx. 260 and 370 respectively), though more current estimates have shown these numbers at both sites have decreased significantly (mark-recapture estimates of approx. 45 and 10, respectively (Harasti, 2016)).

#### 2.2. Seahorse Hotels

Three designs of Seahorse Hotel were tested in this experiment. The standard open-cage design was based on the size and materials of commercial fish traps, with most materials expected to break down in the water over time. The open-cage design consisted of an aluminium angle frame of dimensions 1 m × 1 m × 0.35 m, with galvanised steel mesh (1 mm wire, 50 mm aperture) enclosing the frame (Fig. 2a). The mesh wire was attached to the frame with twisted 2 mm galvanised steel wire, and each cage was open on two opposite sides to allow water flow-through and prevent trapping of marine macroalgae and fish.

Two “additional complexity” designs were tested alongside the open cage design to explore whether additional holdfasts suspended within the structure would result in increased seahorse recruitment and abundance, with complexity defined as the number of holdfasts available for seahorses to attach. Both designs had additional holdfasts of 0.35 m length installed, suspended vertically throughout the interior of the structure at a density of 25 per m². The “rope holdfast” hotel design had 12 mm diameter polypropylene rope, and the “wood holdfast” design contained 12 mm diameter dowel pine wood suspended throughout (Fig. 2b-c). Polypropylene is a material that is not known to naturally break down over time, however was included in this experiment as previous research has shown that similar materials were the most successful artificial holdfast for *Hippocampus guttulatus* (Correia et al., 2013), and it was important to determine whether this material was necessary in the design of an artificial habitat that would otherwise break down. Similar holdfast diameters were used in this experiment as per other previous studies (Correia et al., 2013). House bricks were used to weigh the hotels to the seafloor to stop them from moving (Fig. 2).

Six replicates of each hotel design were placed at both sites at approximately 6 m depth (low tide), and approximately 10 m from nearby natural habitats. At each site, hotels were installed in three groups of six that each included two replicates of each hotel design.
Within each group, hotels were placed haphazardly in a circular fashion with 1.5 m between hotels to reduce the influence of directional biases for seahorses to encounter hotels and ensure all designs of Seahorse Hotel are equally available for the seahorses to choose to inhabit. Additionally, the circle formation of the Seahorse Hotels allowed for sampling access by divers during surveys. Each circle had a diameter of approximately 5 m, with approximately 10 m between groups.

2.3. Seahorse sampling

The Seahorse Hotels at each site were surveyed at approximately monthly intervals for 12 months after their deployment in November 2017; nine complete design assessment surveys for seahorses on the hotels were completed, in which the number of seahorses on each Seahorse Hotel replicate was recorded, and 16 seahorse marking occasions in total in which all seahorses inhabiting the hotels were counted and tagged (this number includes the nine complete design assessment surveys as seahorses were also tagged on these surveys). The number of total marking occasions on the Seahorse Hotels was greater than the number of surveys in which specific hotel replicates were recorded because the Seahorse Hotel structures had largely started to break down in the final months, causing physical differences between designs. Therefore, surveys undertaken in these months were only counted as seahorse tagging occasions (see below) and not as complete design assessment surveys. Marking occasions continued during this later period to observe whether the Seahorse Hotels continued to support seahorse populations after they started to collapse from the materials perishing and the addition of added weight from epibiotic growth.

All new seahorses found inhabiting the Seahorse Hotels over the course of the experiment were given a unique mark for identification purposes. Seahorses were marked with small visible implant fluorescent elastomer tags (VIFE, Northwest Marine Technologies, USA; www.nmt.us) using techniques previously described (Woods and Martin-Smith, 2004), which have been successfully applied in other studies on H. whitei (Harasti et al., 2012; Harasti and Gladstone, 2013). Each seahorse was given three 1–2 mm coloured tags (red or green) in-situ. The capture, tagging and release of seahorses took ~1 min per individual, with the individual placed back onto the same substratum once marking was completed. Seahorses were placed back onto the Seahorse Hotels ensuring that reattachment occurred to ensure that seahorses had not moved to another structure as a result of handling. On each survey, the number of seahorses, total length (top of coronet to end of tail) and sex (presence/absence of brood pouch) of each seahorse found on individual hotels was recorded to the nearest mm using a standard ruler. Seahorses smaller than 70 mm total length were recorded as juveniles as at this size the brood pouch has not fully developed, so identification of sex is difficult (Harasti et al., 2012). Seahorses that were first observed as juveniles and then later observed as mature seahorse based on presence/absence of a brood pouch were recorded as the sex they matured into. We tested the null hypothesis that there would be no significant difference in the number of seahorses to colonise the different hotel designs over time with a repeated measures ANOVA with hotel design as a fixed factor (3 levels), Group as a random factor (3 levels) and sampling time (9 levels) as the repeated measure (Table S1). Only the data for the Pipeline site were analysed here, as there were insufficient seahorse numbers (n = 1) on the Seahorse Gardens Seahorse Hotels. A repeated measures ANOVA was used here as the same seahorses were found on subsequent dives resulting in temporal non-independence. Data were not transformed, as Mauchly’s test of sphericity was non-significant (35 df, P = 0.364). Each time an individual seahorse was found on a survey, the substratum used as an attachment holdfast was recorded. There has been no evidence that suggests any difference in habitat preference between H. whitei sexes (Harasti et al., 2014b), so this was not explored here.

To assess the population size of seahorses on the Seahorse Hotels, an open population Jolly-Seber model was applied using the POPAN model in Program Mark (White and Burnham, 1999). The population was considered open, rather than closed, as the surveys were conducted over 12 months, which means that immigration, emigration, births and mortality would likely have occurred during the surveys of the Seahorse Hotels. The POPAN model provides survivability estimates (φ), probability of resighting individuals (p) and an estimate of the total population size (N). We tested the null hypothesis that there would be no significant difference in site persistence of H. whitei among the three Seahorse Hotel...
designs over fourteen survey occasions with a Kaplan-Meier log rank test in SPSS (Kaplan and Meier, 1958; Pollock et al., 1989). This analysis observed the presence or absence of the first 7 seahorses to inhabit each design of Seahorse Hotel over 14 surveys from January 2018 until November 2018. Fourteen surveys only were used for this analysis, as this was the number of surveys where 7 seahorses had inhabited each hotel design to run a Kaplan-Meier log rank test, in which the presence or absence of each seahorse on all following surveys was analysed as per (Harasti and Gladstone, 2013).

2.4. Mobile epifauna and epibiotic growth

The abundance of mobile epifauna present on each structure was measured after approximately 8 months. Sampling for epifauna was only conducted on one occasion as we were only concerned about endpoint differences between designs after sufficient epibiotic growth had occurred on the hotels. Mobile epifauna were sampled with an airlift suction sampler (Rostron, 2001). The airlift tube was a 1 m length of 30 mm mesh sieve into a removable plastic chamber of 250 ml capacity, as per previous similar studies (Hellyer et al., 2011). To sample the epifauna on each hotel, 1 min timed samples were used, with the suction sampler held 5–10 mm from the surface of the hotel mesh. On the open cage design, the outer cage mesh was sampled for 1 min, and on the additional complexity designs, the outer mesh and interior holdfasts were each sampled for 30 s so that every replicate was sampled for a total time of 1 min regardless of design. After collection, samples were preserved in 5% formalin solution until they were sorted in the laboratory, after which samples were decanted into 75% ethanol solution. Epifauna were sorted into major taxonomic groups that were considered prey for seahorses (gammaridean and caprellid amphipods, harpacticoid copepods, shrimps and nematodes) as per previous experiments (Hellyer et al., 2011). Univariate abundance of seahorse prey across hotel designs were analysed using a one-way ANOVA with hotel design as fixed factor (three levels: open, wood and rope) and group as random factor (three levels: 1, 2 and 3; Table S2). The null hypothesis that there was no multivariate difference in the assemblage of epifauna among hotel designs was tested with PERMANOVA (Anderson, 2001), using Bray-Curtis dissimilarity measures (Bray and Curtis, 1957; Clarke, 1993) on square-root transformed data from 999 permutations (Table S3).

Sessile epibiotic growth on the hotels was measured every three months after deployment, in order to explore how growth developed on the hotels and taxonomic groups changed over time. It was expected that, over time, the Seahorse Hotels may become fouled with preferred habitat-forming organisms for seahorses. Photographs of the top and sides of each structure were taken from a distance of 1 m with a GoPro Hero 3™ camera. These images were used to assess changes in epibiotic growth on structures over time, and differences in epibiotic growth between Seahorse Hotel designs. As photographs were taken of the top, side and holdfast orientations for each Seahorse Hotel replicate, each image was sampled and the mean of the multivariate data extracted from all orientations was used for each replicate during analyses. The total cover (%) of all sessile epibiotic growth was also calculated as a univariate measure. Photo analysis was conducted in CPCe 4.0 (Coral point count with excel extension; National Coral Reef Institute, 2011), with thirty random points distributed across a 100 × 35 cm quadrat overlayed over each photograph. Preliminary photo analysis showed that 30 points were sufficient to estimate epibiotic growth cover on the hotels. The null hypothesis that there would be no significant difference in the univariate measure of total growth cover (%) across hotel designs was analysed using a repeated measures analysis of variance (ANOVA) with hotel design as a fixed factor (3 levels), Group as random factor (3 levels) and sampling time (3 levels) as the repeated measure (Table S4). The null hypothesis that there would be no significant difference in the multivariate assemblage of epibiotic growth among hotel designs was tested using PERMANOVA, as before (Table S5).

3. Results

3.1. Seahorse colonisation onto Seahorse Hotels

At the Seahorse Gardens site, six of the hotels were lost from the site two months after deployment, likely dragged away by boat anchors. Over the remaining 10 months, only one seahorse was detected at the remaining 12 Seahorse Hotels at this site, therefore, the statistical analyses are based on data collected from the Pipeline site only.

Over 16 marking occasions, 58 individual seahorses were observed and tagged on the Pipeline Seahorse Hotels, including 18 males, 34 females and six juveniles. Eight seahorses were juveniles (less than 70 mm) at the time of tagging and were later recaptured after maturing, thus are classified as male or female. Thirteen pregnant males were observed at the Seahorse Hotels in October 2018, indicating that breeding was occurring in the population of seahorses that was inhabiting the hotels. The largest seahorse found inhabiting a hotel was 130

![Photographs of artificial habitats for seahorses (Seahorse Hotels). A., open cage design; B. rope holdfast design; and C. the wood holdfast design.](image-url)
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The estimated number of seahorses inhabiting the hotels appeared to vary over time (Fig. 3), with a general pattern of increasing abundance over time for both males and females and levelling off around survey ten with some variation. Seahorses had an average probability of being resighted over all surveys (p) of 0.39 (±0.034 S.E) and an average survivability (φ) of 0.97 (±0.013 S.E). Male seahorses had a mean p of 0.47 ± (0.049 S.E) and a mean φ of 0.956 (±0.027 S.E), while females had a mean p of 0.39 (±0.038 S.E) and a mean φ of 0.948 (±0.022 S.E). Juveniles had a mean p of 0.339 (±0.097 S.E) and a mean φ of 0.72 (±0.096 S.E).

3.3. Site fidelity

No H. whitei were observed to have moved between the Pipeline and Seahorse Gardens site, with tagged seahorses being resighted only at the site at which they were initially tagged. Seahorses had moved onto the hotels within two months of installation. The longest amount of time that a seahorse was observed to be inhabiting the Seahorse Hotels was 11 months, with three seahorses (two males and one female) tagged on the first tagging occasion (January 2018) later resighted on the final tagging occasion (November 2018) with the number of sightings in between varying from two to nine. The most occasions an individual seahorse was resighted was a male with twelve sightings on different tagging occasions. Kaplan-Meier comparisons showed that there was no significant difference in the site-persistence of H. whitei across the three hotel designs (p² = 0.011, d. f. = 2, p ≥ 0.995; Fig. 4A). From the initial tagged seahorses (January 2018) for the site persistency surveys, there was one H. whitei remaining for both the rope and wood hotel designs (female and male respectively), and two remaining in the open design in the last survey (one female and one male; November 2018).

3.4. Seahorse hotel designs

The abundance of seahorses on the Seahorse Hotels was significantly different among survey times, with no significant difference across groups or hotel designs (Table S1). On each design, seahorse usage over time was variable (Fig. 4B). Seahorses were observed using the cage mesh as a holdfast in 221 out of the total 245 sightings, and the interior mesh as a holdfast in 221 out of the total 245 sightings, and the interior

3.5. Mobile epifauna and epibiotic growth

There was no significant difference in the total abundance of mobile epifauna across Seahorse Hotel designs or groups (Fig. 5A; Table S2). There was no significant difference in the multivariate epifauna prey groups across Seahorse Hotel design or group, with no significant interactions (Table S3) and no observable pattern in the multidimensional scaling (MDS) plot (Fig. 5B, Stress 0.12).

The epibiotic growth on Seahorse Hotels was significantly different among times, groups and designs (Table S4), as the Time*Group*Design interaction term was significant. There was a general pattern of increasing epibiotic growth over time, with the mean epibiotic growth on all hotel designs increasing from a mean of <70% on the first survey, to a mean of >90% on the third (Fig. 6). The amount of epibiotic growth on structures appeared to vary among group rather than design at each sampling occasion, and designs appeared to have a different rate of growth over the three surveys depending on group (Fig. 6).

Multivariate epibiotic growth assemblages differed significantly across survey times and among groups (Table S5; time*group interaction). Among all hotel designs, a clear divide among the assemblages at different survey times can be seen, with the largest difference separating survey three from surveys one and two (samples taken in February and May 2018; Fig. 7). Overlaid vectors show that the assemblages of the first two surveys are defined by assorted barnacles and bare structure, while the assemblages of the third survey across all designs were defined by an increased abundance of assorted sponges, red macroalgae and green macroalgae.

4. Discussion

With natural habitats in decline worldwide, due largely to anthropogenic influences (Travis, 2003; Lai et al., 2015), novel solutions are required to support threatened species, especially those that are at high risk of population collapse following habitat displacement. Artificial habitats have the potential to be a powerful conservation tool in many cases, including but not limited to the protection of threatened marine fish such as H. whitei. In this study, Seahorse Hotels were found to support a large population of seahorses in an area where natural habitat has been in decline. Studies of H. whitei in the wild have shown that larger, more complex natural habitats are likely to contain seahorses (Harasti et al., 2014b), whereas increased complexity of the Seahorse Hotels created by additional holdfasts did not result in an increase in seahorse abundance, with no difference in seahorse numbers among designs that had the additional holdfasts constructed of two different materials.

This research was unfortunately limited to a single study site due to a number of reasons. Firstly, six out of the eighteen hotels deployed at Seahorse Gardens disappeared, likely due to a boat anchoring in the middle of a group and then pulling the hotels into deeper waters. This decreased the surface area and environmental carrying capacity of the structures at this site, resulting in decreased likelihood of new seahorses discovering and colonising the habitats. Secondly, recent population estimates have shown that seahorse numbers at Seahorse Gardens have decreased more significantly than at Pipeline (Harasti, 2016). In addition, two surveys at Seahorse Gardens in 2018 found only one seahorse on each occasion (Harasti, pers. Obs.). This suggests that Seahorse Hotels may have a smaller effect at sites where seahorse populations are too sparse. For further research in the use of Seahorse Hotels it would be beneficial to trial them in multiple locations and try to deploy them in areas where boat anchoring is minimal or not permitted, or to engage with relevant organisations to prevent boat anchoring while re-establishing populations.

Declines in the availability of natural habitat at Pipeline in recent years has resulted in significant declines in seahorse numbers (Harasti,
Seahorses are especially vulnerable to habitat loss as they are sedentary and use their prehensile tail to cling onto holdfasts while resting and feeding, as well as relying on cryptic behaviour to avoid predation (James and Heck, 1994; Harasti et al., 2012). Holdfast availability may be especially important at sites such as the Pipeline, as the Port Stephens estuary is highly hydrodynamic, with strong tidal currents. It has previously been shown that *H. whitei* in the estuary prefer larger, more complex habitats such as sponge and soft coral (*Dendronephthya australis*) as this likely provides them with shelter and food availability (Harasti et al., 2014b). A lack of holdfast availability
Fig. 5. A. Mean abundance of mobile epifauna across Seahorse Hotel designs, with data clustered by group. B. Non-metric MDS showing similarities between multivariate mobile epifauna samples. Data were square-root transformed, and nMDS constructed from Bray-Curtis similarities. Samples are labelled (shape) by hotel design, as well as sample number (text).

Fig. 6. Mean coverage of epibiotic growth on Seahorse Hotels. Means are given for three survey occasions (February, May and August 2018), with data sorted by factors hotel design and group. Bars represent standard error.
prevents seahorse colonisation at sites, which can limit mating and recruitment potential. The addition of holdfasts into these areas where natural habitats are absent could help promote recovery of seahorse populations.

The Seahorse Hotels at the Pipeline site supported a large population of seahorses for a period of 11 months, with individuals displaying relatively strong site fidelity. With an average of 16.33 seahorses observed inhabiting the 18 m$^2$ of Seahorse Hotels per survey, this equates to an average seahorse density of 0.91 m$^{-2}$. These numbers are higher than has been recorded for \textit{H. whitei} at Pipeline previously (0.035 m$^{-2}$), and are similar to densities found previously on the swimming net in Manly, Sydney (1.050 m$^{-2}$) (Harasti et al., 2012). Generally, a greater number of females was estimated to have used the Seahorse Hotels, which is consistent with previous estimates of seahorse populations on artificial structures (Harasti et al., 2012). These results corroborate previous finding that complex artificial habitats can be associated with rapid colonisation and high abundances of fish species. The densities of \textit{H. whitei} found here were greater than densities of \textit{H. guttulatus} and \textit{H. hippocampus} found on natural habitats in the Ria Formosa Lagoon, south Portugal (Correia et al., 2015a), though were smaller than densities of these two species found on artificial habitats (Correia et al., 2015b). \textit{Hippocampus whitei} density on the Seahorse Hotels was also found to be greater than the density of \textit{H. capensis} on artificial reno mattresses in the Knysna estuary, South Africa (Claassens, 2016). These comparisons help highlight that the success of artificial habitats in terms of supporting populations of threatened species of seahorse may vary, both between species and locations. Seahorse density on artificial habitats may vary according to the quality of surrounding natural habitats as well as the number of seahorses inhabiting natural habitats prior to installation of artificial habitats (Correia et al., 2015b).

Seahorse numbers on the hotels were found to differ over time, with population estimates suggesting an increase in abundance over the duration of the study. This pattern was, however, more variable when comparing seahorse abundance among hotel designs. The presence of pregnant males on the Seahorse Hotels towards the start of the \textit{H. whitei} breeding season (October to February), and the presence of juveniles, is a good indicator of population health and demonstrates that seahorses are interacting on the structures. Seahorses may struggle to interact and find a mate when natural habitat is sparse and patchy (Correia et al., 2015b). Site persistence of \textit{H. whitei} on the Seahorse Hotels was similar to that recorded at Pipeline in recent studies, with the probability of recapturing seahorses higher than has been previously found at Pipeline (0.20 ± 0.05), but not as high as has been recorded on the swimming net at Manly, Sydney (0.62 ± 0.04) (Harasti et al., 2012).

Additional complexity or holdfast coverage in artificial habitats has previously resulted in increased seahorse numbers (Hellyer et al., 2011; Correia et al., 2015a); however, no differences in seahorse numbers across Seahorse Hotel designs were observed in our results. There are a number of reasons this could have occurred. The base holdfast density of the wire mesh used to construct the Seahorse Hotels may have been sufficient in that the addition of more holdfasts did not result in an increased abundance of seahorses. Similar patterns were observed in Ria Formosa, Portugal, in which no difference in seahorse numbers were found on artificial habitats with medium and high holdfast densities (Correia et al., 2013). There are also some species of seahorse, such as \textit{Hippocampus hippocampus}, that do not display a strong preference for more complex habitats as other species of seahorse (Curtis and Vincent, 2005; Correia et al., 2013, 2018; Woodall et al., 2018). Another explanation is that the gradual build-up of epibiotic growth on the wood and rope holdfasts themselves may have rendered them too thick to be used as holdfasts for \textit{H. whitei}, as was observed previously when the build-up of epibiotic growth on artificial holdfasts, with a result in increased thickness, was reflected in decreased seahorse abundance (Correia et al., 2015b). The presence of the internal holdfasts often resulted in the accumulation of wrack such as kelp, which may have limited seahorses ability to inhabit the middle of the structures while potentially allowing seahorse predators such as red rock cod (\textit{Scorpaena jacksoniensis}) and octopus (\textit{Octopus tetricus} and \textit{Hapalochlaena fasciata}) to hide.

Fish abundance across different types of habitat is often dependant on epifaunal prey as well as the amount of epibiotic growth present (Coleman and Connell, 2001), a pattern also observed in seahorses such as \textit{H. whitei} (Harasti et al., 2010; Hellyer et al., 2011). Here, as in previous studies (Clynick, 2008), seahorses took a few months to colonise the hotels, with seahorses observed in January after hotel deployment in November. This delay in colonisation may be attributed to limited seahorse movement around the site due to their small home range (approximately 9–14 m over small time scales (Vincent et al., 2005)) and high site fidelity, as well as the lack of epibiotic growth on new
structures, which can take months to develop before the habitat becomes suitable for seahorse colonisation. Additionally, the mobile epifaunal prey that seahorses predate is correlated with cover of epi-biotic growth (Martin-Smith, 1993). The lack of difference in epibi-tic growth and mobile epifaunal prey between Seahorse Hotel designs may help explain the similar numbers of seahorses observed between designs. While similar densities of mobile epifauna were found on the Seahorse Hotel designs as found on other artificial habitats such as swimming nets in a previous study (Helliwer et al., 2011), these results contradict this study’s observations of increasing mobile epifauna with the addition of complexity to an artificial habitat. Thus, the complexity of the wire mesh used to construct these habitats must be sufficient to allow for high abundances of mobile epifauna. The general pattern of increasing epibi-tic growth on the structures over time, as well as the increasing relative abundance of macroalga and sponge, may help explain the general pattern of increasing seahorse numbers over time (Fig. 3) as H. whitei has been shown to display preference for sponge habitats (Harasti et al., 2014b). Seahorse colonisation to new artificial structures has been observed to take up to four months (Clynick, 2008). Comparisons between the numbers of mobile epifaunal seahorse prey found here and with numbers found on natural habitats for H. whitei or other species (Ape et al., 2019) cannot be compared as this has not yet been studied, with similar sampling methods as used here.

The capability of artificial habitats to host similar biodiversity to that of natural habitats has been supported by a number of studies, though has also been questioned by some. While studies have shown that artificial habitats have been able to support diverse assemblages of organisms similar to natural habitat (Wen et al., 2016; Burt et al., 2013), other have found contrary results (Burt et al., 2009), and there exists the possibility that structures such as artificial reefs may act as fish aggregation devices with no net gain in site-wide abundance (Grossman et al., 1997; Pickering and Whitmarsh, 1997). From the results of our study, we are unable to determine whether Seahorse Hotels are acting as a source or sink, and it is important to know whether artificial habitats are actually helping increase the population size of seahorses at a site, or whether they are simply aggregating existing animals away from natural habitat. Aggregation of fish on a habitat such as an artificial structure may have negative impacts for threatened species as they may be more vulnerable to anthropogenic disturbance such as increased fishing pressure, spread of disease or other adverse events (Franks, 2001; Dempster et al., 2004; Dempster and Taquet, 2004; Reubens et al., 2013). Further research needs to explore whether the presence of artificial habitats like Seahorse Hotels is resulting in increased site-wide abundance and the colonisation of new seahorses.

This research confirms the value of artificial habitats as a conservation tool for seahorses as suggested by previous finding (Correia et al., 2015b; Claassens, 2016). Seahorse Hotels are an inexpensive novel conservation tool that can be used to support populations of seahorses that are in decline due to loss of natural habitat. They may be an effective temporary replacement habitat when used in conjunction with wider conservation strategies such as the rehabilitation of natural habitat, the prevention of live seahorse collection from the wild, or during the management and cleaning of artificial structures that aggregate large populations of seahorses such as swimming nets. Because additional complexity is unnecessary beyond wire mesh frame, these structures can be easily constructed with accessible biodegradable materials and for minimal cost. As there is continuing concern about the loss of seahorse species and associated habitats worldwide, these Sea-horse Hotels could be employed in areas where local seahorse popula-tions have declined. The results from this initial trial of Seahorse Hotels have been encouraging and the next step would be to test out their effectiveness on other threatened seahorse species in other areas around the world, as well as environmental managers integrating their use into existing artificial structure management plans and natural habitat remediation strategies. Further research may also explore the development of more permanent artificial habitats for use in areas where natural habitat restoration is not occurring.

Data accessibility

The relevant data will be lodged in the Sydney University library’s Data Repository and a DOI provided upon acceptance.

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CRediT authorship contribution statement

Michael Simpson: Methodology, Formal analysis, Writing - original draft. Ross A. Coleman: Methodology, Writing - original draft. Rebecca L. Morris: Methodology, Writing - original draft. David Harasti: Methodology, Writing - original draft.

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Appendix A. Supplementary data

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