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Short communication

Sea ranching release techniques for cultured sea cucumber *Holothuria scabra* (Echinodermata: Holothuroidea) juveniles within the high-energy marine environments of northern Australia

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ABSTRACT

The valuable sea cucumber *Holothuria scabra* has potential as a ranching species to contribute to the economic growth of northern Australia. However, the high-energy environments of north Australia present certain atypical environmental challenges for sea cucumber ranching, proving commonly practiced ranching techniques ineffective. This study aimed to develop a suitable method for the effective deployment of cultured sea cucumber juveniles within the constraints of north Australian environmental conditions. Two boat-based release techniques were trialed: temporary, floorless cages; and a chute. Sea cucumber recovery rates, dispersal distance and direction were compared to assess the relative merit of each. The proportion of sea cucumbers recovered from the chute release treatment (18.9%) was significantly higher than those from the cage release treatment (10.6%). Recaptured individuals were assigned to their nearest release point, as the tagging method allowed differentiation between methods but not between sites. However, unanticipated sea conditions and equipment failure caused a flawed deployment at one site, which corresponded with atypical recapture results, relative to other sites, and led to the analyses of two possible scenarios explaining sea cucumber movement post-release. Scenario 1 assigned individuals by proximity to release points, and Scenario 2 assigned a group of far-lying individuals to the site where the flawed deployment occurred. There was no significant difference in mean angle ($\bar{a}$) of movement, between the chute and cage methods, for both scenarios (Scenario 1 - 80.3° and 71.16° respectively, Scenario 2 - 81.04° and 74.84° respectively) and the directionality statistic (r) and the angular dispersion (s^*) for both methods and scenarios indicate that the strength of any preferred direction was very weak. There was a significant difference in mean distance travelled between the two methods for both scenarios (Scenario 1: cage and chute 10.8 m and 20.2 m with 95% CI's of 2.57 m and 4.42 m respectively; Scenario 2: cage and chute 11.1 m and 20.4 m with 95% CI's of 2.99 m and 4.52 m respectively). However, this difference is caused primarily by the group of individuals thought to have washed away from the flawed deployment–if these are treated as outliers and removed from overall distance and dispersion analysis, no significant difference is found between distance travelled ($F_{1,184} = 1.25$, $p = 0.264$) or dispersion ($F_{1,165} = 0.385$, $p = 0.636$) between the two methods. The cause of the flawed deployment at one site is easily rectified and, given the significantly higher recovery rates, lower cost, ease of construction and efficiency, the chute release method proved superior. The improved sea ranching release techniques identified in this study will provide practical and economically sound release methods for sea cucumber ranching, and stock enhancement activities across northern Australia.

Statement of relevance

This study provides a logistically sound alternative to hand release of juvenile sandfish in areas where environmental factors, such as high tidal energy and crocodiles, prevent hand release for ranching and stock-enhancement. Chute release by boat during the slack of a neap tide, onto open ranching area, yielded comparable recapture rates to those reported in hand-released sea pen containments.

1. Introduction

Holothuria scabra (Jaeger 1833) is a commercially valuable species of holothurian (sea cucumber), distributed throughout the tropical Indo-Pacific (Hamel et al., 2001). This species is predominantly found on

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sandy or muddy substrate, is a deposit feeder and exhibits diel and tidal burying behaviour (Hamel et al., 2001). Sea cucumbers have been fished for many centuries; its dried form (known as either trepang or bêche-de-mer) is prized within the Asian market for its culinary and perceived medicinal properties (Hamel et al., 2001; Toral-Granda et al., 2008). Historic localized overfishing leading to the gradual expansion of the fishery into new grounds has resulted in the global overexploitation of sea cucumber stocks throughout most of their range (Hamel et al., 2001; Purcell et al., 2013). This depletion of wild stocks has led to a focus on developing effective hatchery and field techniques for restocking and sea ranching of sea cucumbers to increase commercial wild stock yields, create aquaculture businesses and/or replenish stocks depleted below natural recovery capacity (Purcell et al., 2012). A number of countries have investigated the production of hatchery-bred *H. scabra* for grow-out in the sea, such as in the Solomon Islands (Battaglene et al., 1999), the Maldives (Azari and Walsalam, 2012), the Federated States of Micronesia (Jimmy et al., 2011), Fiji (Hair, 2012), the Philippines (Mills et al., 2012; Gamboa et al., 2004), Vietnam (Pitt and Duy, 2004a, 2004b), New Caledonia (Kinch et al., 2008), Madagascar (Eriksson et al., 2011; Tsiresy et al., 2011), Australia (Ivy and Giraspy, 2006) and more recently in Papua New Guinea (Hair et al., 2016; Southgate et al., 2012).

The Northern Territory, Australia has one of the last remaining viable sea cucumber fisheries in the world and, unlike many of its Indo-Pacific counterparts, is subject to strict fisheries management and devoid of significant poaching activity (Fleming, 2012). A single commercial operator owns all available licenses, while Indigenous peoples own 85% of the Northern Territory coastline including the intertidal zone (Bowman, 2012; Fleming, 2015), which poses a range of atypical environmental challenges for sea cucumber farming. These include extreme tidal variations of up to 8 m, strong current flows of up to 2.5 m/s, site access difficulties and the presence of saltwater crocodiles (Williams and Wolanski, 2003; Williams et al., 2006).

Effective release techniques are critical to the success of sea ranching practices as mortality is generally greatest immediately following release (Purcell, 2004; Purcell and Simutoga, 2008). Potential causes for this high mortality include vulnerability of hatchery-produced juveniles to predation and stress during release and/or transport (Robinson and Pascal, 2012). They have also been shown to have poorly developed natural behaviours compared to their wild counterparts, such as poor predator avoidance behaviour (i.e. burying) and feeding behaviour (Purcell, 2004). Therefore, sea cucumber releases generally occur in low energy, protected sites, such as sheltered bays, where juveniles are released by hand, either by divers in shallow water or by farmers wading onto exposed sites at low tide (Battaglene, 1999; Purcell, 2004; Purcell and Simutoga, 2008). In addition, the low energy conditions at these study sites allow for the use of sea pens to hold sea cucumbers for both experimental (i.e. monitoring growth and survival) and sea farming purposes (Juinio-Meñez et al., 2014; Juinio-Meñez et al., 2013; Ward, 2006). Such structures provide many benefits to farmers such as protection, containment, control and clarity regarding stock ownership (Purcell and Simutoga, 2008; Purcell et al., 2012).

The extreme environmental conditions in north Australia prevent the use of pens or other structures in the sea. Suitable spring tides with daytime low water occur for only a few months of the year, and may not correspond with the availability of hatchery-produced juveniles (Williams et al., 2006). Hand release at night during low spring tides is dangerous due to the presence of saltwater crocodiles. Furthermore, rapid incoming tidal flows may displace released sea cucumbers if they do not bury immediately (Purcell, 2004; Williams et al., 2006). In contrast, neap tides present minimal tidal range (mean variation of 3 m), an extended period of slack water during tidal change and occur during the daytime year round (Williams and Wolanski, 2003). Hand release is still not recommended during neap tides due to the presence of crocodiles; however, the slower water movement provides an opportunity for juvenile deployment from a boat. The aim of this study was to develop a suitable boat-based method for the effective release of juvenile sea cucumbers during the slack period of neap tides.

2. Materials and methods

2.1. Study site

A five hectare intertidal site, adjacent to an area locally known as Wigu, is the primary study site for sea cucumber ranching on South Goulburn Island, located in the Arafura Sea off the coast of west Arnhem Land, Northern Territory, Australia (Fig. 1). It has the required characteristics of a productive sea cucumber ranching area including the presence of extensive seagrass beds, soft organic rich sediments, a healthy population of wild sea cucumber stocks, and is accessible on foot at very low tides.

Four sites were selected within the Wigu ranch area for the experimental sea cucumber releases. Each site comprised of two release points; one for each of the two release methods tested. The size of the trial release area was chosen based upon providing consistent substrate and water movement, which limited the distance possible between release points. Therefore, and considering previous studies have shown that released juvenile sea cucumbers typically do not move large distances for many months post deployment (Purcell and Kirby, 2006), site spacing of 50 m was considered an appropriate distance. The two release points within each site were positioned 10 m apart; close range deployment was possible since the juveniles for each release treatment were tagged with different fluorochrome markers, allowing for future identification (Purcell et al., 2006). Geographic coordinates of each deployment point were recorded using GPS (Garmin GPSMAP78). In addition, a painted brick was attached to a buoy one week prior to experimental release and used as a physical marker at each deployment point, to allow for observation from the boat.

2.2. Experimental releases

Newly settled juveniles (3–15 g) were provided by Tasmanian Seafood P/L and held at the Darwin Aquaculture Centre (DAC), Darwin, Australia. Twelve days prior to release the juveniles were separated into two replicate treatment groups. Juveniles were tagged with fluorochrome markers, following methods described by Purcell and Blockmans (2009). Juveniles for the cage release treatment were marked with calcein and those for the chute release treatment were marked with tetracycline. Juveniles from each treatment group were held separately in 5000 L nursery tanks with 800% daily raw seawater flow-through for a recovery period of ten days after fluorochrome marking. To monitor stain quality and longevity throughout the duration of the release trial a control sample of six marked sea cucumbers from each treatment group were held back at the hatchery.

Experimental treatments were deployed at neap tide in late August 2012. Fluorochrome-tagged juveniles ($n = 1400$) were transported to the Wigu release site using the methods described by Purcell et al. (2006). Water salinity was 33 ppt, and water temperature was 25.2 °C. Wind strength was 8.2 knots on average, with maximum speeds of 20 knots, and day length was 11 h 50 min. Juveniles were released onto the sediment in water depths ranging from 0.9 to 1.2 m, over a 3 h period during the slack of a low neap tide. Four replicate groups of juveniles ($n = 175$) were deployed by each release treatment, as follows:

(i) Temporary cage release: Four replicate floorless square cages were constructed from a weighted 1 m^2 40 mm PVC pipe frame and covered with a 1 mm mesh that formed a peak, supported by a buoy secured to the top of the cage (Fig. 2a). Just before the cage was deployed to the seafloor, a torn paper bag was filled with the sea cucumber juveniles and secured inside the apex of the cage. Shortly after deployment, the paper bag became saturated and broke apart, releasing the juveniles onto the sea floor

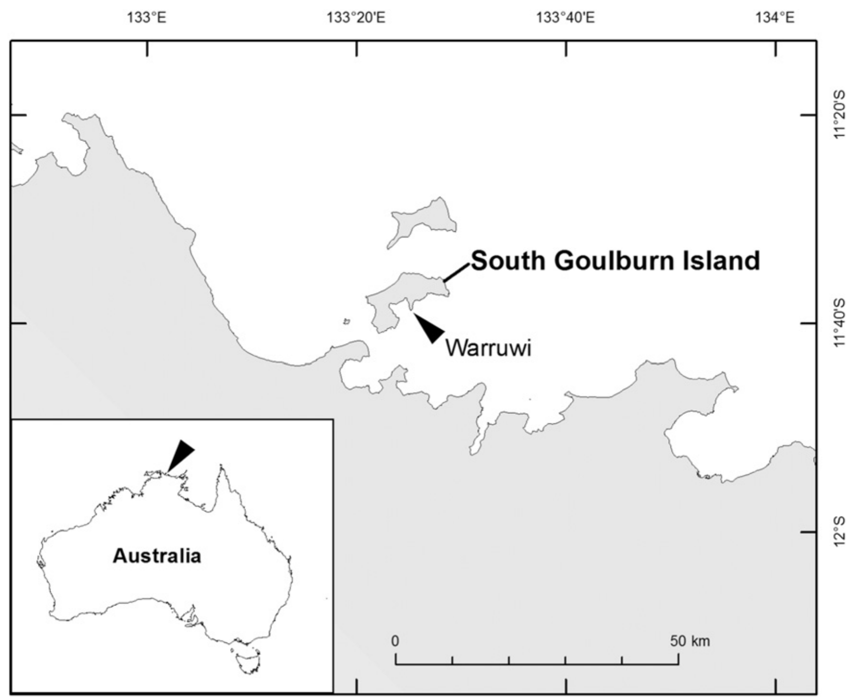

Fig. 1. Location of South Goulburn Island, Northern Territory, Australia.

within the cage. The cages were removed after 24 h. Wind speed was 4.9 knots on average, with maximum speeds of 15.9 knots during the time of cage removal.

(ii) Chute release: Juveniles were released via a 2 m length of 90 mm diameter PVC pipe (Fig. 2b), which was held in place (approximately 10 cm above the sea floor) by an operator from the boat deck. Underwater viewers were used to ensure the chute remained close to, but not touching, the sea floor so that juveniles were not injured on contact with the substratum. A second operator fed the juveniles down the chute and a third operator poured seawater into the chute to assist their passage to the seafloor.

To demonstrate the difference in recapture rates between boat-based releases and traditional hand release, hand release was considered as a third treatment. However, as this is only possible during low spring tides, which occur one week prior/following neap tides, it was not logistically possible to deploy this treatment under the same conditions as the two boat release treatments. As hand releases are not a practical deployment method for commercial ranching in northern Australia due to very limited access to the sea floor during spring tides, this study focused on developing boat-based release methods only. Assessment of recovery rates from previous hand release studies on a smaller scale at the same site (*unpublished data*) may provide a qualitative reference point for more commercially practical deployment methods in this area.

Sites were deployed in order from 1 to 4. Sites 1–3 were deployed according to the described methods, and individuals were delivered to the sea floor within 0.5–1 m of release points shortly after the slack period of the tide. However, the final deployment at site 4 was atypical because wind speed and tidal movement had increased significantly and sea conditions deteriorated, causing deviation of the cage and chute deployment by 2–3 m from the release points. In addition, several individuals released by chute at site 4 were observed being dispersed by the

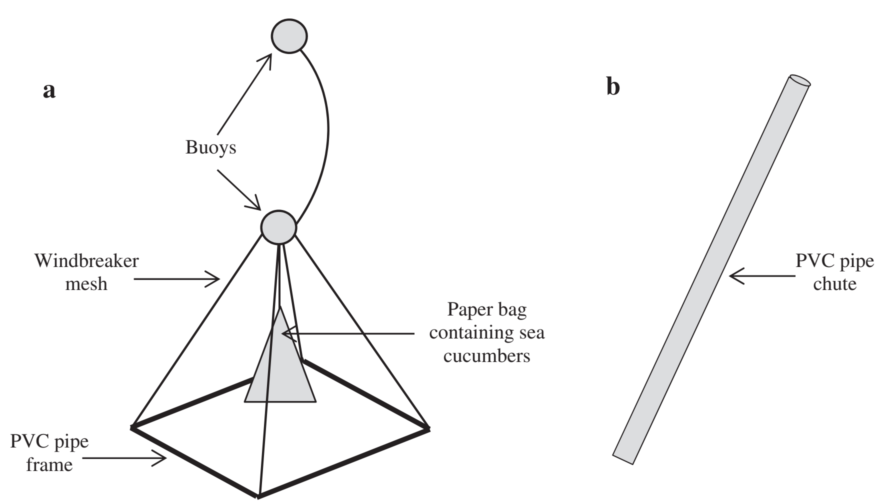

Fig. 2. Trial methods equipment design diagrams (a) temporary cage and (b) chute.

current after chute lengths had briefly been disconnected by worsening sea conditions, and so were not delivered directly to the sea floor.

2.3. Survey

In December 2012, 20 weeks after the releases, the site was intensively surveyed by foot at low spring tide over three consecutive days. Salinity was 32 ppt, water temperature was 30.5°, averaged over the three days and day length was 12 h 51 min. Initially, a designated 25 m zone around each release site (i.e. release point for chute and cage releases) was thoroughly searched for sea cucumbers that had remained close to their release sites. Thereafter, more distant zones of the study area were searched in a straight line, grid pattern to locate sea cucumbers that may have moved greater distances, ensuring the majority of the Wigu ranching area exposed at low tide was surveyed. Published values for *H. scabra* growth indicate that maximum size after 5 months is likely to be 200 mm (300 g) (Juinio-Meñez et al., 2014; Pitt and Duy, 2004a, 2004b), therefore *H. scabra* up to a length of 250 mm were sampled; a small epidermis sample taken from the ventral surface of the sea cucumber and length and width recorded (mm). Samples were immediately stored in 70% ethanol in labeled 2 mL Eppendorf tubes to prevent tissue degradation and covered with aluminum foil to prevent photodegradation of the fluorochromes in stained ossicles (Honeyfield et al., 2008; Samuelsen, 1989). The location of each sampled sea cucumber was marked by GPS and then it was removed from the release site to prevent re-capture on subsequent days' survey. On survey day 3, once all the surveys were complete, all captured animals were returned to the ranching area.

All epidermis samples (including samples taken from the control animals) were subsequently processed in the laboratory to assess the presence and colour of fluorochrome-stained ossicles, based on methods described by Purcell and Blockmans (2009) and Taylor (2016). As it was not possible to use multiple coloured markers to distinguish the eight release points, the GPS location of each tagged individual was used initially to assign them to the closest release point by distance.

2.4. Statistical analyses

The proportion of individuals recovered from each release method (pooled for all release points) was compared using a two-sample binomial test for equality of proportions with continuity correction (Fleiss, 1981).

The distance and direction from each release point for each recaptured sea cucumber was determined using orthodrome trigonometric functions applied to the known release and recapture locations. Distance (D in metres) was calculated using:

$$a = \sin^2\frac{\Delta\varphi}{2} + \cos\varphi_1 * \cos\varphi_2 * \sin^2\frac{\Delta\lambda}{2}; c = 2 * a\tan2\left(\sqrt{a}, \sqrt{(1-a)}\right); D = R * c$$

where φ is latitude and λ is longitude (in radians) and $R = 6{,}371{,}000$ (the earth's radius in metres). Angle of movement (θ in degrees) was calculated using:

$$\theta = a\tan2(\sin\Delta\lambda * \cos\varphi_2,\ \cos\varphi_1 * \sin\varphi_2 - \sin\varphi_1 * \cos\varphi_2 * \cos\Delta\lambda) * d$$

where $d = 57.29577952$ (for converting radians to degrees).

Data for the distance travelled from release points for individuals in each treatment using the release points as a blocking factor were analysed by two-way analysis of variance (ANOVA) to determine whether the mean distance travelled over the 20 week trial period differed between release methods (Zar, 1996).

Descriptive statistics for angular data (direction travelled by individuals) for both methods from each of the eight release points were calculated for mean angle ($\overline{a}$), angular dispersion (s^*) and directionality (r) as described in Zar (1996). Only animals recorded as having moved any distance from each release point were included for these parameters. For circular distributions, angular dispersion can be considered as the analogue of the standard deviation, or shape description, of linear data, while directionality is a measure of the concentration of the angles, and varies from 0 (angles very widely spread, but not necessarily uniform) towards 1 (all angles very similar). A generalised Watson-Williams test (Zar, 1996) was used for comparison of the mean angles calculated for each release method.

As mentioned in Section 2.3, individuals were assigned to their closest release point. However a group of chute released individuals were found in the north-east corner of the release area up to 113 m away from site 4, which did not match the limited dispersal found around sites 1 to 3. The addition of an unusually low recapture rate near site 4, combined with the technical problems experienced during deployment at this site, raised the strong possibility that these distant and scattered individuals may have been swept away by currents during site 4 release. Fluorochrome tagging distinguished between release methods but not sites; therefore, they may have originated from site 4 or site 3, the nearest release sites by distance (according to our stated methods). To account for these different potential scenarios, two separate analyses of dispersal, distance and direction analysis were carried out: (1) recaptures of all individuals, based on proximity to release site; and (2) recaptures of all individuals, assigning the scattered group to the north-east to site 4.

3. Results

3.1. Recovery

Survival of the control sea cucumbers retained at the DAC hatchery was 100% across both stain methods. Tissue samples taken from these control sea cucumbers also showed 100% stain retention in epidermis ossicles, and clearly visible colour difference between the treatment groups. Therefore, it can be assumed that the staining results from field samples accurately identified released sea cucumbers and distinguished between the treatment groups. A total of 394 sea cucumbers were sampled during the recovery survey. Of these, 206 were tagged (hatchery- produced) individuals, i.e. 14.7% of the 1400 released. They ranged in length from 70 to 210 mm (117.7 ± 1.7) and width from 20 to 60 mm (32.4 ± 0.5). Ossicle processing showed that 132 of recaptured individuals were chute released (18.9% recovery) and 74 were cage released (10.6% recovery). The proportion of sea cucumbers recovered from the chute release treatment was significantly higher than from the cage release treatment ($\chi^2 = 8.77$, df = 1, $p < 0.001$). Individuals were assigned to deployment sites by proximity as per methods, and an alternative explanatory scenario, summarized in Table 1.

3.2. Distance, dispersal and direction

Spatial patterns of distances and directions travelled by individuals released at the four sites by each method are summarized in Fig. 3. Release sites are positioned from the south-east corner (site 1) diagonally up to the north-west corner (site 4) and are paired for each method (chute and cage). Patterns of dispersal were very similar for sites 1 to 3 (sea cucumbers were found in various directions, approximately 80% <15 m from release points) (Fig. 3). Comparatively few individuals were found in close proximity to site 4, and a group of individuals was found in the north-east corner of the release area and along the shoreline up to 113 m from site 4. These individuals were assigned by proximity to sites 4 (n = 9), 3 (n = 7) and 2 (n = 2). However, given the observations during the compromised site 4 release and the low number of individuals found in close proximity to site 4, relative to other

Table 1
Total number (and %) of recaptured sea cucumbers from each site for each release method, assigned by Scenario 1 (proximity to release point) and Scenario 2 (alternative analysis based on observations during deployment of site 4).

	Scenario 1			Scenario 2		
	Cage	Chute	Total	Cage	Chute	Total
Site 1	26 (12.6%)	51 (24.8%)	77 (37.4%)	26 (12.6%)	51(24.8%)	77 (37.4%)
Site 2	34 (16.5%)	18 (8.7%)	52 (25.2%)	33 (16.0%)	17 (8.3%)	50 (24.2%)
Site 3	12 (5.8%)	45 (21.8%)	57 (27.7%)	12 (5.8%)	38 (18.4%)	51 (24.2%)
Site 4	2 (1%)	18 (8.7%)	20 (9.7%)	3 (1.5%)	26 (12.6%)	29 (14%)
Total	74 (35.9%)	132 (64.1%)	206	74 (35.9%)	132 (64.1%)	206

sites, an alternative scenario was also analysed - that this group had been released at site 4 and washed away.

- Scenario 1: Proximity

o Juveniles released via the cage and chute methods from sites 1 to 4 moved mean distances of 10.8 m (95% confidence interval = ±2.57 m) and 20.2 m (95% confidence interval = ±4.42 m) respectively. There was a significant difference in mean distances travelled between the two methods from sites 1–4 ($F_{1,204} = 8.77, p = 0.003$). Over 60% of the recaptured individuals did not move >10 m from the release point (Fig. 4), irrespective of release method. Just fewer than 80% of the recaptured juveniles were found within 20 m of the release point (Fig. 4).

o Dispersal from sites 1 to 4 from either release method was quite similar (Table 2). Of the individuals recaptured, 73 cage released (98.6% of the 74 recaptured) and 122 chute released (92.4% of the 132 recaptured) animals had moved away from the release point. Cage and chute released juveniles exhibited mean angles ($\overline{a}$) of movement of 80.3° and 71.16° respectively (when referencing north as 0.0°). The directionality statistic (r) and the angular dispersion (s^*) for both methods indicate that the strength of any preferred direction was very weak. Analysis of the mean angle for each method (combining sites 1–4) indicates they were not significantly different ($F_{1,193} = 0.076$, $p = 0.784$) having a common angle of 12.5° with an angular dispersion of 74.5°.

- Scenario: Far-lying individuals assigned to site 4

o Juveniles released via the cage and chute methods from sites 1 to 4 moved mean distances of 11.1 m (95% confidence interval = ±2.99 m) and 20.4 m (95% confidence interval = ±4.52 m) respectively. There was a significant difference in mean distances travelled between the two methods from sites 1–4 ($F_{1,204} = 8.21$, $p = 0.005$). Approximately 50% of the recaptured individuals did not move >10 m from the release point (Fig. 4), irrespective of release method. Approximately 80% of the recaptured juveniles were found within 20 m of the release point (Fig. 4).

o Dispersal from sites 1 to 4 from either release method was quite similar (Table 3). Of the individuals recaptured, 73 cage released (98.6% of the 74 recaptured) and 122 chute released (92.4% of the 132 recaptured) animals had moved away from the release point. Cage and chute released juveniles exhibited mean angles ($\overline{a}$) of movement of 81.04° and 74.84° respectively (when referencing north as 0.0°). The directionality statistic (r) and the angular dispersion (s^*) for both methods indicate that the strength of any preferred direction was very weak. Analysis of the mean angle for each method (combining sites 1–4) indicates they were not significantly different ($F_{1,193} = 0.007$, $p = 0.934$) having a common angle of 17.7° with

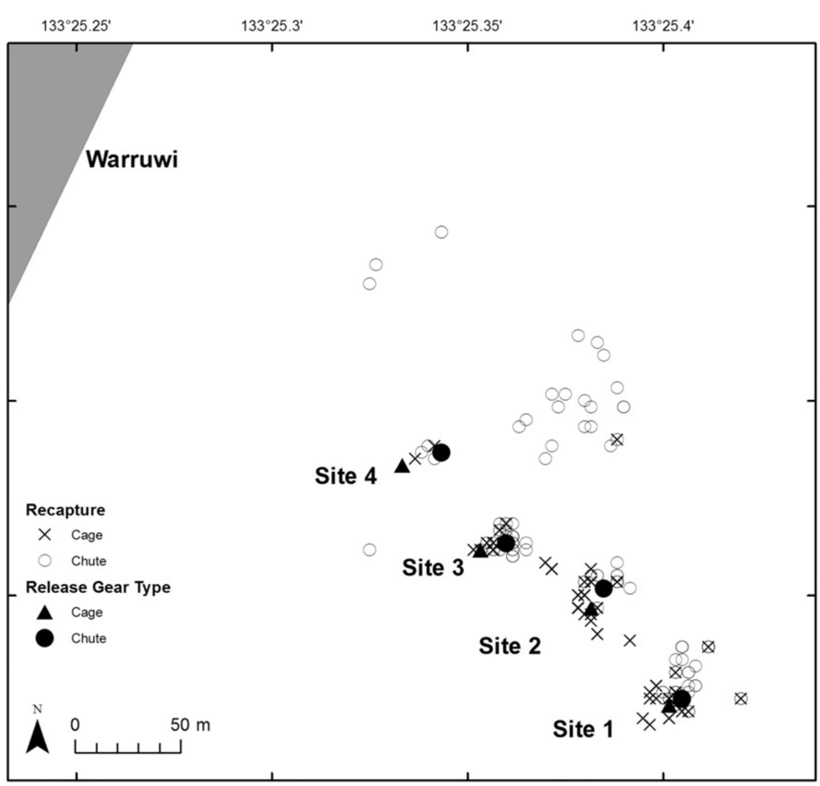

Fig. 3. Dispersal patterns for individual sea cucumbers released using each method at sites 1 (bottom right) to site 4 (top left), release points are shown by solid triangles (cage release) and dots (chute release) and the recaptured individuals are represented by crosses (cage release) and circles (chute release).

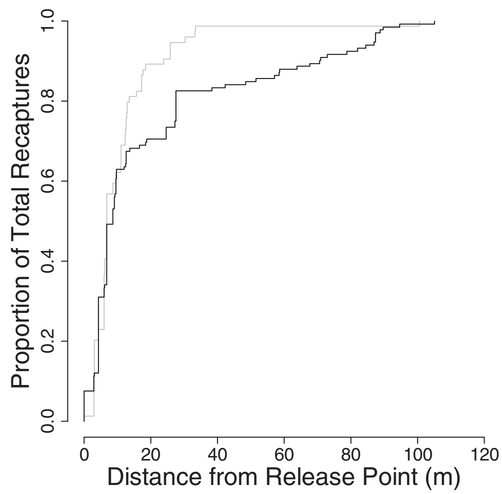

Fig. 4. Empirical cumulative distribution plot of proportion of recapture by distances (metres) moved by individuals from cage (grey) and chute (black) release points for sites 1 to 4.

an angular dispersion of 77.1°.

- o Distances travelled by animals assigned to site 4 in Scenario 2 were assumed the product of a flawed deployment. If site 4 data in this scenario is treated as outliers and removed from overall distance and dispersion analysis, the remaining cage and chute released individuals moved mean distances of 11.1 m (95% confidence interval = ±2.99 m) and 13.8 m (95% confidence interval = ±4.52 m) respectively. No significant difference is found between distance travelled ($F_{1,184} = 1.25, p = 0.264$) between the two methods.

4. Discussion

Both chute and cage release methods were shown to be effective methods for deploying 3–15 g sea cucumber juveniles from a boat during the slack of a neap tide. Recovery rates from the chute method were significantly higher than those from the cage method ($p < 0.001$). Typically the acclimation of sea cucumber juveniles is considered an important release strategy (Dance et al., 2003; Purcell, 2004). Interestingly these results suggest that immediate protection of juveniles after release (i.e. within a cage) may not be a critical factor in their subsequent recovery and survival when deployed during the slack of a neap tide.

In addition to the eventual recovery rate, there are other factors to consider when selecting methods for large scale releases, such as; the cost and ease of constructing release structures; presence of predators; the duration of deployment events and associated stress on animals; and the cost of the deployment event for commercial scale volumes (Purcell, 2004). When considering the results obtained in this study, in addition to these broader selection criteria for large-scale releases, the chute release method proved to be superior from both an economic and logistic perspective.

The result for the chute release method was near the upper level reported in previous sea cucumber release studies. Purcell and Simutoga (2008) predicted that 7–20% of 5 g released sea cucumbers would survive to a market size of 700 g, 2.6 years after release in to 500 m^2 sea pens located in sheltered bays in New Caledonia. Survival of juveniles released into 100 m^2 sea pens in Fiji (Hair et al., 2011) and the Philippines (Juinio-Meñez et al., 2012) was 28% and 2–39% respectively. These and other reports on sea cucumber recovery rates are predominantly for grow-out within cages or sea pens, allowing ease of recapture and monitoring. In contrast, animals from the current study were released into their natural habitat (i.e. not enclosed). Given this, results obtained in this study appear promising.

The distance and direction that juveniles travel after release is an important consideration for ranching as they indicate where future harvestable stock will be located (Purcell, 2004; Purcell et al., 2012). Results from the current study display low levels of movement post release; around 60% of the recaptured individuals, for both release methods, were recaptured within 10 m of their closest release point in both scenarios. Approximately 90% of cage released and 70% of chute-released individuals were found within 20 m of their assigned release points. Although the distance travelled was different between chute and cage released groups, the primary cause of this difference is the group of far-lying individuals thought likely to have been released from site 4. As this was a flawed deployment, we are confident that, with the minor technical improvements required, future deployment of chute released individuals will show similar distances travelled to those in the cage released treatment. Post-release movement findings in this study are supported by Purcell and Kirby (2006) who developed a model to predict long-term dispersal of sea cucumbers released, based on short-term movement paths of individual juvenile *H. scabra*. Two years after release, the model predicted that 92% and 75% of the surviving animals would still be in the release area under high- and low-growth scenarios, respectively (Purcell and Kirby, 2006). Furthermore, they predicted the direction of sea cucumber movement was variable over two years; adults moved in the full range of compass bearings, with no apparent movement towards a common direction. Similarly, our study showed that although 98.6% cage and 92.4% chute release recaptures had moved away from their deployment point, this movement appeared random; sea cucumbers displayed a weak preference for directionality and dispersion. This is further supported by Mercier et al. (2000) who reported that young *H. scabra* released into three different habitats exhibited apparently random displacement and changed direction daily.

We suspect that juveniles released at site 4 may have been influenced by tidal conditions, as they were the last to be deployed, the tide was rising and equipment failure during deployment resulted in a number of chute released individuals to be released into the water column rather than on the sea floor. These individuals did not experience the same slack tidal conditions to become established on the sea floor as those deployed at the other sites. This is the most plausible

Table 2
Directionality, angular dispersion, and mean angle for all sites, juveniles assigned by proximity (Scenario 1). N is the number of individuals that moved away from the release site(s). †Site 4 cage data contained too few individuals for analysis to be reliable.

Site	Method	N	Directionality (r)	Angular dispersion (s^*) in degrees	Mean angle ($\bar{a}$) in degrees (N = 0, E = 90, S = 180, W = 270)
1	Cage	26	0.375	80.25	21.95
	Chute	48	0.595	58.42	350.8
2	Cage	34	0.381	79.62	336.4
	Chute	17	0.645	53.59	21.18
3	Cage	11	0.745	44.0	59.0
	Chute	39	0.271	92.6	36.7
4	Cage†	2	0.999	2.65	47.95
	Chute	18	0.558	61.87	33.15

Table 3
Directionality, angular dispersion, and mean angle for all sites, juveniles assigned according to Scenario 2 (alternative analysis based on observations during deployment of site 4). N is the number of individuals that moved away from the release site(s). †Site 4 cage data contained too few individuals for analysis to be reliable.

Site	Method	N	Directionality (r)	Angular dispersion (s^*) in degrees	Mean angle ($\bar{a}$) in degrees (N = 0, E = 90, S = 180, W = 270)
1	Cage	26	0.375	80.25	21.95
	Chute	48	0.595	58.42	350.8
2	Cage	33	0.366	81.22	334.2
	Chute	16	0.627	55.37	22.96
3	Cage	11	0.745	44.0	59.0
	Chute	32	0.128	116.1	59.44
4	Cage†	3	0.967	14.71	58.09
	Chute	26	0.636	54.48	53.17

explanation for the very small number of tagged animals recovered in close proximity to site 4 and the group of chute released individuals recovered further away from sites 4 and 3. An additional but untested consideration is that sea cucumbers migrated from site 4 due to microhabitat preferences. In recent biophysical sampling (S. Nowland, *unpublished data*), the study team found that site 4 habitat is characterised by sparser and taller seagrass (mostly *Enhalus acoroides*) whereas sites 1, 2 and 3 are dominated by shorter seagrass (mostly *Thalassia hemprichii*). *H. scabra* will move away from sub-optimal conditions (Mercier et al., 2000), and this could possibly have affected sea cucumber movement in this study.

The atypical results from the site 4 release highlights the importance of timing releases during periods of minimal tidal movement. It also indicates that improvements should be made to the chute delivery equipment to reduce mishaps. Our study shows that juveniles may travel further than anticipated in these environments, and our sandfish movement data can be used to inform future research regarding release site spacing, if methods of marking each deployment group separately are not available. Careful selection of release microhabitat should also be considered in future work of this kind. Incorporating these minor refinements into boat based chute releases at neap tides will improve this strategy for sea cucumber ranching and research in extreme environmental conditions experienced in northern Australia.

5. Conclusions

This study demonstrated that boat-based releases of juvenile sea cucumbers, during the slack of a neap tide, using either cage or chute methods resulted in recovery rates that are comparable to those reported in prior studies up to five months post deployment. The approximate 20% recovery rate achieved using the chute method is at the range achieved in other studies (Hair et al., 2011; Junio-Meñez et al., 2012; Purcell and Simutoga, 2008). Due to higher recovery rates, lower equipment cost, ease of construction and time and efficiency during release, the chute release method offers a more commercially viable approach. We anticipate that the application of the chute release method will improve release operations of sea cucumber juveniles in subtidal and intertidal ranching and stock enhancement areas in northern Australia and other places, where hand release by diving or on foot is not practically or economically feasible.

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