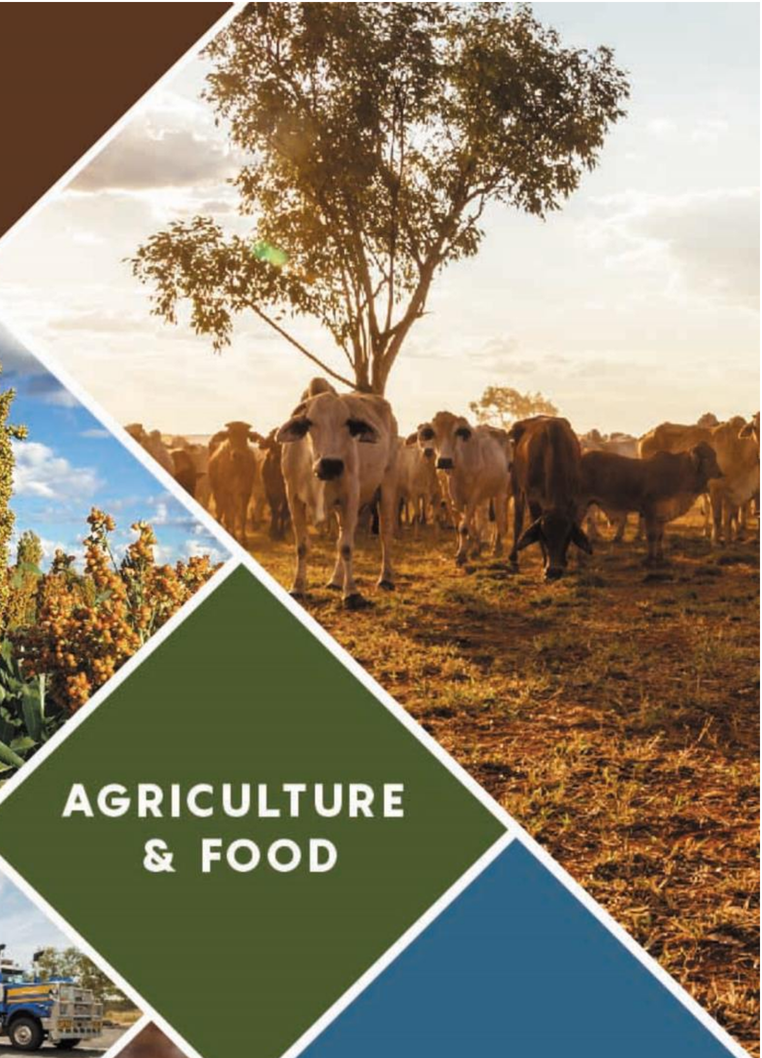

NORTHERN HEALTH SERVICE DELIVERY

TRADITIONAL OWNER-LED DEVELOPMENT

AGRICULTURE & FOOD

Field trial report: tropical rock oysters in the Pilbara

A.2.1819053 WA

Aisling Fontanini

Department of Primary Industries and Regional Development

CRCNA DEVELOPING NORTHERN AUSTRALIA

GOVERNMENT OF WESTERN AUSTRALIA

Department of Primary Industries and Regional Development

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Disclaimer

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Acronyms and Abbreviations

Ah	Ampere hour
ANOVA	Analysis of variance
BOLD	Barcode of Life Data System
cm	Centimetres
cm^2	Square centimetres
CO1	Cytochrome c oxidase subunit 1 mitochondrial gene
°C	Degrees Celsius
DNA	Deoxyribonucleic acid
DPIRD	Department of Primary Industries and Regional Development
FLUPSY	Floating upweller system
g	Grams
hr	Hour(s)
ID	Identification
L	Litres
NCBI	National Centre for Biotechnology Information (GenBank databases)
µm	Micron or micrometre
mL	Millilitre
mm	Millimetre
n	Sample size
ØD	Outer diameter
PCR	Polymerase chain reaction
qPCR	Quantitative polymerase chain reaction
rRNA	Ribosomal ribonucleic acid
SE	Standard error
T_0	Time zero or start of a trial
V	Volts
W	Watt
WA	Western Australia

Glossary

Biofouling	The unwanted growth and accumulation of biological fouling organisms such as barnacles, oysters, soft corals, sponges, algae, and other small plants and animals on permanently and intermittently submerged oyster farming gear such as vessels, anchors, moorings, baskets, posts, etc.
Bottom shell	Cupped shell of a rock oyster.
Breadth	Oyster shell width is the anteroposterior measurement along the axis perpendicular to the hinge to bill (or length) axis. This is sometimes also referred to as the width of the oyster shell.
Buoyant	Refers to oyster baskets with a floatation device of some kind attached. This allows the baskets to float and causes a rumbling action with incoming and outgoing tides at intertidal sites (see Figure 3 of this report).
Depth	Oyster shell depth is the measurement of the depth of the cup of the oyster shell from the top shell to the bottom shell.
Gear	Usually used in reference to the type and manufacturer of oyster basket, but also extends to farm equipment such as posts, anchors, lines, clips etc.
Grow-out	Reference to an oyster's time spent growing up to marketable size and shape on a farm. May also be used in reference to gear type.
Hatchery	Facility that produces shellfish seed/spat.
Height	Oyster shell height is the dorsoventral measurement from the hinge to the bill of the oyster. This is sometimes also referred to as the length of an oyster.
Intertidal	An intertidal farm sits within the high and low tidal mark for that area. Intertidal lines will be submerged and exposed with the incoming and outgoing tides exposing the farm to more extreme fluctuations in temperature, sun exposure, and salinity changes.
Length	Oyster shell length is the dorsoventral measurement from the hinge to the bill of the oyster. This is sometimes also referred to as the height of an oyster.
Nursery	Grow-out stage or farming systems (land- or ocean-based) that house and grow juvenile oysters.
Overcatch	Overcatch in an oyster farming context refers to other juvenile bivalves and crustaceans that attach to and grow on cultivated/farmed oysters. In northern WA, it is often rock oysters of the same species, barnacles and mussels that recruit onto the shells of farm stock and become a problem.
Rumble	To rumble or tumble oysters is a husbandry technique that promotes stronger and more favourable shell shapes. This is achieved by agitating oysters within a mechanical tumbler or basket on the farm which causes oyster shells to be chipped/damaged mildly. Better shell and abductor muscle strength are promoted through the repair process. Rumbling on the farm can be caused by high energy in the water from wind, waves and swell or from basket rotation (in a 180° arc) around the farm line with the incoming and outgoing tide for buoyant gear types.
Seed/spat	Juvenile shellfish. Definitions of actual size, however this report, the terms 'seed' and 'spat' are generally reserved to refer to oysters less than 10.0mm.
Static (gear)	Gear that is not buoyant and therefore does not experience a rumbling action at intertidal sites. May also be referred to as 'hanging' gear.
Subtidal	A subtidal farm is below the intertidal zone and always remains submerged.
Top shell	Flat shell of a rock oyster.
Tumble	See 'rumble' above.
Upweller	A nursery system where water and food particles are drawn up from underneath the oysters, across the permeable surface. This directional flow allows the spat to feed with the upwelling water current (Figure 11 of this report).
Width	Oyster shell width is the anteroposterior measurement along the axis perpendicular to the hinge to bill (or length) axis. This is sometimes also referred to as the breadth of the oyster shell.

Project participants

Department of Primary Industries & Regional Development

Maxima Rock Oyster Company Pty Ltd

Athair Aquaculture Pty Ltd

Murujuga Aboriginal Corporation

Hexcyl Systems Pty Ltd

Zapco Aquaculture[1]

SEAPA

[1] Zapco Aquaculture have recently rebranded to 'Submerge'. They are referred to throughout this report as Zapco.

Executive Summary

The WA tropical rock oyster research and development project investigated the aquaculture potential of two native (or endemic) rock oyster species, *Saccostrea* A and *Saccostrea echinata* by growing (wild and hatchery-reared) spat at several intertidal and subtidal sites in the Pilbara and Kimberley regions of WA. Initial stages of this project involved retrofitting a research hatchery in Perth with the goal to produce oyster spat and developing farm sites in northern WA in preparation to receive and grow-out these spat to determine their suitability as aquaculture candidates in a northern WA context.

Whilst the project started well in late 2019 with farm site development, it is important to note that the project outcomes were significantly impacted by several factors including the onset of the COVID-19 pandemic and associated regional travel restrictions and isolation protocols in place throughout WA until mid-2022, the departure of key personnel and project lead scientist prior to project completion and ongoing water quality issues in the hatchery that limited the supply of spat for field trials. Despite this, both *Saccostrea* A and *S.echinata* were able to be grown in the Pilbara for 17 and 21 months respectively and showed promise as aquaculture products. This report summarizes the key findings of the field growout trials of oysters.

A crucial objective to develop a sustainable tropical rock oyster industry in northern WA is securing a reliable supply of spat for farmers. To address this, the viability of both collecting wild and hatchery rearing spat of the two target species was explored. It was determined that relying on wild spat collection alone is unlikely to be feasible for growth of a tropical rock oyster industry in the Pilbara or Kimberley with target species being either absent from wild collection devices or mixed with unsuitable species. Hatchery spat will most likely be required to complement wild collections or fully supply commercial farm operations.

Recognizing the importance of hatchery spat and limited nursery capacity necessitated investigations into optimizing nursery culture systems and techniques that could reduce time and resources spent in land-based hatchery systems. Ocean-based nursery systems such a solar-powered floating upwellers, trays, and mesh inserts for Hexcyl and SEAPA oyster baskets were shown to be suitable alternatives to land-based nursery systems available at the time in growing *Saccostrea* A spat up to 5.0mm.

Despite being a smaller species at maturity, *Saccostrea* A oysters grew at the same rate as *S. echinata* during their deployment at Cossack intertidal site. Neither species reached the desired market size (>60 - 70mm) during their 17- and 22-month deployment at site under this project due to initial delays in spat supply. Meat weight and condition measurements at the conclusion of the field trials determined both species of tropical rock oysters were less conditioned than typical market size oysters of other species (e.g. Sydney and Pacific rock oysters). However, this was expected considering the oysters were not yet market size and likely reflect the regions seasonality, with measurements taken during the Pilbara's cooler months. Both the growth trajectory and condition results for *Saccostrea* A and *S. echinata* were encouraging, and commercial partner Maxima Rock Oyster Company Pty Ltd are continuing to grow these to test their marketability beyond these trials.

Saccostrea A oysters may require more 'work' to promote a favourable shell shape as they develop a narrow and shallow shell shape, compared to a deeper and rounder shell for *S. echinata*. Despite these differences, both species have a favourable width to height shell ratio greater than 45%. Static baskets were better to optimise growth metrics such as weight and shell length, however rumbling baskets improved shape, reduced overcatch and appeared to improve meat condition slightly, although conditioning trials should be repeated at more favourable times of the year.

Site selection and installation was a critical factor in optimising oyster growth and reducing both biofouling and overcatch on cultivated oysters. A subtidal Flipfarm at Withnell Bay became inoperable after excessive biofouling put excess stress on gear, whilst a subtidal site at Flying Foam Passage experienced few issues with fouling and oyster overcatch. When *Saccostrea* A oysters were grown at several sites for 13 – 17 months, oysters at Cossack intertidal site put on the most weight compared with those at Flying Foam Passage and West Lewis intertidal sites and the Withnell Bay Flipfarm site. Oysters on the subtidal farm at Flying Foam Passage put on less weight than those at Cossack intertidal site, however this wasn't statistically different. *Saccostrea* A oysters deployed at all sites put on weight during their deployment, however growth at Flying Foam Passage intertidal site was negligible.

Management of overcatch was incredibly challenging particularly at Cossack intertidal site. Overcatch was well established on oysters by the time they reached the 35mm size, accounting for as much as 49% of a cultivated oyster's weight in oysters that had never been rumbled in floating baskets. Some overcatch management strategies such as 'cooking' were trialled, however proved impractical for smaller cultivated oysters when overcatch appears to take hold. More work is required to understand how to minimise the prevalence of overcatch and biofouling while reducing the manual labour input required.

Project outline/Introduction

Sustainable oyster aquaculture is best based on locally adapted species. Previous research shows a range of endemic oyster species and strains occur across northern Australia and that several of these have aquaculture potential.

Northern Australia presents unique challenges to oyster production, and husbandry and management techniques will need to be adapted or developed to establish successful commercial operations in the region. This report outlines results from oyster grow-out trials at a range of intertidal and subtidal sites in the Pilbara and Kimberley in northern Australia. The trials evaluated a range of production practices and gear types on oyster growth rate, meat quality and shell shape throughout the oyster production cycle. Findings from the trials will support future commercial development of the industry in northern Australia.

Species

Tropical rock oyster farming is an emerging industry in northern Western Australia (WA). Recent efforts have been made to better understand the distribution and identity of rock oyster species in WA and determine their potential for aquaculture development. Four rock oyster species endemic to WA were identified at an industry development meeting in 2018; *Saccostrea* A, *Saccostrea echinata, Saccostrea scyphophilla,* and *Saccostrea glomerata* (Osborne, 2018). The geographic distribution and aquaculture potential of the four species was then assessed in a translocation risk assessment prepared for DPIRD (Snow, 2020).

A 2018 trial led by DPIRD grew batches of *S. scyphophilla* at sites in the South West, Mid-West, Gascoyne, and Pilbara regions of WA, but the species was ultimately found not suitable for commercial aquaculture development (Fontanini & Bermudes, 2020). While *S. glomerata* is grown commercially in southwest WA, it is an introduced species and there is limited access to wild populations and broodstock. This species has been detected as far north as Carnarvon in the Gascoyne region with one commercial nursery operating in the area but its grow-out potential in northern WA has not been assessed. Given the harsh climatic conditions in northern WA, it is likely *S. glomerata* may not flourish in the region without selective breeding and renewed genetic diversity. The Blacklip rock oyster (*S. echinata*) is currently farmed in areas of northern Australia (Northern Territory and Queensland), however wild populations are not widely distributed throughout WA, and they appear to be limited to the Kimberley region. *Saccostrea* A spat have been produced in the Albany Hatchery and on-grown in some small-scale trials following wild spat collection in the Mid-West region of WA.

This report outlines results of investigations into the endemic WA species *Saccostrea* A and *S. echinata* (Figure 1)*. Saccostrea* A is thought to be a unique lineage in WA and inhabits a range of environments from Shark Bay to the Broome Peninsula (Snow, 2020). Wild *Saccostrea* A vary in size depending on the environment they inhabit. Oysters collected from intertidal rock platforms at Back Beach, Karratha ranged in length from 28.1mm to 64.4mm (average = 42.9mm ± 0.44mm, n = 189). Wild populations of *S. echinata* were about twice as long with samples from the Northern Territory ranging in length from 56.3mm to 192.2mm (average = 105.3mm ± 2.1mm, n = 527) (Nowland, et al., 2019) and similar sized oysters were collected from Broome, Derby and Kalumburu in northern WA.

A note on nomenclature

It is widely accepted among industry and regulators that consensus is needed for common and scientific naming conventions in Australian rock oyster species. However, reaching such a consensus is difficult due to the complex taxonomic histories of rock oysters and the challenges involved in accurate identification.

For example, *Saccostrea echinata* has previously been known as both *Saccostrea* Lineage J (Snow, 2020) and non-mordax J (Sekino & Yamashita, 2016) while its registered common name is the Blacklip rock oyster (Standards Australia, 2021). In this report, the species is referred to as *S. echinata* throughout.

Saccostrea Lineage A has previously been known as non-mordax A (Sekino & Yamashita, 2016) and *S. cucullata* A (Lam & Morton, 2006). While it has colloquially been referred to as the coral rock oyster and less commonly the western blacklip rock oyster (WBRO), the species does not have a registered common name and overall has a confusing taxonomic history (see summary in Snow, 2020). Use of 'WBRO' for *Saccostrea* A is not encouraged given its similarity to the registered common name of *S. echinata*. Continued use of this terminology will only proliferate confusion in naming conventions of Australian rock oysters. In this report, the species is referred to as *Saccostrea* A throughout (following suggestion in Snow, 2020). Rock oyster identification tools and protocols have been described in a separate report.

Figure 1. Wild *Saccostrea* A oysters collected from Karratha in the Pilbara region of WA (top) and wild *S. echinata* oysters collected from Cone Bay in the Kimberley region of WA (bottom).

Sites and gear

Gear

Basket manufacturers, Hexcyl Systems Pty Ltd, SEAPA Pty Ltd, and Zapco Aquaculture participated in the project and supplied gear for the research (Figure 2). Hexcyl Systems supplied Hexcyl Pro baskets in several mesh sizes (3mm, 5mm, 10mm, 15mm, and 20mm), which were installed to hang from their Vexcyl lines. Hexcyl baskets were also used in the Flipfarm System which is described in more detail below. SEAPA supplied baskets that can be either 'hanging' or 'rumbling' following attachment of a SEAPA float case to the spine of the basket. SEAPA baskets in this project included mesh sizes of 6mm, 12mm and 20mm. Zapco Aquaculture supplied tumblers (with in-built floats) in 3mm and 8mm mesh.

Throughout this report gear types are referred to as a either float/floating/buoyant or as static/hanging/no float. Baskets fitted with a flotation device enable the baskets to rise with the incoming tide at intertidal sites, which effectively tips the basket upside down via a 180° arc around the farm line and 'rumbles' or 'tumbles' the oysters within (Figure 3). Baskets without a flotation mechanism (static/hanging/no float) will continue to hang from the line regardless of the water rising around them and the oysters within receive less movement and rumbling than those in a rumbling or floating basket. Hanging intertidal baskets are subject to movement from choppy water, however this is more of a shaking action than a rumbling action as they are not completely inverted.

There was no modification of baskets and gear used in any of the oyster growing trials described in this report.

Figure 2. Five types of baskets from manufacturers were used during the tropical rock oyster grow-out trials in the Pilbara, WA: a) Hexcyl baskets[1] from Hexcyl Systems Pty Ltd; b) SEAPA baskets[2] and c) SEAPA baskets fitted with float case from SEAPA Pty Ltd; d) Zapco grow out tumblers[3] from Zapco Aquaculture; and e) Flipfarm installation[4] which uses Hexcyl baskets attached to a backbone from Flipfarm Systems Pty Ltd.

[1] Images from: https://www.Hexcylsystems.com.au/images-oyster-baskets-shellfish-baskets-adjustable-long-line-inter-tidal-oyster-farming-shellfish-aquaculture.html
[2] Images from: https://seapa.com.au/oyster-baskets/
[3] Images from: https://www.Zapcoaquaculture.com/equipment/grow-out-tumblers
[4] Image from: https://www.globalseafood.org/advocate/innovation-award-2021-finalist-flipfarm/

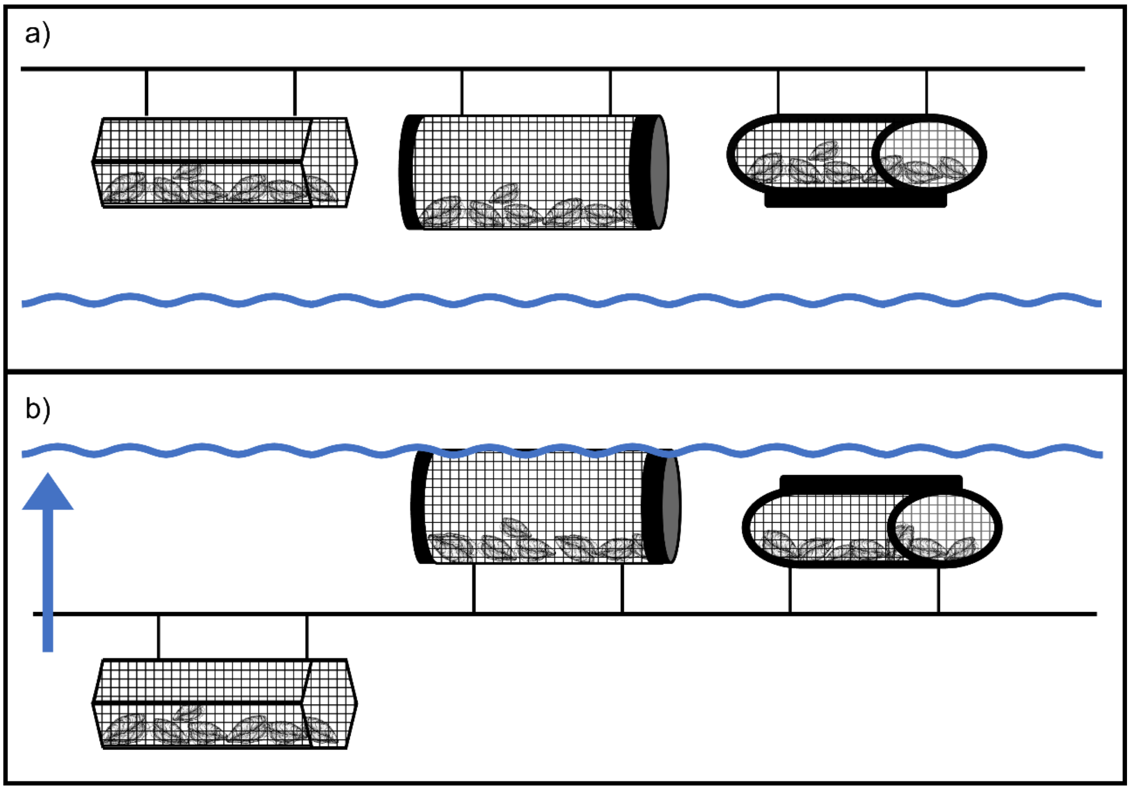

Figure 3. At intertidal sites, baskets can be fitted with floats along the spine of the basket (far right) or to the bases of the baskets (middle). a) Baskets emersed at low tide, hang from the gear line above the water level. b) As the tide rises, baskets are submerged and baskets with floats or buoyancy devices will rise with the water level to sit above the gear line.

Site setup

Cossack in the Pilbara is an intertidal site with several lines to accommodate Hexcyl, SEAPA and Zapco baskets (Figure 4). The Cossack intertidal lines are installed on a sandy embankment opposite Vampire Island in the tidal estuary of the Nullagine River. The baskets sit between 2.7 and 2.8m tidal height. At Flying Foam Passage, subtidal and intertidal lines are installed to accommodate single Hexcyl, Hexcyl ladders, and Zapco baskets (Figure 8). The West Lewis site is an intertidal trestle table farm that accommodates Hexcyl and SEAPA baskets (Figure 5), and Withnell Bay is a subtidal site where a Flipfarm system is installed (Figure 6).

The subtidal lines for the Flipfarm were installed in Withnell Bay in August 2020. A Flipfarm system does not represent a true subtidal site as baskets can be flipped or rotated so oysters are no longer submerged. The amount of time oysters remain submerged is at the discretion of the farmer. The baskets along the Flipfarm were initially rotated by hand (Figure 6b), making the site labour intensive and difficult to operate. To address the manual labour, a helix and return basket flipper, along with a shuttle hull were added to site operations in August 2021 making the site easier to operate (Figure 6c). The farm was operating well with oysters initially submerged for 8-10 days, and flipped to be emersed for 2-3 days, however this schedule gradually changed over time and was eventually 3-4 days submerged and 2-3 days out, reflecting a similar amount of time in the water as an intertidal site. The Flipfarm at Withnell Bay was eventually removed from the water in July 2022 due to excessive barnacle growth (biofouling) on baskets causing baskets to separate and place pressure along the backbone of the line. The excessive biofouling also prevented the baskets from fitting within the dimensions of the flipper (Figure 6c) with the pressure causing baskets to rip open from the backbone attachments (Figure 6d).

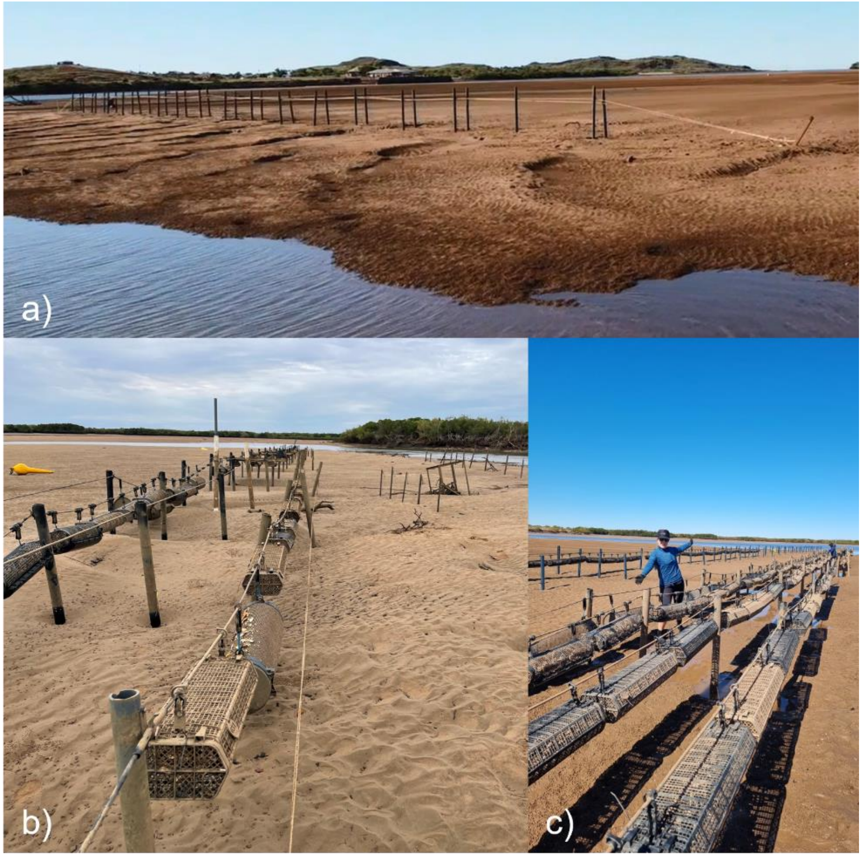

Figure 4. a) Initial long line installed at the Cossack intertidal site in 2020. b) Additional Hexcyl and new SEAPA and Zapco lines installed northeast of the original line in 2021. c) Continued farm expansion at Cossack during 2022.

Figure 5. Trestle table baskets at the West Lewis intertidal site.

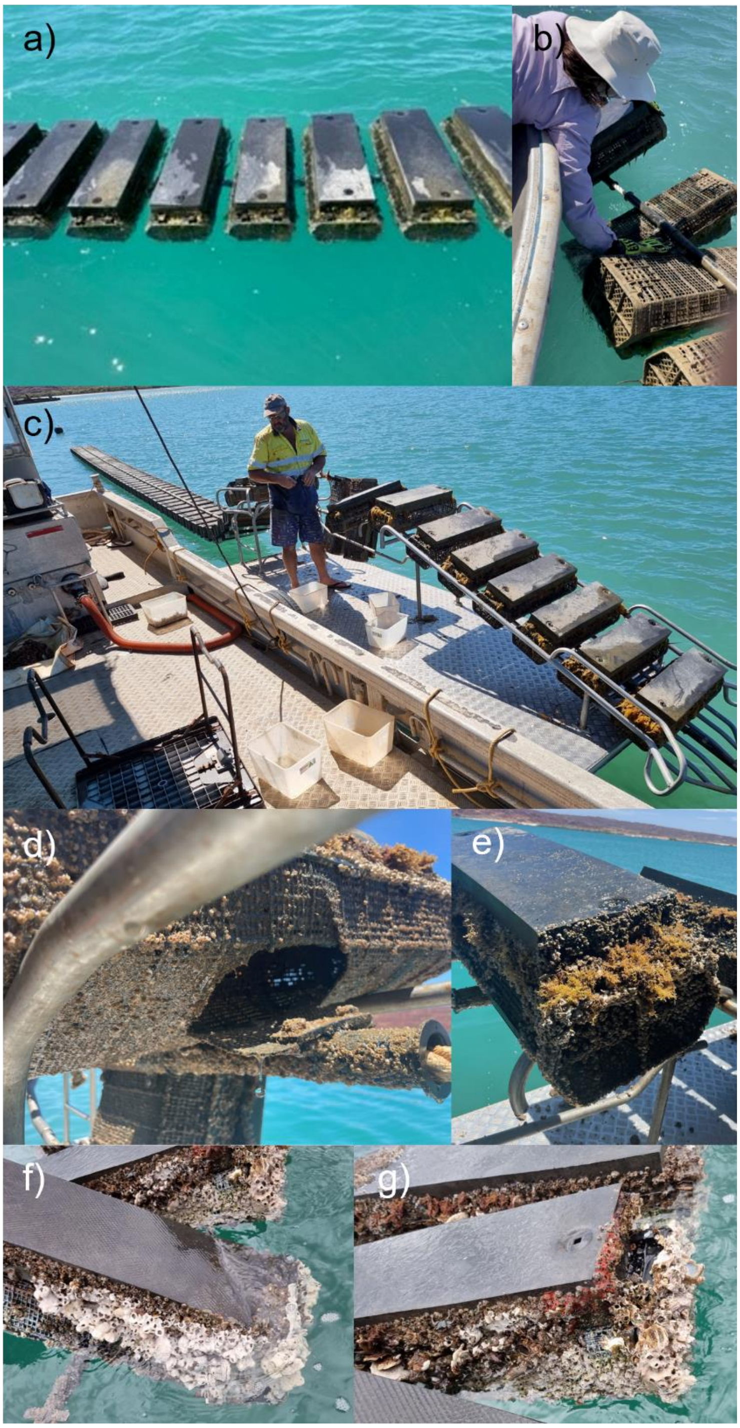

Figure 6. a) Hexcyl baskets with floats at the Flipfarm subtidal site at Withnell Bay, Karratha showing oysters submerged. b) Baskets were flipped manually by driving along the line and hanging over the side of the boat. Image shows baskets being flipped from submerged to emersed. c) A basket flipper was added to the site to remove the need to manually flip baskets. Image shows baskets coming up the flipper in a submerged configuration then being flipped to emersed. d) Damage to basket with fouling, which caused oysters to be lost. e) – g) biofouling on Flipfarm baskets.

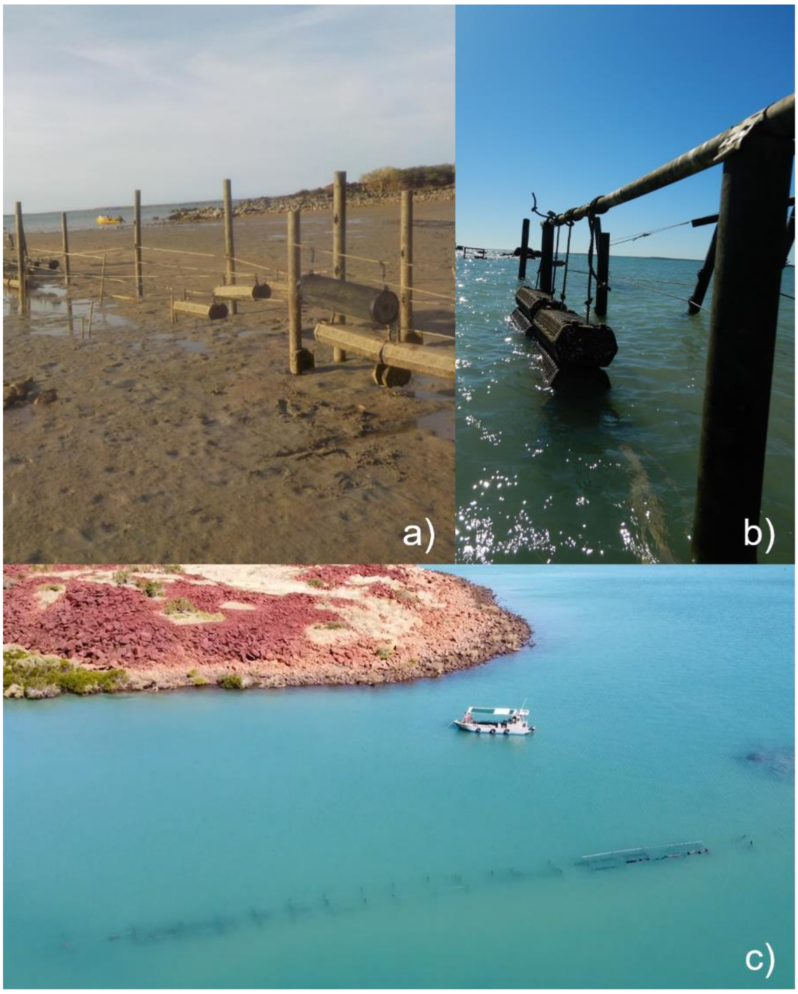

Figure 7. a) Oyster lines at Flying Foam Passage after cyclone damage in 2020. b) Oyster lines with Hexcyl ladders attached after repairs. c) Aerial shot of intertidal site at Flying Foam Passage completely submerged during high tide.

In 2020, several trial sites were also established in the Kimberley region of WA. An intertidal longline was installed at Snapper Cove (Figure 8b) and stocked with *S. echinata* spat in December 2020. However, upon returning to the site nine weeks later, two of the three baskets had been damaged by either predators or strong tides, resulting in the loss of oysters.

Maxima Rock Oyster Company Pty Ltd has a base at Cone Bay, however at the time of the trial it was not staffed permanently. With the onset of the COVID-19 pandemic and WA travel restrictions, this remote site became unserviceable. Limited availability of hatchery-spat also meant the site could not be restocked to resume trials. While growth data is limited for this site, *S. echinata* oysters reached 50mm within 14 months, which was encouraging (see Kimberley section of this report).

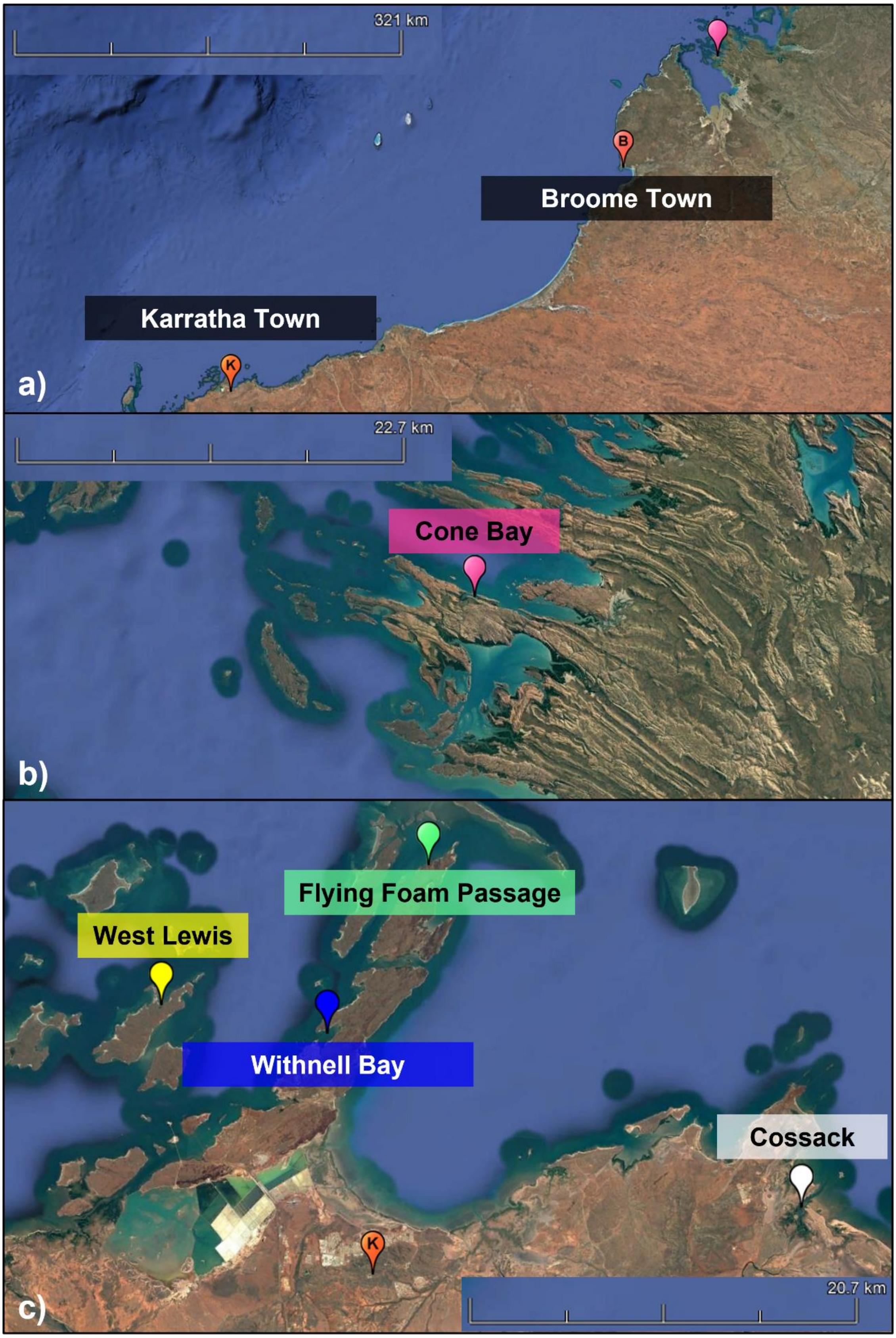

Figure 8. a) Location of trial oyster farm sites established in the Pilbara and Kimberley regions of Western Australia. b) Lines were installed at Cone Bay, 250km from Broome. c) Four sites were set up within 40km of Karratha in the Pilbara (West Lewis, Flying Foam Passage, Withnell Bay and Cossack).

Collection of wild spat for farming operations: bioprospection

Securing reliable supply of spat is vital to the sustainability of a tropical rock oyster industry in northern WA and was therefore a key objective of this project. Collection of wild rock oyster spat was attempted to determine if this was a viable and reliable means of securing and on-growing spat in the Pilbara and/or Kimberley regions.

Collecting wild oyster spat for transfer to grow-out farms forgoes the need for, and costs involved in, rearing spat in hatcheries. For example, commercial oyster operations in Queensland, Fiji, French Polynesia, Indonesia, Philippines and Papua New Guinea have successfully collected wild spat of *S. echinata* using spat collectors (Nowland et al., 2020).

S. echinata is clearly distinguishable from other oyster species using morphological characteristics alone, however *Saccostrea A* is more challenging to collect in the wild as it is difficult to distinguish visually from other rock oyster species. Without genetic testing, it is not possible to be 100% confident of the oyster species being collected.

Four spat collectors were deployed at sites of interest in northern WA (Table 1). Collectors were left in situ for several months to allow oyster larvae from nearby populations to settle and grow on the slats (Figure 9a), which were then stripped of wild spat and a random sample of oysters sent to Macquarie University for species identification (0-months). The remainder of the wild spat from the collectors were stocked in baskets and on-grown at either the Cossack intertidal site (Pilbara) or Hidden Harbour (Kimberley) for 16 to 22-months to determine how species composition changed over time under farming conditions.

Table 1. Location of four oyster spat collectors deployed in the Kimberley and Pilbara regions for bioprospecting.

Region	Site	GPS coordinates
Kimberley	Hidden Harbour	16°25'46.20"S 123°32'39.50"E
	Snapper Cove	16°30'23.40"S 123°32'47.50"E
Pilbara	Flying Foam Passage	20°26'33.9"S 116°51'40.1"E
	Cossack	20°41'09.6"S 117°11'12.5"E

Sample collection and analysis

Random samples of spat were taken from the baskets after 6–8 months and again at 16–22 months and sent to Macquarie University for species identification. Only oysters displaying the distinct grooves of the collection slats (Figure 9b) were included in species identification analyses to exclude the possibility that they were recruited into the baskets while on-farm, rather than from the spat collectors.

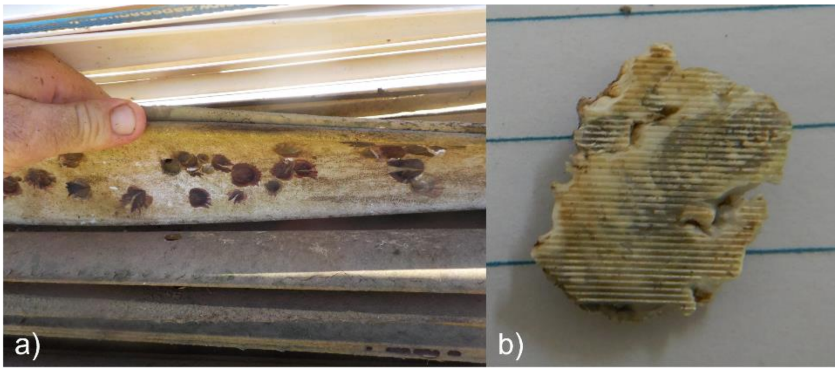

Figure 9. a) wild oysters on spat collector slats. b) distinct grooves on the bottom shell of wild collected spat indicated the spat had settled on collector slats rather than being recruited into baskets from the grow-out farm sites.

Specific identification was carried out at Macquarie University by PCR (16S mt DNA) and subsequent DNA sequencing. Identifications were based on 16S sequencing with a subset of samples also analysed at the COI gene (which supported classifications made via 16S sequences). Positive species-level identification was made based on 98% or greater sequence similarity. Sequences were used to interrogate the NCBI GenBank Database, as well as *S. glomerata, S. echinata,* and *Saccostrea* A samples which were submitted alongside wild spat for validation.

Feasibility of wild spat collection

Across the four research sites in the Kimberley and Pilbara, four distinct oyster lineages were identified. Three of these belonged to *Saccostrea cucullata (non-mordax)* species complex, representing lineages A, B and E. All other samples belonged to a lineage other than *Saccostrea*. Current molecular evidence suggests that these oysters belong to the genus *Talonostrea*, with the closest species match to *Talonostrea zhanjiangensis*.

In the Kimberley, *Talonostrea* sp. initially dominated the spat collectors at both sites, however they did not survive after 22 months in the farm environment. In contrast, *Saccostrea* B, and a small proportion (<20%) of *Saccostrea* E remained (Figure 10). No wild *S. echinata* were ever retrieved from wild spat collectors, which was the target species for the area. Only limited samples of wild *S. echinata* populations have been found around Broome, Derby and Kalumburu in the Kimberley with this species often inhabiting cryptic inshore environments and embayments (Snow, 2020) and it is not thought to have a widespread distribution in WA (Osborne, 2018). However, the absence of *S. echinata* oysters on the spat collectors was surprising, given the collector in Hidden Harbour was within 1km of known *S. echinata* populations and the collector in Snapper Cove within 8km. Collection of wild spat from the Kimberley collectors occurred in March 2020 during the monsoonal season when gonad index is known to be high in wild Northern Territory populations of *S. echinata* (Nowland et al., 2019). It is possible that the wild *S. echinata* populations were not spawning during the collection period or that this species was outcompeted by other species when it came to settling on the collector slats.

In contrast to the two Kimberley sites, species composition differed between the Cossack and Flying Foam Passage sites in the Pilbara. Wild spat collected at Cossack was initially dominated by *Talonostrea* sp however their dominance dwindled over time with *Saccostrea* A making up 25% of the surviving oysters after 16 months (Figure 10). More than 50% of wild spat collected at Flying Foam Passage were the target *Saccostrea* A lineage with the remainder from *Talonostrea* sp. *Saccostrea* A outperformed *Talonostrea* sp. in the farm environment over 16 months, however overall survival of wild spat was poor in the Pilbara (n_{FFP} = 17, $n_{Cossack}$ = 29). Pilbara spat collectors were deployed in the early summer of 2020, a timing that aligns with the conditioning and spawning window for wild rock oysters in this area (DPIRD [unpublished data], 2021-2022).

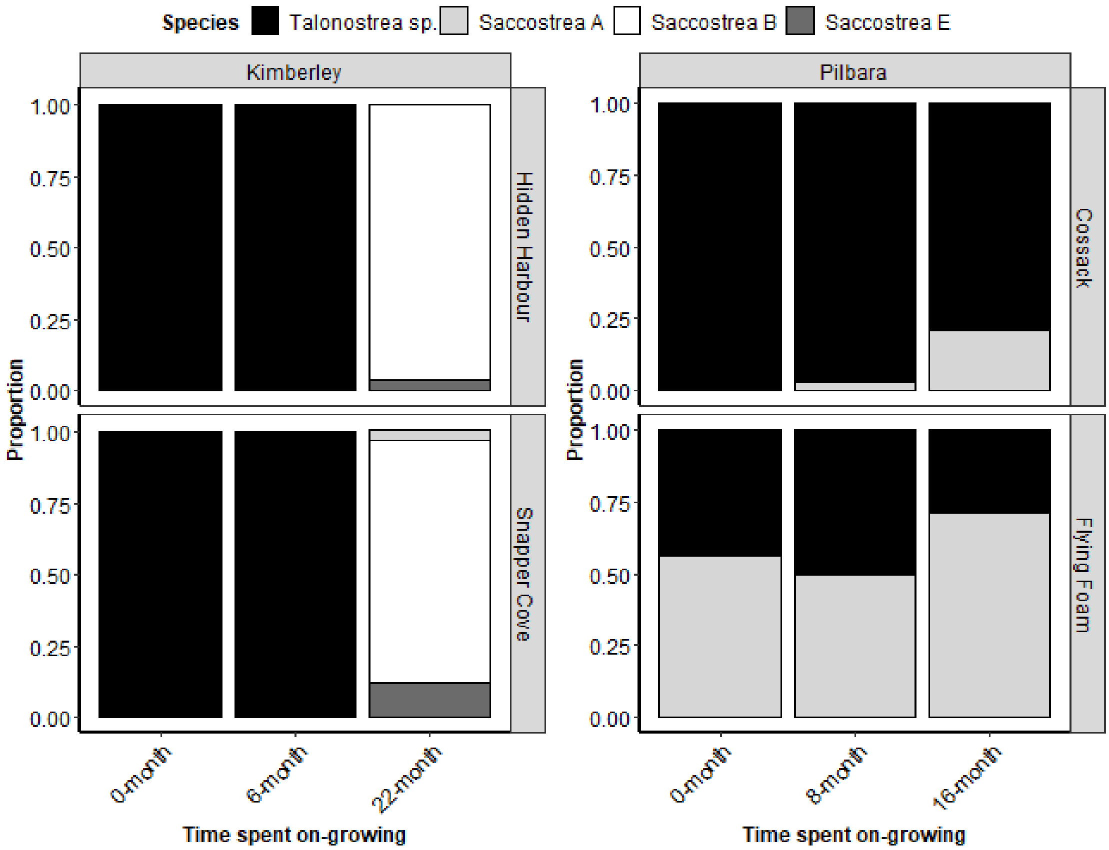

Figure 10. The proportion of wild oyster species on-grown at four sites in the Kimberley and Pilbara regions of Western Australia. Wild spat were collected and on-grown in baskets to determine which species survived in a farm environment over a period of 16 –22 months. Relying on wild spat alone is unlikely to be feasible for the development of tropical rock oysters in the Kimberley and Pilbara because seasonal variability limits spat supply to certain times of the year. In addition, recruitment of several non-

target species occurs alongside *Saccostrea* A and there is no morphological way to discriminate between these species.

The prevalence of *Talonostrea* sp. (colloquially referred to as the 'cats ear oyster') in wild-collected samples has also been noted in other Indo-Pacific regions. *T. zhanjiangensis* is a species that inhibits the wild collection of favoured oyster species intended for cultivation due to its niche competitiveness on collection devices (Wu et al., 2013). *T. zhanjiangensis* is a cupped oyster characterised by small body size and rapid post-settlement growth that slows significantly later in life with mass mortality (Wu et al., 2013). It is therefore not suited for cultivation. High initial colonisation of spat collectors by *Talonostrea* sp. followed by high mortality was also observed at the Kimberley (100% mortality) and Pilbara (>50% mortality) sites. The higher proportion of *Talonostrea* sp. remaining at the Pilbara sites could reflect more favourable environmental conditions for this species at high latitudes. The prevalence of *Talonostrea* sp. spat at collector locations was a significant hinderance to the successful collection of our target oyster species.

Target species were either absent (*S. echinata* in the Kimberley) or mixed with unsuitable species (*Saccostrea* A vs. *Talonostrea* sp. in the Pilbara). Relying on wild spat in commercial operations would therefore necessitate ongoing labour to grade out undesired species, which would prove challenging given there are no morphological distinctions between the desired and undesired species. As a result, a mixed species product would likely be sent to market. Wild spat supply will also be seasonal with interannual variations to be expected, and this could limit supply at certain times of the year and add risk to commercial operations. Relying on wild spat alone is therefore unlikely to be feasible for growth of tropical rock oysters in the Kimberley and Pilbara. It is likely hatchery-generated spat will be required to complement or fully supply commercial oyster farm operations.

Grow-out and field trials

Following failed attempts to recruit wild spat of the target species, work began on generating spat at DPIRD's shellfish hatcheries in Hillarys and Albany. *S.echinata* spat were generated at Hillarys Shellfish Hatchery in March 2020 from Cone Bay broodstock and then grown out in farm trials. Producing this species in the hatchery proved challenging and numbers were limited to less than 60,000 spat in total. For this reason, only field grow-out (no nursery) trials were undertaken with *S. echinata* spat. *Saccostrea* A spat were reared as larvae at the Albany Shellfish Hatchery in October 2020 before being set and grown to between 2.4 and 5mm at Hillarys Shellfish Hatchery. These were produced from a mix of Pilbara and Carnarvon broodstock and subsequently used in both nursery and field trials. All batches of spat were species identified and health certified through the DPIRD Diagnostic Laboratories before being transferred to the farm sites.

Optimising growth of nursery culture

Expanding shellfish aquaculture in WA will rely heavily on the availability of hatchery-reared spat. Commercial oyster hatcheries can produce hundreds of millions of settled spat (<1.0mm) however, the nursery phase to grow these oysters up to 5.0mm is challenging, requiring significant space, labour, and feed. As settled oysters grow, their demand for food increases and they need to be regularly graded and split across an increasing number of tanks, which increases their footprint in the hatchery. The production of live microalgae feed accounts for 30–60% of total production costs at hatcheries (Coutteau & Sorgeloos, 1992). In addition, competition for and availability of space can be challenging for hatcheries with limited capacity to expand.

For these reasons, hatcheries consider alternative methods of feeding and rearing spat to reduce costs and maintain production. One solution is to deploy small spat (typically sub-5.0mm) to ocean-based nurseries, where space is less limited, and food is naturally available in the water, negating the need for hatcheries to produce live feed. The disadvantages of ocean-based nurseries include exposing young oysters to predators and more variable environmental and feed conditions than they experience in a controlled hatchery environment.

In this research we compared the performance of a land-based nursery at the Hillarys Shellfish Hatchery with several ocean-based nursery systems to grow 2.4–3.3mm *Saccostrea* A spat to the standard basket deployment size of 5.0mm. If ocean-based nursery systems perform as well as land-based systems, spat can leave the hatchery much earlier, reducing production cost.

Land-based nursery

Nursery installations

An upweller is a nursery system where oyster spat sit on a mesh fitted at the bottom of a pot or basket that is submerged in water. Water and food particles are drawn up from underneath the oysters, across the mesh and this directional flow allows the spat to feed as well as have their excrement removed with the upwelling water current (Figure 11).

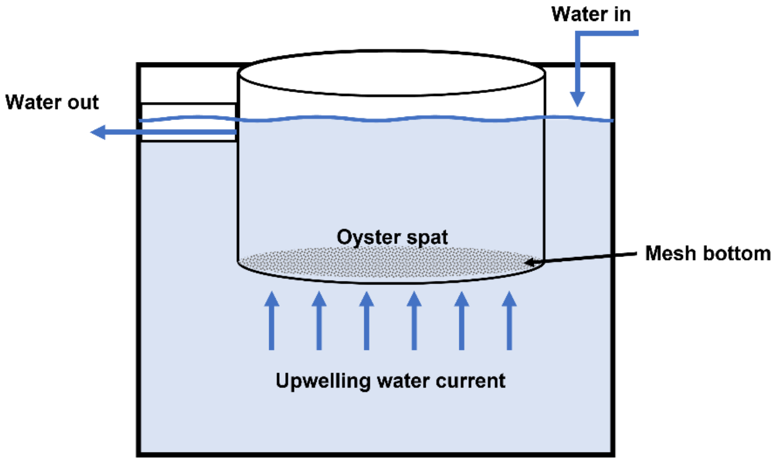

Figure 11. Diagram of an upweller oyster nursery where an upward water current is generated to pass through a layer of oyster spat bringing them food and helping to remove waste (adapted from AJ (2017)).

Saccostrea A spat (2.4–3.3mm) produced at Hillarys Shellfish Hatchery were held in 450mm (internal diameter) upweller pots with >600µm nylon mesh bases (~1,590cm^2). Upweller pots were stocked with between 130,000 – 180,000 spat (~80 – 115 spat/cm^2) depending on size. Up to three spat pots were suspended in a coffin tank with 24°C, 5µm filtered seawater recirculating through the bottom of the mesh and out through the outlet at the top of the pot (Figure 12). Water from the outlet was collected in a sump and pumped back into the coffin tank with a submersible pump to maintain the upwelling current across the surface of the spat. Complete water exchanges occurred three times per week. Spat were graded every two to three weeks and each tank was fed a daily diet of approximately 550L of live microalgae produced in a continuous culture system at Hillarys Shellfish Hatchery. The diet was predominantly a mix of *Chaetocerous muelleri*, *Tisochrysis lutea*, and *Diacronema lutheri* at an average concentration of 2.15 million cells of live algae per mL. The average concentration of residual cells of microalgae in the land-based nursery system was 22,400 ± 2,900 cells per mL.

Figure 12. *Saccostrea* A spat held in a land-based upweller nursery system at the DPIRD Hillarys Shellfish Hatchery.

Ocean-based nursery

Ocean-based nurseries, which follow on from the land-based nursery stage above, are a cost-effective means of growing seed to a size suitable for transfer on farms. Three types of ocean-based nursery systems were trialled to supply farm operations with seed of different sizes (see Appendix A for design specifications):

- Solar floating upwellers,
- Spat trays, and
- Mesh basket inserts.

Solar-powered Floating Upweller System

A Floating Upweller System (FLUPSY) is an ocean-based upwelling nursery that can be superior to land-based upwellers because it requires comparatively less power to operate. The pump used in a FLUPSY system to generate the upward current across the mesh bottom only needs to lift water a few millimetres, instead of the metres required in land-based systems. The other advantage of the FLUPSY system is that, with appropriate site selection, food is naturally available in the water and there is no requirement to produce or purchase feed for the spat.

A ’flat-pack’, solar-powered FLUPSY was designed and constructed by DPIRD for easy transport and operation in remote and regional areas for tropical rock oyster operations. Each solar FLUPSY unit cost about AU$3,500[5] to make and comprised the following components (Figure 13):

- High-density polyethylene buoyant floatation frame (Figure App A.1)
- 350W monocrystalline solar panel
- Four 350mm outer diameter (ØD) spat pots with a 600µm mesh bottom (705cm^2) (Figure App A.4)

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[5] Cost estimates based on purchases made in early 2021 (FY21).

- 4,600L/hr submersible pump
- Electronic 'brain' comprising a 135Ah 12V lithium battery, 20Ah lithium solar charger and other electronic control components (Figure App A.2) housed in a waterproof case (Figure App A.3).

The submersible pump sits in the centre of the FLUPSY unit and draws water through the outflow of the spat pots, creating an upward current across the oysters in the bottom of the pot (as shown in Figure 11). The pump is powered by the lithium battery, which is charged by a solar panel that sits on top of the buoyant frame. The bottom of the spat pots was reinforced with >1mm stainless steel mesh to provide structural strength and protect the more fragile 600µm nylon mesh. The outlets were also covered with mesh to prevent any spat being sucked out of the pot and into the pump reservoir in the event of turbulence.

Figure 13. Solar FLUPSY unit deployed at Kaiser Marina, Karratha WA.

Three solar FLUPSY units were installed at Kaiser Marina (20°40'12.67"S 116°41'43.32"E) and moored against the jetty. Each pot was stocked with between 8,250–77,750 *Saccostrea* A spat (2.4 to 3.3mm) depending on size (11–110 spat/cm^2). To preserve power, the water pumps were programmed to operate for 18hrs per day on a 45min on and 15min off cycle. Spat pots were removed from the frames and rinsed once a week due to the large amount of silt in the water and limited natural water movement (other than tides) at this site.

Spat trays

Spat trays were constructed from H6 treated pine timber and oyster mesh (see dimensions in Figure App A.5). Each unit had six compartments encased within 1.5mm oyster mesh (top and bottom) and were screwed shut with stainless steel screws to prevent loss of spat. Trays had oyster line clips fastened to the top of each corner of the frame and either side of the middle of the tray. Each end and the middle section of the tray clipped onto one of three parallel longlines at the Cossack intertidal site. The trays hung from the lines, parallel to the seabed (effectively like oyster baskets).

To avoid spat spill-over when opening the trays only three compartments from each tray were filled with spat (adjacent compartments remained empty) (Figure 14). However, under commercial farm conditions every compartment could be filled with spat. Compartments were stocked with between

1,000–5,000 3.3mm *Saccostrea* A spat (0.6 –3.3 spat/cm^2). Stocking densities in spat trays are low compared to densities in the solar FLUPSY pots and basket inserts as there is little vertical leeway in this nursery design (i.e. spat stacking on top of each other).

Figure 14. *Saccostrea* A spat in a tray compartment at the Cossack intertidal site showing some spat spillage into adjacent compartments upon opening.

Basket inserts

Several basket manufacturers offer mesh inserts or 'socks', which are designed to fit within existing baskets to reduce the basket mesh size. Mesh inserts were used in the subtidal Flipfarm system at Whitnell Bay (1.4mm Hexcyl mesh inserts), and 1.6mm mesh SEAPA spat socks (Figure 15) were used at the Cossack intertidal site. Hexcyl mesh inserts were stocked with between 12,200–25,600 *Saccostrea* A spat (2.4–3.3mm grade) and deployed to the Flipfarm subtidal site at Withnell Bay (6–13 spat/cm^2). Between 10,000–14,000 3.3mm spat were deployed to the Cossack intertidal site in SEAPA spat inserts (7–10 spat/cm^2).

Figure 15. SEAPA spat sock inserts fit inside baskets to hold spat <5mm.

Results

Ocean-based nursery systems resulted in superior growth of *Saccostrea* A spat compared to land-based nursery culture with more ocean-based spat reaching 5.0mm, regardless of density, over a two-month period. Spat growth did not differ between stocking density treatments in the trays and basket inserts. However, lower densities in the solar FLUPSY units produced a greater proportion of 5.0mm spat than higher densities.

The land-based nursery at Hillarys Shellfish Hatchery was restricted by large numbers of stock (high density), the need to produce high volumes of live microalgae feed, and a small nursery footprint with limited capacity to expand. Only 15.3% of spat reached a 5.0mm grade within two months under these conditions. Despite the hatchery upweller environment producing the lowest proportion of 5.0mm spat, due to the high densities used, the land-based hatchery was still responsible for the second highest total numbers of 5.0mm spat (Table 2). A total of 145,900 5.0mm *Saccostrea* A spat were produced from six pots in the hatchery during this period. While this is encouraging, the hatchery upweller system had limited capacity to expand and therefore these numbers can be considered close to the maximum that the hatchery could produce without significant investment in expansion. Comparatively, stocking 2.4mm spat into one FLUPSY unit (i.e., four pots) at the highest density of 110 spat/cm^2 (or 78,000 spat/pot), would produce ~130,000 spat over the same time.

Water temperatures were 1°C warmer for ocean-based nursery systems with an average sea surface temperature of 25.2°C ± 0.11°C compared to 24.3°C ± 0.19°C for the land-based system at the hatchery. Whilst warmer conditions for the ocean-based nursery systems would have promoted better growth, it would not have accounted for the differences seen here and the cost of heating water at the Hillarys Shellfish Hatchery is another ongoing cost and limitation to consider.

Oysters in basket inserts at the Withnell Bay subtidal site reached 5.0mm faster than those in inserts at the Cossack intertidal site. This is unsurprising as subtidal spat have more time to feed while submerged. However, as mentioned earlier, the Flipfarm was operated on a near 50/50 submerged/emersed cycle towards the end of the project, making it more similar to an intertidal site than a true subtidal site in other areas. The difference in total number of spat that reached 5.0mm between the two sites was between 2,500–3,300. This is not a large difference and when considering that the intertidal site at Cossack could be accessed more readily and easily than the Withnell Bay subtidal Flipfarm, operating and labour input requirements would be an important consideration when deciding which ocean-based nursery system to go with.

The intertidal tray units had the lowest stocking densities of the trial with all densities resulting in >98% of the spat reaching 5.0mm in two months. Therefore, all spat compartments should be stocked with at least 5,000 oysters (30,000 per unit) to maximise the total number of spat making the required grade for transfer to farm baskets. Interestingly, this makes a tray comparable to the SEAPA sock inserts also used at the Cossack intertidal site. A tray unit occupied the space of three baskets on the farms longlines at Cossack. Mesh inserts in SEAPA baskets stocked with 14,000 *Saccostrea* A spat saw 81% of stock reach 5.0mm. This is equivalent to more than 11,000 spat/basket, or 33,000 spat across three baskets. Whilst Cossack farm site had three lines available for spat trays, many intertidal sites use quad lines, which would allow for four baskets and therefore 44,000 spat. In this trial, trays and SEAPA inserts were comparable ocean-based nursery solutions, however if working with quad lines basket inserts would be preferred to maximise spat numbers. The trays, however, result in an even spat size (above 5mm) which does not require further grading before going into the next stage of grow-out in 3mm baskets.

Basket inserts and trays could be used on established farms as they require farm lines to be installed. Therefore, little extra labour and capital effort would be needed to implement an ocean-based nursery on a pre-existing farm site. Higher stocking densities during early grow-out require less baskets than larger, older oysters and therefore oyster seed for nursery grow-out would be responsible for the smallest footprint on a farm lease. As farms begin to operate at scale additional lines may be needed to accommodate the nursery systems as well as the larger oysters. However, depending on the size of spat intake, nursery space on the farm is expected to be around 5% of the total farm capacity.

Table 2. Comparison of land- and ocean-based nursery systems producing 5.0mm *Saccostrea* A spat within two months. The land-based nursery system produced the greatest number of 5.0mm spat, however this was due to a high stocking density. The proportion of original 2.4–3.3mm spat reaching 5.0mm (% 5.0mm spat) was lowest for the land-based system and all ocean-based nursery systems out-performed the land-based system in terms of proportion of original spat numbers reaching 5.0mm.

Nursery	Stock starting size	Type	Stocking density (spat/cm^2)	Equivalent # spat per pot	Average % of 5.0mm spat	# of new 5.0mm spat
Land	2.4–3.3mm	Hatchery upweller pots	80 – 115	130,000 – 180,000	15%	27,000
Ocean	2.4mm	Solar FLUPSY pot	28	19,500	87%	16,985
			110	77,750	42%	32,934
		Subtidal basket inserts	13	25,500	87%	22,354
			9	18,000	88%	15,789
	3.3mm	Subtidal basket inserts	9	17,000	86%	14,651
			6	12,250	90%	11,035

		Intertidal basket inserts	10	14,000	81%	11,354
			7	10,000	85%	8,473
		Intertidal tray compartments	3.3	5,000	99%	4,941
			0.67	1,000	98%	984
		Solar FLUPSY	47	33,000	55%	18,133
			12	8,250	96%	7,945

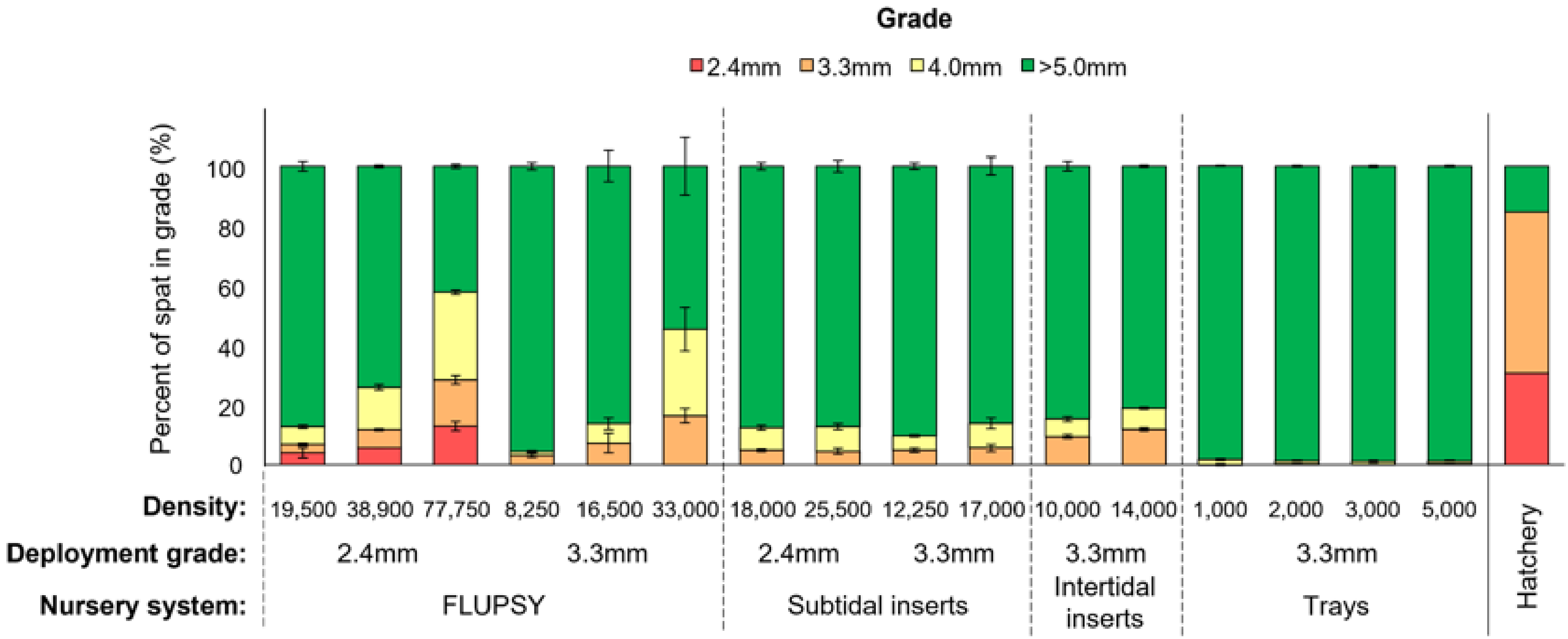

Figure 16. Grade distribution as a percentage of total stock (± SE) of ocean-based nursery *Saccostrea* A spat after two months at their respective field sites (more information in Table 2). *Saccostrea* A spat reared at the Hillarys land-based nursery over the same period have been included for reference. All ocean-based nursery systems out-performed the land-based system in terms of proportion of original spat numbers reaching 5.0mm.
N.B. 4.0 x 4.0mm grading screen was not used in the land-based hatchery.

Pilbara grow-out

Trial methods

Field trials in the Pilbara consisted of six sequential experiments using both *Saccostrea* A and *S. echinata*. Field measurements were done at different intervals throughout deployment due to COVID-19 travel restrictions and weather disruptions. The stocking of field trials was limited by availability of hatchery-reared spat. The total weight of oysters in each basket was measured with kitchen scales (1g readability) with average oyster weight calculated from this measure and basket density. All shell dimension measurements were done using vernier callipers (0.1mm readability).

Experiment 1: 5-8mm density trial

Oysters were graded on a 5 x 5mm nylon screen at Hillarys Shellfish Hatchery. Larger oysters that remained on the 5mm screen (generally >7mm width) were homogenised and divided into different basket stocking densities for Experiment 1 (Table 3). The total weight of the oysters in each basket was determined at the start of the trial (T_0) and oysters were then deployed to the Cossack intertidal site in 3mm hanging Hexcyl baskets. The total weight of the oysters in each basket was measured at several time intervals until the oysters had grown to the next size class (8mm).

Table 3. Pilbara Experiment 1: density of oysters per Hexcyl basket.

Saccostrea A	*S. echinata*	*S. echinata*
1,000	-	-
1,250	1,200	1,250
2,125	-	1,800
2,500	2,400	-
4,000	-	-

Experiment 2: 8-16mm density trial

Following Experiment 1, all oysters of the same species were combined and graded on an 8 x 8mm mesh grading screen stacked underneath a 12 x 12mm stainless steel mesh. Larger oysters that fell through the 12mm screen but remained on the 8mm screen (generally with a width of at least 11mm, but not greater than 17mm) were homogenised and used as stock for Experiment 2. Basket stocking densities for the trial are shown in Table 4. Total weight of oysters in each basket was measured at the start of the trial (T_0) and oysters were re-deployed to Cossack intertidal site in 5mm hanging Hexcyl baskets. The total weight of the oysters in each basket was measured several times until the oysters had grown to the next size class (16mm).

Table 4. Pilbara Experiment 2: density of oysters per Hexcyl basket.

Saccostrea A	*S. echinata*
600	600
1,200	1,200
1,800	-
2,400	-

Experiment 3: 16-22mm density trial

Following Experiment 2, all oysters from the trial were combined and graded on 16 x 16mm stainless steel mesh to obtain the 16mm grade oysters (~22mm width), which were then split into the basket stocking densities outlined in Table 5. Initial (T_0) weight of the oysters was measured before the oysters were re-deployed to Cossack intertidal site in 10mm hanging Hexcyl baskets. The total weight of the oysters in each basket was measured several times until they had grown to the next size class (22mm).

Table 5. Pilbara Experiment 3: density of oysters per Hexcyl basket.

***Saccostrea* A**	***S. echinata***
300	300
500	500
700	700
900	900

Experiment 4: 22mm gear trial

Oyster aquaculture has traditionally focussed on optimising the quality of the meat. However, over the past few decades, the importance of shell appearance in producing a palatable and marketable oyster has become increasingly important (Mizuta & Wikfors, 2019; Yuan et al., 2023). Optimal shell appearance varies across species and countries however in Australia, the most common standard is a height, width, depth ratio of 3:2:1 (Brake et al., 2003; Mizuta & Wikfors, 2019; Ryan, 2008). An extension of this ratio considers the shape score of each oyster, which is a metric used to indicate whether an oyster is deep and wide (small score) or narrow and flat (large score). The shape score is calculated as the ratio of oyster height to width against oyster depth to length (Rankin et al., 2018):

$$\text{Shape score} = \frac{\frac{\text{Height (mm)}}{\text{Width (mm)}}}{\frac{\text{Depth (mm)}}{\text{Height (mm)}}}$$

All trial *Saccostrea* A oysters were grown in hanging intertidal baskets and then sorted into a 22mm size class. Most *S. echinata* oysters were also grown in hanging intertidal baskets at Cossack, except for several baskets that had been deployed to the Flipfarm at Withnell Bay five months prior. Oysters within the 22mm grade were homogenised and a T_0 sample of oyster dimensions (height, width and depth) taken with vernier callipers. Oysters were then stocked into one of five gear types (Table 6). Basket densities differed slightly between gear types as they were standardised by the linear length of each basket type. Zapco tumblers were the largest (x 1.00), followed by Hexcyl (x 0.93) and SEAPA (x 0.78). All gear type held the same number of oysters per meter of basket on the farm. Total oyster weight per basket was measured, and baskets deployed to the Cossack intertidal site and Withnell Bay Flipfarm. Total oyster weight and shell dimensions of 25 oysters were determined for each basket every 4–8 weeks depending on site accessibility. Oyster baskets from the Cossack intertidal site were removed from the farm and processed at the operational base and returned to the farm the next day while oysters at Withnell Bay were processed out on the water as this subtidal site was more challenging to access and service.

Table 6. Pilbara Experiment 4: species, densities (oysters/basket), stock origin and gear type of basket deployments (22mm grade).

<table>
<tr><th>Species</th><th>Site</th><th>Gear</th><th>Buoyant</th><th>Density</th><th>Stock Origin</th></tr>
<tr><td rowspan="5">S. echinata</td><td>Withnell Bay</td><td>Flipfarm</td><td>-</td><td>175</td><td>5 months in tumbling baskets</td></tr>
<tr><td rowspan="4">Cossack</td><td>Hanging SEAPA</td><td rowspan="2">No</td><td>310</td><td rowspan="4">9 months in intertidal hanging baskets</td></tr>
<tr><td>Hanging Hexcyl</td><td>365</td></tr>
<tr><td>Tumbling SEAPA</td><td rowspan="2">Yes</td><td>310</td></tr>
<tr><td>Zapco tumbler</td><td>400</td></tr>
<tr><td rowspan="5">Saccostrea A.</td><td>Withnell Bay</td><td>Flipfarm</td><td>-</td><td>153</td><td rowspan="5">10 months in intertidal hanging baskets</td></tr>
<tr><td rowspan="4">Cossack</td><td>Hanging Hexcyl</td><td rowspan="2">No</td><td>153</td></tr>
<tr><td>Hanging SEAPA</td><td rowspan="2">131</td></tr>
<tr><td>Tumbling SEAPA</td><td rowspan="2">Yes</td></tr>
<tr><td>Zapco tumbler</td><td>164</td></tr>
</table>

Experiment 5: 35mm gear trial

As the cultivated oysters in these trials reached the 35mm size class (~14 months at site for both species), unmanaged overcatch was becoming a significant issue. Due to limited time on site, it was not feasible to manually remove overcatch from all the oysters within the timeframe of the project and therefore a primary focus of these gear trials was to compare how gear type and prior husbandry impacted growth and establishment of overcatch on these oysters. It was clear by this stage that overcatch management strategies should be employed earlier in the growth cycle, however a lack of consistent spat supply to site meant this could not be investigated further during this project (discussed below in Further Research). The dimensions and growth metrics discussed here are therefore overstated as the presence of overcatch often hindered the ability to make accurate measurements of the cultivated oyster. Estimates of the impact of overcatch are discussed below in the Overcatch section.

Cultivated oysters were sorted into a 35mm size class and weights and dimensions taken as outlined in Experiment 4. Stocking densities were reduced for the larger oysters, however the standardised ratio between baskets remained the same. Most *S. echinata* oysters used in this trial had been grown in hanging intertidal baskets at the Cossack site for the previous 14 months. However, some baskets were stocked with oysters that had spent the previous five months in buoyant baskets at the Cossack site to determine if time in buoyant baskets would impact shell shape and oyster weight. More gear and stock combinations could be trialled with *Saccostrea* A stock than *S. echinata* stock as there was more rumbled *Saccostrea* A stock available. *Saccostrea* A oysters came from one of three stock origins at the Cossack intertidal site: previous 14 months in hanging baskets, or previous four months in a buoyant basket (floating SEAPA or Zapco tumbler). A summary of the stock origin, gear type and stocking densities are shown in Table 7. Oyster baskets from the Cossack intertidal site were removed from the farm and processed at the operational base while oysters at Withnell Bay were processed on farm as the site was not as accessible.

No 35mm *Saccostrea* A oysters were trialled using the Flipfarm gear at Withnell Bay as the site was decommissioned in May 2022 due to excessive overcatch and barnacle fouling making the site inoperable (Figure 6d – 4g).

Table 7. Pilbara Experiment 5: species, densities (oysters/basket), stock origin and gear type of basket deployments (35mm grade).

Species	Site	Gear	Buoyant	Density	Stock origin
S. echinata	Withnell Bay	Flipfarm	-	112	14 months in intertidal hanging baskets
	Cossack	Hanging Hexcyl	No	112	
		Zapco tumbler	Yes	123	
		Hanging SEAPA	No	95	
				112	
		Floating SEAPA	Yes	95	
				112	5 months in intertidal tumbling baskets (SEAPA)
Saccostrea A.	Cossack	Hanging Hexcyl	No	98	14 months in intertidal hanging baskets
				135	4 months in intertidal tumbling baskets (SEAPA)
				117	4 months in intertidal tumbling baskets (Zapco)
		Floating SEAPA	Yes	81	14 months in intertidal hanging baskets
				104	4 months in intertidal tumbling baskets (SEAPA)
		Zapco tumbler	Yes	105	14 months in intertidal hanging baskets
				117	4 months in intertidal tumbling baskets (Zapco)

Experiment 6: Finishing trials

The final field trial compared the condition of the largest oysters in each species (>35-45mm shell height). To determine the impact of husbandry techniques on oyster condition, oysters were transferred between gear types and deployed to either the Cossack or Flying Foam Passage intertidal sites at one of two densities (Table 8). Low density treatments represented half of the high-density treatments. The total weight of oysters in each basket, dimensions of oyster shells (n = 100) and weight of meat and shell (n = 25) were measured from a sub-sample at the time of deployment. Total weight and shell dimensions were measured again during deployment and finally the total whole weight of baskets, shell dimensions (n = 25), and meat and shell weight (n = 20, readability 0.01g) were determined at the conclusion of the trial. At this time, a sample of oysters from each basket (n = 10) also had their overcatch removed and weighed to estimate the amount of fouling on shells under different husbandry treatments. These results are discussed further in the 'Overcatch' section below. Meat condition was calculated as the proportion of visceral (meat) mass to whole shell weight as per previous studies (Rankin et al., 2018).

No *Saccostrea* A stock at Flying Foam Passage could be recovered for condition or shape assessment at the end of the trial. All information about conditioning and meat to shell ratio for *Saccostrea* A is therefore taken from Cossack.

Table 8. Pilbara Experiment 5: species, densities (oysters/basket), stock origin and gear type of basket deployments (>35mm grade).

Species	Site	Gear	Buoyant	Density	Stock Origin
S. echinata	Flying Foam Passage	Hanging SEAPA	No	60	18 months in intertidal hanging baskets
				30	
				60	9 months in intertidal tumbling baskets (SEAPA)
				30	
		Floating SEAPA	Yes	60	
				30	
	Cossack	Hanging SEAPA	No	60	18 months in intertidal hanging baskets
				30	
				60	9 months in intertidal tumbling baskets (SEAPA)
				30	
		Floating SEAPA	Yes	60	
				30	
Saccostrea A.	Cossack	Hanging Hexcyl	No	150	14 months in intertidal hanging baskets
				75	
				150	4 months in intertidal tumbling baskets (SEAPA)
				100	
				75	
		Floating SEAPA	Yes	100	
				50	
				80	14 months in intertidal hanging baskets
				40	

Species comparison

Hanging baskets at Cossack intertidal site

Most data collected during the field trials came from the Cossack intertidal site. Cossack had several operational advantages including being close to infrastructure and amenities (e.g., boat ramp). It was also easily accessed, the farm site being only a short boat ride away. This meant it could be checked and serviced more frequently than other sites that were more challenging to operate (subtidal sites and sites that were further afield). Cossack intertidal site also produced the highest growth rates, allowing differences to be detected between treatments sooner.

The following sections outline the results from hanging baskets deployed at the Cossack intertidal site during the field trials mentioned above (see Trial methods). These treatments allowed the most direct comparison between the two target rock oyster species over time.

Species weight comparison – project duration

S. echinata was first deployed to the intertidal farm at the Cossack site in hanging baskets in November 2020. *Saccostrea* A was deployed to the farm five months later in March 2021. Despite being a smaller species at maturity, *Saccostrea* A oysters grew at the same rate (on average) as *S. echinata* during the 17–21 months on the farm (Figure 17). After 17 months at the site, *Saccostrea* A had achieved an average weight per oyster of 25.1g ± 0.6g and *S. echinata* had achieved an average weight of 26.0g ± 0.1g. Growth rates increased for both species during warmer months. For *S. echinata*, the highest growth rate occurred between 99 and 216 days at site and corresponded with an average water temperature of 29.6°C ± 0.1°C. *Saccostrea* A experienced an average water temperature of 23.3°C ± 0.1°C during the deployment period, which coincided with the cool season. Between days 348 and 416 *Saccostrea* A achieved a higher growth rate than *S. echinata*, which corresponded with an average difference in water temperature of 4.1°C (29.4°C ± 0.3°C for *Saccostrea* A vs. 25.3°C ± 0.2°C for *S. echinata*).

To put these growth rates in a broader context, Sydney rock oysters (*S. glomerata*) typically go to market (plate grade) at 50–60g whole weight per oyster, which can take 3.5 years for wild-collected spat. However, following a selective breeding program, hatchery-reared *S. glomerata* spat reach this size 11 months earlier (Nell, 2005)[1]. Neither *S. echinata* nor *Saccostrea* A rock oysters achieved an average weight per oyster of 50g within the duration of this project, which was 2.4 and 1.9 years (1.8 and 1.4 years in the field once deployed from the hatchery) for each species respectively. However, if the same growth rates were maintained and husbandry techniques (in both the nursery and field grow-out stages) are optimised, each species would be on track to achieve a similar size within 3.5 years, if not sooner. The growth of each tropical rock oyster species will continue to be monitored at site by commercial partner Maxima Rock Oyster Company.

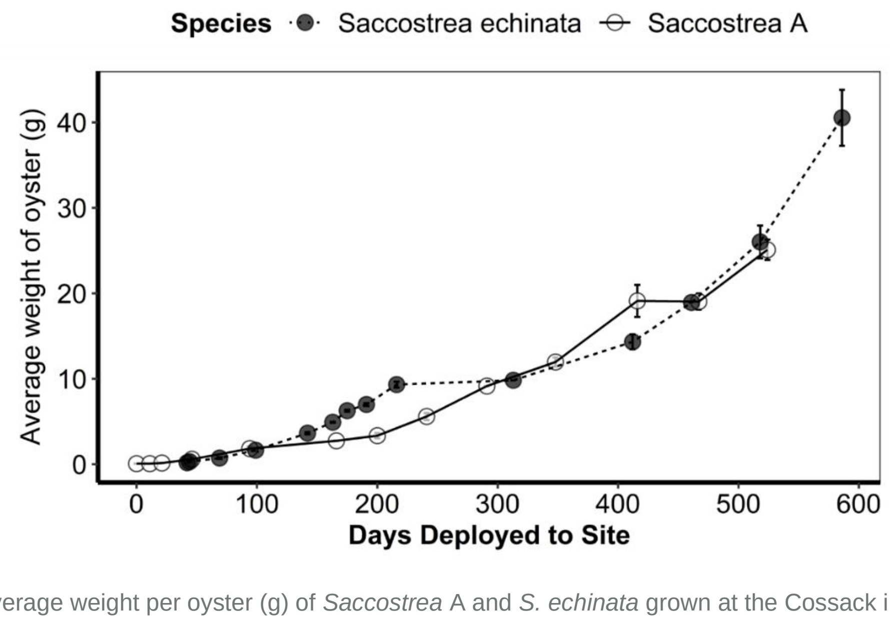

Figure 17. Average weight per oyster (g) of *Saccostrea* A and *S. echinata* grown at the Cossack intertidal site in hanging baskets was similar over their respective 586 and 524 deployment periods, despite being received on site four to five months apart. Weights per oyster have been averaged across all densities and grades with 95% confidence intervals shown.

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[1] Tropical rock oysters in WA have not yet benefited from a selective breeding program to improve growth rates of hatchery-bred stock. The oysters in this research project are first generation from wild populations.

N.B. Data from the *Saccostrea* A 8mm grade trial has been omitted as this trial was a secondary deployment of the same batch that remained under hatchery conditions for an additional 242 days.

Shell height and shape project duration

Oyster height (or length), width and depth were measured for field trials four to six, and a shape score calculated from these measurements (described in Experiment 4: 22mm gear trial). Before reaching a 22mm grade, oysters were graded over nylon and stainless mesh screens and placed into size categories or grades. To calculate oyster growth on the farm, height was estimated (as opposed to measured) for some grades. The height estimate is based on a height to width ratio of 3:2 and the date that oysters were graded. For example, to be retained on a 5.0mm square grading screen, oysters would need to be at least 7.1mm wide. Using the 3:2 ratio assumes these oysters have a minimum oyster height of ~10.6mm.

The average height of *Saccostrea* A and *S. echinata* oysters farmed in hanging baskets at Cossack intertidal site was 57.4mm ± 1.3mm and 59.2mm ± 1.0mm at the conclusion of the farm trials (524 and 694 days at site respectively, Figure 18). These shell heights were just shy of several recommended market sizes for mid-range Australian Sydney and Pacific rock oysters (Table 9). However, measurement of shell height in this research reflects the distance from hinge to the edge of the bottom shell, which is greater than the heights in Table 9, which show the length of the top shell only. Therefore, 23-month-old[2] *Saccostrea* A oysters could likely have been compared to a cocktail-sized Sydney rock oyster by the end of this trial. However, 29-month-old[2] *S. echinata* were still too small to be considered marketable as they are typically marketed as a larger oyster. It is recommended both species continue to be grown and the marketability of both species be investigated to determine their optimum sizes.

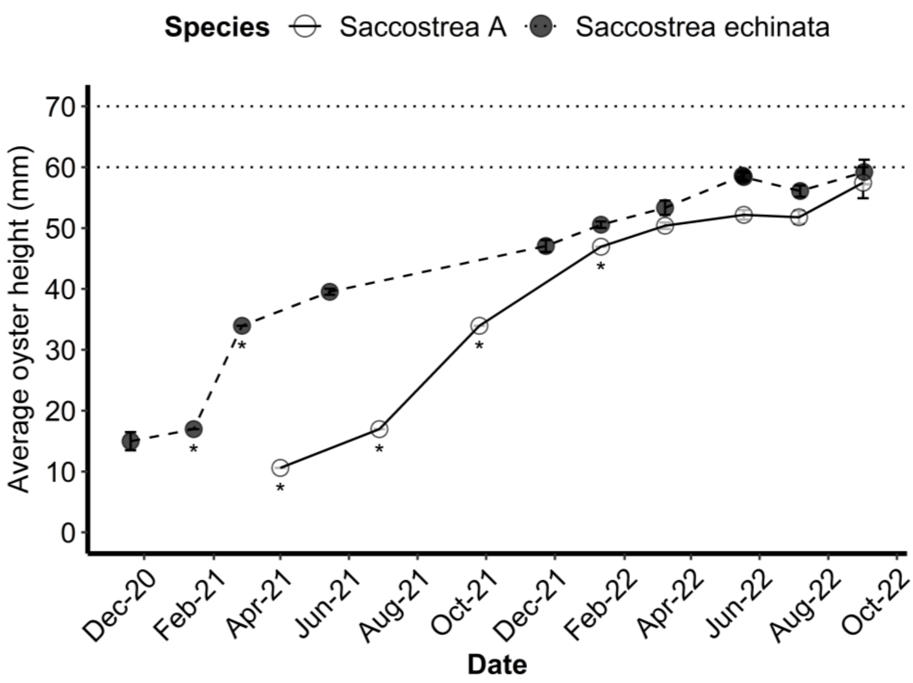

Figure 18. Average height of *Saccostrea* A and *S. echinata* oysters (± 95% confidence intervals) grown in hanging intertidal baskets at the Cossack farm site. Height measured just under 60mm after 17 months for *Saccostrea* A and 21 months for *S. echinata*. Data points denoted with a * underneath were calculated (based on grading), rather than measured.
N.B. shell heights shown here are not corrected for overcatch.

Managing overcatch also had a significant impact on oyster height. At the conclusion of Experiment 6, a sample of oysters was taken from each basket and their dimensions recorded before and after any overcatch was removed. A one-sided, paired T-test ($\alpha = 0.05$) indicated that the mean height of *Saccostrea* A oysters grown in hanging baskets at Cossack intertidal site (for 17 months) was, on average, 5.6mm less once overcatch oysters had been removed ($t = 11.02$, $df = 88$, $p < 0.001$). Similarly, a paired, Wilcoxon rank test ($\alpha = 0.05$, $n = 60$) indicated the median height of *S. echinata* oysters from hanging intertidal baskets at Cossack (for 21 months) was significantly less once overcatch had been removed (W+

[2] These ages are days post hatch and include time in the hatchery. *Saccostrea* A spent 17-months in the field, whilst *S. echinata* were deployed for 21 months.

= 1,830, p <0.001)[3]. The mean difference in height for *S.echinata* once overcatch was removed was 5.15mm less. Therefore, once overcatch is effectively managed, tropical rock oysters are likely to be ~5-6mm smaller than stated in this study.

Table 9. Market sizing recommendations for Australian Sydney and Pacific rock oysters based on top shell length (Ryan, 2008).

Size	***Saccostrea glomerata*** **Sydney Rock Oyster**	***Crassostrea giga*** **Pacific Rock Oyster**
Cocktail	45-55mm	-
Bistro	55-65mm	50-60mm
Buffet	-	60-70mm
Plate	65-75mm	-
Standard	75-90mm	70-85mm
Large	90-100mm	85-100mm
Jumbo	-	100-120mm

In addition to length, the overall shape of the oyster shells was assessed to determine if a good cup was developing in line with favourable height to breadth ratios. Shape score for both *Saccostrea* A and *S. echinata* oysters declined over time, with *S. echinata* exhibiting deeper and wider dimensions than *Saccostrea* A (Figure 19). This indicated that the oyster cup was becoming deeper over time. The impact of overcatch had an even greater impact on shape score than shell height. This is likely because the most prolific overcatch occurred on the bottom shell of oysters which likely compromised the ability to take accurate depth measurements of the shells. A paired T-test ($\alpha = 0.05$) at the end of the trials demonstrated that mean shape score of *Saccostrea* A increased from 3.91 ± 0.16 to 5.65 ± 0.26 once overcatch was removed (t = 10.9, df= 8, p< 0.001), and from 2.65 ± 0.08 to 4.09 ± 0.06 for *S. echinata* (t =16.6, df =5, p<0.001). Differences in shape score between the two species were substantial and indicated *S. echinata* oysters possessed a favourable shape for market, while *Saccostrea* A were a more narrow, shallow oyster that required more time to increase the depth of their cup. However, it is important to acknowledge that while a shape score metric is a useful guide for oyster shape development, it does not define what makes a marketable oyster. For example, other studies have shown that depth to height and width to height ratios are more accurate predictors of 'good' shell shape than using the two ratios together in a shape score metric (Mizuta & Wikfors, 2019). Until further research is done to understand market demand for these tropical rock oyster species, it is not clear which shape metrics or ratios are most appropriate.

To explore the natural difference in shape between the two tropical rock oyster species, the width to height shell ratios were compared between species, ignoring cup depth. An industry workshop found that the shell width of cultivated oysters should not be less than 45% of the height of the shell (Ryan, 2008). An independent T-test ($\alpha = 0.05$) confirmed that the mean width to height ratio of shells was different between the tropical rock oyster species grown in hanging baskets at Cossack intertidal site (t = 5.09, df = 11, p < 0.01). The mean width to length ratio of *Saccostrea* A oysters was 0.63 ± 0.17, while the ratio for *S. echinata* shells was 0.81 ± 0.02. This supports anecdotal observations of *S. echinata* forming a more rounded shell shape, while *Saccostrea* A tends to be a 'skinnier' or more narrow shape. Both species grown in the Pilbara develop a favourable width to length shell ratio greater than 45%.

[3] The assumption of normality could not be satisfied for initial measurements of *S.echinata* before overcatch was removed. Therefore, a non-parametric test was used for this species.

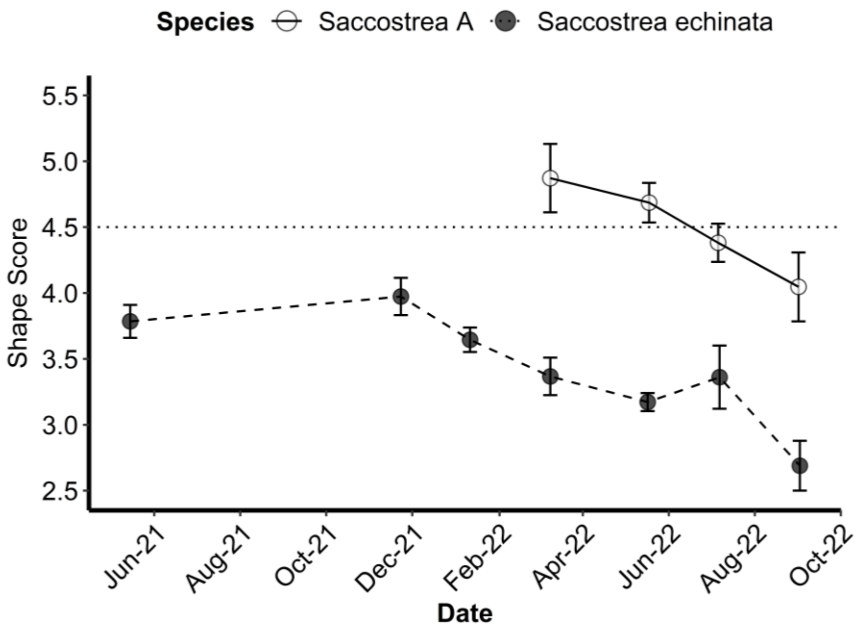

Figure 19. Average shape score for *Saccostrea* A and *S. echinata* oysters grown in hanging baskets at Cossack intertidal site (for 17 and 21 months respectively). Shape scores decrease over time, indicating deeper and wider shell development. A shape score of 4.5 is considered desirable (Rankin et al., 2018).

Stage one grow-out – density trials

The first field trial (5mm *S. echinata* density trial) deployed on 7 October 2020 had two densities: 1,200 and 2,400 oysters per basket. The oysters grew quickly and were graded into the next size class sooner than expected. For this reason, a second 5mm density trial was attempted in November 2020. In this second trial the replication was low (n = 2) in the low-density treatment and no statistically valid conclusions could be drawn. A Kruskal Wallis test (α = 0.05) comparing the impact of density on oyster weight by the end of the trial (57 days) did not detect any differences between stocking densities of 1,250 or 1,800 (χ^2= 3, df= 3, p= 0.083) for the 5mm *S. echinata* spat. A one-way repeated measures ANOVA (α = 0.05, n = 3) confirmed that mean weight of *S. echinata* oysters increased over time when stocked at 1,800 oysters per basket ($F_{1,4}$ = 483.7, p< 0.001). A similar trend was seen in the first 5mm trial with *S. echinata*. An independent T-test (α = 0.05) showed that there was no difference in mean weight per oysters stocked at 1,200 per basket (0.33g/oyster ± 0.01g/oyster) or at 2,400 per basket (0.30 g/oyster ± 0.01g/oyster, T = 2.25, df = 8, p = 0.05). The trend was for the lower stocking densities (1,250 and 1,200 per basket) to have a greater mean weight per oyster after 57 and 44 days on the farm in each trial respectively, however this was not statistically different in either case. With only a marginal improvement in average oyster weight between the 1,250 and 1,800 and 1,200 and 2,400 stocking densities, farmers could stock their baskets at the higher density without significantly impacting growth rates.

For the 5mm *Saccostrea* A density trial[4], a repeated measure ANOVA (α = 0.05) determined that basket stocking density influenced the mean weight per oyster over time ($F_{6,24}$ = 11.6, p < 0.001). As spat were slow to reach 5mm in the hatchery, two deployments (11 days apart) were used for this trial[5]. There was no significant influence of stocking density on the mean weight per oyster at each time interval for the two deployments. However, there was a significant difference in mean weight per oyster at each time interval between the two deployments. All baskets, regardless of density or deployment, increased the mean weight per oyster as they spent more time on the farm. Summary statistics for the 5mm density trials for both species are shown in Table 10.

To achieve good growth across as many oysters as possible, farmers at the Cossack intertidal site would be best to use higher stocking densities (2,000–2,500 oysters per basket) when beginning stage one grow-out of both *Saccostrea* A and *S. echinata* 5mm spat. However, density is a less influential factor than time in the water. Anecdotally, it appeared that doubling densities to 4,000 oysters per basket in *Saccostrea* A trials started to reduce oyster weights, however this has not yet been confirmed.

[4] The 4,000 oysters per basket treatment is excluded from this analysis as a basket was lost, reducing the sample size to two.
[5] These two deployments are pooled across time intervals for the repeated measure ANOVA.

Table 10. Mean weight per oyster (g) (± SE) for 5mm spat of *Saccostrea* A and *S. echinata* at the Cossack intertidal site stocked at different densities. There was no significant difference in final oyster weight regardless of density treatment, however all density treatments put on weight from the start to the end of the trial.

***Saccostrea* A:** 5mm grade									
Density	**n**	**T_0**	**T_1**	**PWG**	**T_2**	**PWG**	**T_3**	**PWG**	**Test**
		T_0: deployment	T_1: 21 days		T_2: 46 days		T_3: 94 days		
1,000	3	0.07	0.20 ± 0.00	a	0.83 ± 0.03	c	2.49 ± 0.14	ef	Repeated measure ANOVA & post-hoc pairwise comparisons
2,125	3	0.07	0.02 ± 0.01	a	0.79 ± 0.01	c	2.09 ± 0.03	e	
		T_0: deployment	T_1: 10 days		T_2: 35 days		T_3: 83 days		
1,250	3	0.06	0.09 ± 0.00	b	0.42 ± 0.02	d	1.66 ± 0.10	ef	Repeated measure ANOVA & post-hoc pairwise comparisons
2,500	3	0.06	0.10 ± 0.00	b	0.44 ± 0.02	d	1.58 ± 0.06	f	
4,000	2	0.05	0.08 ± 0.00	NA	0.35 ± 0.01	NA	1.12 ± 0.06	NA	NA
S. echinata: 5mm grade									
Density	**n**	**T_0**	**T_1**	**PWG**	**T_2**	**PWG**	[redacted]		**Test**
		T_0: deployment	T_1: 27 days		T_2: 57 days				
1,250	2	0.20	0.53 ± 0.01	NA	1.30 ± 0.06	NA			NA
1,800	3	0.15	0.40 ± 0.01	a	1.01 ± 0.03	b			Repeated measure ANOVA & post-hoc pairwise comparisons

T_0 has no SE as all samples were homogenised to be the same at start of the experiment. 'n' is the sample size or number of baskets. PWG = pairwise significance grouping based on adjusted p-values, where sharing a letter indicates no difference.

Repeated measures ANOVA's (α = 0.05) were also done on the 8mm and 16mm field trials (Experiments 1 - 3) to determine if density had a significant impact on the mean weight gained per oyster. The initial weights (T_0) were not included in this analysis as all baskets were homogenised with the same weight of oysters to start the trials and therefore this time point did not meet the requirement of normality.

There was a significant interaction between the density of oysters stocked in the baskets and the amount of time growing at site for the 8mm grade of both *Saccostrea* A ($F_{3,40}$ = 64.0, p <0.001) and *S. echinata* oysters ($F_{2,40}$ = 21.0, p <0.001). Post-hoc, pairwise comparisons were used to analyse the effect of density on the mean weight per oyster at greatest time interval of deployment on the farm. Considering Bonferroni adjusted p-values (p_{adj}), the simple main effect of density was significant at both 48 days and 106 days deployment for *Saccostrea* A (p_{adj} < 0.001). There was no difference in the mean weight per oyster between the 600–1,200, 1,200–1,800, and 1,800–2,400 density treatments after only 48 days of deployment (p_{adj} = 1, p_{adj} = 0.40 and p_{adj} = 1 respectively), however the difference between these treatments was significant by day 106 on this trial (p_{adj} = 0.01, p_{adj} = 0.04, p_{adj} = 0.03 respectively). For the *S. echinata* trial, all three-time intervals showed significant increases in the mean weight per oyster for both density treatments (p_{adj} < 0.001), however there was only a significant difference in mean weight per oyster between the 600 and 1,200 density treatments after 98 days (p_{adj} < 0.001). Summary statistics for the 8mm density trials for both species are shown in Table 11. A summary of the post-hoc test statistics are available in Table App B.1. Therefore, where trying to optimise the growth rate of 8mm *Saccostrea* A and *S. echinata* oysters at the Cossack intertidal site, it is recommended that a stocking density of 1,200 be used up until about 48–55 days, before dropping the density to 600 up until 98–106 days.

Table 11. Mean weight per oyster (g) (± SE) for 8mm spat of *Saccostrea* A and *S. echinata* stocked at Cossack intertidal site at different densities. Mean weight was significantly different by the end of the trials. While all density treatments gained weight from the start to the finish of the experiment, the lower densities resulted in greater mean weight gain.

***Saccostrea* A: 8mm grade**									
Density	**n**	**T_0**	**T_1**	**PWG**	**T_2**	**PWG**	[redacted]		**Test**
		T_0: deployment	T_1: 48 days		T_2: 106 days				
600	6	0.27	1.61 ± 0.02	a	4.40 ± 0.14	d			Repeated measure ANOVA & post-hoc pairwise comparisons
1,200	6	0.27	1.53 ± 0.04	ab	3.20 ± 0.10	e			
1,800	6	0.27	1.38 ± 0.04	bc	2.63 ± 0.08	f			
2,400	6	0.27	1.32 ± 0.03	c	2.28 ± 0.05	g			
***S. echinata:* 8mm grade**									
Density	**n**	**T_0**	**T_1**	**PWG**	**T_2**	**PWG**	**T_3**	**PWG**	**Test**
		T_0: deployment	T_1: 25 days		T_2: 55 days		T_3: 98 days		
600	6	0.33	0.87 ± 0.08	a	1.93 ± 0.05	b	4.02 ± 0.12	c	Repeated measure ANOVA & post-hoc pairwise comparisons
1,200	6	0.29	0.84 ± 0.03	a	1.79 ± 0.05	b	3.06 ± 0.10	d	

T_0 has no SE as all samples were homogenised to be the same at start of the experiment. n is the sample size or number of baskets. PWG = pairwise significance grouping, based on adjusted p-values, where sharing a letter indicates no difference.

There was a significant interaction between the density of oysters stocked in the baskets and the amount of time spent growing at site for the 16mm grade of *S. echinata* ($F_{9,48} = 22.7$, $p < 0.001$). Post-hoc, pairwise comparisons were used to analyse the effect of density on the mean weight per oyster at each time interval of deployment on the farm. For *S. echinata*, all density treatments put on weight between each measurement ($p_{adj} < 0.05$), except for the treatment with 900 oysters per basket between 33 and 49 days ($p_{adj} = 0.154$). There was no significant difference in mean weight per oyster between any density treatments after only 21 days in the trial ($p_{adj} > 0.083$), however the mean weight per oyster was larger in the 300/basket density treatment compared to the 700/basket after 33 days ($p_{adj} = 0.019$). By day 49 of the trial, the mean weight per oyster was the same for the 300 and 500 ($p_{adj} = 0.235$), 500 and 700 ($p_{adj} = 0.696$) and 700 and 900 ($p_{adj} = 1$) density treatments, with only the 300-density treatment having a greater mean weight per oyster than the 700 and 900 density treatments ($p_{adj} = 0.034$ and $p_{adj} = 0.009$ respectively). At the conclusion of the trial (74 days), all density treatments had significantly different mean weights per oyster, except for the 300 and 500 density treatments ($p_{adj} = 0.086$). Therefore, to optimise weight gain of 16mm *S. echinata* oysters, the recommended stocking density and duration is 500 oysters per basket and at least 74 days at Cossack intertidal site as this will give the greatest weight gain across the most oysters. A summary of the post-hoc test statistics are available in Table App B.1. Due to limited stock availability, the 16mm *Saccostrea* A density trials were done over two deployments and this reduced the sample size for each time interval to two baskets and prevented a repeated measure ANOVA being conducted. Instead, a Kruskal Wallis test ($\alpha = 0.05$) compared the impact of density on the weight per oyster at the conclusion of the trial (22 November 2021). No differences in weight per oyster were detected between densities ($\chi^2 = 6.67$, df = 3, p = 0.08). Therefore, farmers would be best to stock 16mm *Saccostrea* A oysters at 900 oysters per basket for finishing off stage 1 grow-out at the Cossack intertidal site. Summary statistics for the 16mm density trials for both species are shown in Table 12.

Table 12. Mean weight per oyster (g) (± SE) for 16mm spat of *Saccostrea* A and *S. echinata* stocked at the Cossack intertidal site at four densities. All density treatments gained weight from the start to the finish of the experiment.

***Saccostrea* A: 16mm grade**											
Density	**n**	**T_0**	**T_1**	**PWG**	**T_2**	**PWG**					**Test**
		T_0: deployment	T_1: 34 days		T_2: 75 days						Kruskal Wallis at T_2 (density effect)
300	2	2.75	4.05 ± 0.04	NA	6.87 ± 0.01	NA					
500	2	2.75	4.03 ± 0.00	NA	6.67 ± 0.05	NA					
700	2	2.75	3.88 ± 0.05	NA	6.12 ± 0.03	NA					
900	2	2.75	3.81 ± 0.03	NA	5.66 ± 0.12	NA					
		T_0: deployment	T_1: 41 days								
300	2	2.75	5.13 ± 0.15	NA							
500	2	2.75	4.91 ± 0.06	NA							
700	2	2.75	4.67 ± 0.06	NA							
900	2	2.75	4.69 ± 0.15	NA							
***S. echinata:* 16mm grade**											
Density	**n**	**T_0**	**T_1**	**PWG**	**T_2**	**PWG**	**T_3**	**PWG**	**T_4**	**PWG**	**Test**
		T_0: deployment	T_1: 21 days		T_2: 33 days		T_3: 49 days		T_4: 74 days		Repeated measure ANOVA & post-hoc pairwise comparisons
300	4	3.70	4.98 ± 0.06	a	6.49 ± 0.04	b	7.42 ± 0.05	e	10.25 ± 0.04	g	
500	4	3.70	4.89 ± 0.04	a	6.40 ± 0.10	bc	7.08 ± 0.12	ef	9.67 ± 0.11	g	
700	4	3.70	4.91 ± 0.05	a	6.11 ± 0.06	c	6.72 ± 0.06	f	8.87 ± 0.02	h	
900	4	3.70	4.87 ± 0.03	a	6.06 ± 0.09	bcd	6.73 ± 0.09	bcdf	8.51 ± 0.05	i	

T_0 has no SE as all samples were homogenised to be the same at start of the experiment. n is the sample size or number of baskets. PWG = pairwise significance grouping, based on adjusted p-values, where sharing a letter indicates no difference.

Stage two grow-out

22mm gear trials

As all treatments in the 22mm grade gear trials came from the same homogenised stock, a one-way ANOVA (α = 0.05) was used to assess if basket type influenced the weight of the 22mm oysters by the end of the trial at Cossack farm site. For *S. echinata*, the mean oyster weight (g/oyster) was not the same for all basket types ($F_{3,12} = 4.65$, $p = 0.02$). Post-hoc Tukey's tests indicated that the mean weight of oysters in floating SEAPA baskets (13.13g ± 0.29g) was less than those in static SEAPA baskets (15.87g ± 0.62g, $p_{adj} = 0.02$). The mean oyster weights were the same across all other basket types after the 99-day deployment (Figure 20). For *Saccostrea* A oysters, the mean weight per oyster was not the same for all basket treatments ($F_{3,21} = 3.88$, $p = 0.02$). Tukey's tests showed the mean weight of oysters in the static SEAPA baskets (23.46g ± 0.48g) was greater than those in the Zapco tumblers (17.55g ± 0.11g, $p_{adj} = 0.01$). The mean weight of *Saccostrea* A oysters was similar in all other baskets after 125 days in the trial (Figure 20). This was unexpected as the floating SEAPA and Zapco tumblers are both buoyant gear types that rumble the oysters and so were expected to have a similar impact on oyster growth and shape. For both species, the analysis was repeated with the baskets (replication unit) categorised as either a buoyant or static gear type and an independent T-test (α = 0.05) was carried out to compare the mean weight per oyster between these gear types at the conclusion of the trial. There was no significant difference in the mean weight per oyster in static or buoyant gear types by the end of the 22mm gear trial for either *S. echinata* (T = 1.34, df = 14, p = 0.20), or *Saccostrea* A (T = 1.99, df = 22, p = 0.06). Static baskets resulted in a mean oyster weight of 15.1g ± 0.46g for *S. echinata* compared to 14.16g ± 0.53g across buoyant gear. The mean oyster weight in static baskets for *Saccostrea* A was 21.62g ± 0.83g, compared to 19.05g ± 0.99g across buoyant gear types.

A one-way ANOVA (α = 0.05) was also used to determine the impact of basket type on shape score and oyster height (mm) for both species at the Cossack intertidal site. For *Saccostrea* A, the mean shape score of oyster shells was significantly different between the oyster baskets after 125 days ($F_{3,21} = 4.86$, $p = 0.01$) with floating SEAPA baskets (5.23 ± 0.15) producing a different shape score to Hexcyl (4.49 ± 0.20, $p_{adj} = 0.08$) and Zapco tumblers (4.60 ± 0.10, $p_{adj} = 0.05$), but not static SEAPA baskets (4.80 ± 0.10, $p_{adj} = 0.22$). When baskets were pooled as either buoyant or static, an independent T-test (α = 0.05) determined that there was no influence of type of gear on the mean shape score of oysters (T = 1.88, df = 23, p = 0.07), but there was a difference in mean shell length (T = 4.01, df = 23, p < 0.001) where oysters in static gears were on average, 2.5mm longer (53.2mm ± 0.44mm) than those in buoyant baskets (50.7mm ± 0.43mm). Static SEAPA baskets produced the longest *Saccostrea* A oysters (54.3mm ± 0.46mm), which were significantly different to oysters in floating SEAPA (51.2mm ± 0.61mm, $p_{adj} = 0.002$) and Zapco tumblers (50.1mm ± 0.47mm, $p_{adj} < 0.001$), but not Hexcyl baskets (52.3mm ± 0.52mm, $p_{adj} = 0.06$).

For *S. echinata,* neither basket nor gear type had an impact on the mean shape score ($F_{3,12} = 0.10$, $p = 0.96$) with all baskets producing a shape score of between 3.94 ± 0.07 (floating SEAPA) and 4.0 ± 0.14 (Hexcyl). However, basket type did impact mean shell length ($F_{3,12} = 4.07$, $p = 0.03$) of the oysters after 99 days. The mean length of oysters in static SEAPA baskets was 3.4mm longer (47.4mm ± 0.36mm) than those in floating SEAPA baskets (44.0mm ± 0.98mm, $p_{adj} = 0.03$), but was not different to those in Hexcyl baskets (46.7mm ± 0.97mm, $p_{adj} = 0.91$) or Zapco tumblers (46.0mm ± 0.15mm, $p_{adj} = 0.55$). An independent T-test confirmed that static gear types resulted in greater mean length for *S. echinata* oysters at the Cossack intertidal site (T = 2.63, df = 14, p = 0.02), however there was no impact on overall shape scores (T = 0.23, df = 10, p = 0.82).

Therefore, as a generalisation, switching 22mm-grade oysters of either species from static baskets into buoyant baskets did not significantly impact their weight or shape score. However, leaving them in static baskets did, on average, produce longer oysters (2.0mm longer for *S. echinata* and 2.5mm longer for *Saccostrea* A). If optimising weight gain and increasing shell length are the ultimate goals at this stage of growth, static SEAPA baskets would therefore be recommended over other gear types (Figure 20). Achieving a better shape of the oysters is also important at this stage of grow-out. While it appears no basket type influenced the shape score of *S. echinata* oysters over the duration of experiment 4 (4.01 ± 0.22 on day 0 and 3.94 ± 0.07 to 4.0 ± 0.14 on day 99), *Saccostrea* A oysters began this trial with an average shape score of 5.23 ± 0.15, so all gear types except for the floating SEAPA baskets (5.23 ± 0.15) worked to improve the cup depth of the oysters and reduce shape score (to at least 4.8 ± 0.1, Figure 20).

S. echinata and *Saccostrea* A appear to have responded quite differently to the Zapco tumbler baskets with *S. echinata* gaining similar weight and length across all gear types, but *Saccostrea* A growing the least in Zapco baskets. The response of *Saccostrea* A oysters to Zapco tumbler baskets is expected, as growth metrics are sacrificed in the pursuit of a better cup depth, shell shape and meat condition with rumbling gear (Leavitt et al., 2017). However, it is not clear why *S. echinata* did not respond to the tumbler basket in a similar fashion at this stage of grow-out. The additional 26-days of growth in the trials for *Saccostrea* A could have played a part in the different response.

It is important to note that as SEAPA baskets had lower stocking densities than Hexcyl baskets and Zapco tumblers, the trend towards greater weight and length in both species may have been a density rather than gear effect. It is therefore important to do a direct comparison between static and buoyant gear types using baskets with the same number of oysters. In both species, the trend was for the rumbling floating SEAPA baskets to slow weight and length gains, (but interestingly the shape score did not improve for either species) (Figure 20).

In the 22mm gear trials, growth was better overall for *Saccostrea* A than *S. echinata.* This may be explained by lower basket densities (>50%) and longer grow-out duration. *Saccostrea* A also experienced warmer water conditions with an average temperature of 29.9°C ± 0.13°C during the 125-day deployment compared to 24.4°C ± 0.13°C for *S. echinata* oysters over the 99-day deployment for this species.

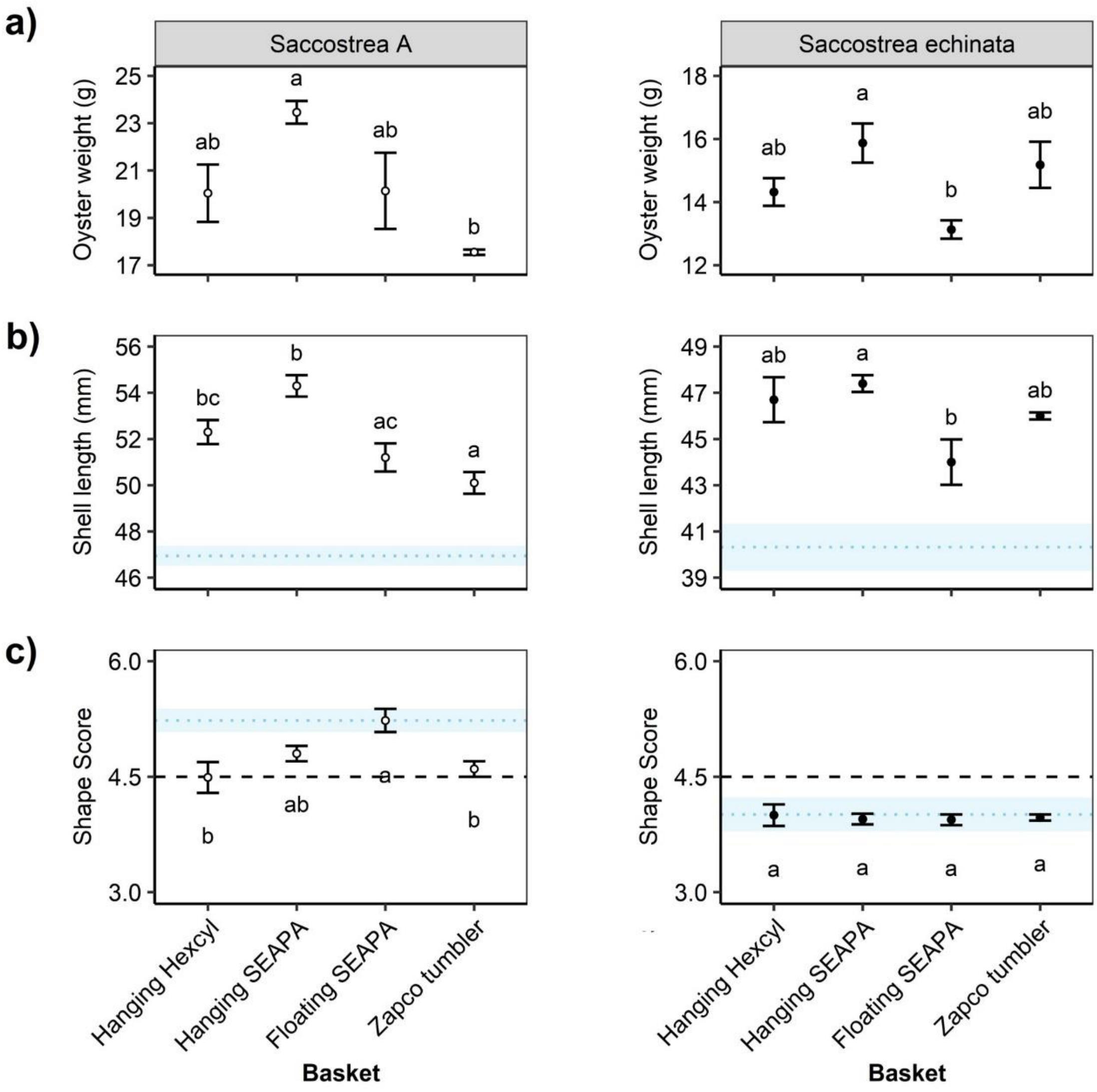

Figure 20. Mean weight per oyster ± SE (a), shell length ± SE (b), and shape score ± SE (c) of two tropical rock oyster species (*Saccostrea* A and *S. echinata*) in a 22mm size grade grown in four baskets (Hexcyl, hanging SEAPA, floating SEAPA, and Zapco tumblers) at Cossack intertidal site for 125 and 99 days respectively. Treatments with the same letter assigned (above or below) indicate these means were not different from each other. The blue dashed line is the mean value at the start of the trial with a SE ribbon around it.

S. echinata oysters (22mm) deployed to the Flipfarm system at Withnell Bay were initially stocked at 365 oysters per basket, however this was too heavy for the baskets to maintain buoyancy and they were destocked to 175 per basket 13 days later. A dependent T-test (α = 0.05) was used to determine if there was a difference in the mean weight per oyster (g) and an independent T-test (α = 0.05) was used to detect any differences in shell length (mm), or shape score for 22mm *Saccostrea* A and *S. echinata* oysters deployed to the Flipfarm at Withnell Bay for 116 and 101 days respectively. Mean weight of oysters increased significantly for both species while deployed at Withnell Bay. *Saccostrea* A oysters grew from 9.15g/oyster to 10.81g/oyster ± 0.31g/oyster (T = 5.33, df = 6, p = 0.002) and *S. echinata* oysters increased from 14.7g/oyster ± 0.36g/oyster to 17.66g/oyster ± 0.42g/oyster (T = 4.15, df = 5, p = 0.009). The mean shape score of *Saccostrea* A oysters was the same at the time of deployment (5.23 ± 0.15) and the end of the trial (5.37 ± 0.07, T = 2.04, df = 6, p = 0.09), while *S. echinata* oysters (previously rumbled at

Cossack site) were reduced in mean shape score from 4.01 ± to 0.22 to 3.36 ± 0.13 (T= 4.97, df= 2, p= 0.04). Mean length of both species also differed with *Saccostrea* A decreasing by an average of 2.31mm (from 46.9mm to 44.6mm ± 0.32mm, T = 7.21, df = 6, p < 0.001) and *S. echinata* increasing by an average of 6.3mm (from 40.3mm to 46.6mm ± 0.83mm, T= 7.60, df= 2, p= 0.02).

Weight and length gain was less in *Saccostrea* A oysters deployed to the Flipfarm at Withnell Bay than at the Cossack intertidal site. Surprisingly, *Saccostrea* A lost length during the initial 116 days at the Flipfarm. *S. echinata* oysters deployed to the Flipfarm from Cossack site had been in Zapco tumblers for the previous five months. It is likely they experienced less rumbling once on the subtidal farm at Withnell Bay allowing them to put more energy into growth (and making their growth metrics comparable to those at the Cossack intertidal farm). The shape score for *S. echinata* continued to decrease indicating a deeper cup development relative to shell width. The five months of rumbling may have established a cupping trajectory, which became more pronounced once on the subtidal site.

35mm gear trials – *Saccostrea* A

Following the 22mm gear trials, Experiment 5 investigated the impacts of basket type on oyster shell dimensions and growth. However, previous husbandry techniques were also considered to determine if switching between different basket types could help cultivate a marketable oyster. Three different stocks of *Saccostrea* A oysters were used in the trial:

- those grown in static Hexcyl baskets at Cossack intertidal site for 14 months
- some grown in static Hexcyl baskets at Cossack intertidal site for 10 months before being switched to rumbling SEAPA baskets for four months
- some grown in Hexcyl baskets for 10-months before being switched to Zapco tumblers for four months.

It was hoped that rumbling the oyster shells for a short period might set oysters that were not yet developing a favourable shape on a corrected trajectory.

A two-way ANOVA[1] ($\alpha = 0.05$) was used to determine if there was a significant interaction between previous husbandry of 35mm cultivated *Saccostrea* A stock (stock origin) and basket type on the mean weight of oysters (g), shell length (mm) and shape score when on-grown at the Cossack intertidal site for 105 days. Neither the simple main effect of basket type ($F_{2,35} = 0.68$, p = 0.51) nor previous husbandry ($F_{2,35} = 1.65$, p = 0.21) impacted the mean weight per oyster. In addition, there was no interaction effect of these two factors ($F_{2,35} = 0.41$, p = 0.67). Therefore, the average weight per 35mm *Saccostrea* A oyster was equal regardless of whether the oysters had previously been tumbled in floating SEAPA or Zapco baskets or whether they had come from static intertidal baskets (Figure 21). Whether these oysters then went into the same or a new gear type also did not impact their average weight gain by the end of the trial.

Similarly, there was no significant interaction effect between previous husbandry and basket types on the mean shape score of oysters ($F_{2,14} = 2.48$, p = 0.12). There was also no significant influence of the simple main effects of either previous husbandry ($F_{2,14} = 3.29$, p = 0.07) or basket type ($F_{2,14} = 0.12$, p = 0.89). The mean shape score of all *Saccostrea* A oysters in the 35mm gear trial at Cossack intertidal site was similar after the 105-day field trial, regardless of current or previous gear types (Figure 21).

There was however, a statistically significant interaction between the type of basket used and prior husbandry techniques for mean shell length (mm) of *Saccostrea* A oysters in this 35mm gear trial ($F_{2,14}$ = 5.28, p = 0.02). The simple main effect of stock origin did not significantly impact mean length ($F_{2,14} = 0.27$, p = 0.76), however basket type was a significant factor for shell length ($F_{2,14} = 5.26$, p = 0.02). A one-way ANOVA ($\alpha = 0.05$), ignoring the factor of 'stock origin' was conducted to determine what was causing the difference in mean length ($F_{6,14} = 3.81$, p = 0.02). Previously rumbled stock from both floating SEAPA (57.5mm ± 1.42mm) and Zapco tumbler (58.4mm ± 0.87mm) baskets that were switched into hanging Hexcyl baskets, produced significantly longer oysters than stock that remained in Zapco tumblers for seven to eight months (51.85mm ± 0.17mm, i.e., stock previously rumbled in Zapco tumblers that were deployed back into Zapco tumblers in this trial).

Dependent T-tests ($\alpha = 0.05$) indicated that the mean weight of *Saccostrea* A oysters increased significantly from 16.96g/oyster over the duration the trial regardless of basket type or prior husbandry techniques (p <0.01). Mean shell length was only significantly greater for stock that had been previously rumbled in Zapco Tumblers (by 1.8mm and 8.3mm for Zapco and Hexcyl baskets respectively, p < 0.01). Shell shape score of oysters that had previously been rumbled in floating SEAPA baskets decreased significantly during the trial (p < 0.04), however no other basket-husbandry combinations resulted in a statistically different shape score by the end of the trial (p > 0.06). This supports the theory that the timing of stock rumbling has the largest influence on oyster shape score. Rumbling *Saccostrea* A oysters in

[1] Residual analysis was performed to test for the assumptions of the two-way ANOVA. Outliers were assessed by box plot method; normality was assessed using Shapiro-Wilk's normality test and homogeneity of variances was assessed by Levene's test. There were no extreme outliers, residuals were normally distributed (p > 0.05) and there was homogeneity of variances (p > 0.05).

floating SEAPA baskets as they entered the 22mm grade class produced the most favourable shape score and switching the oysters back to a static Hexcyl basket for a few months of growth did not alter shape score. However, there were large differences in weight and length between these basket types (Figure 21). The type of farm gear used may therefore end up being determined by a meat condition and/or overcatch management strategy rather than growth or shell shape development.

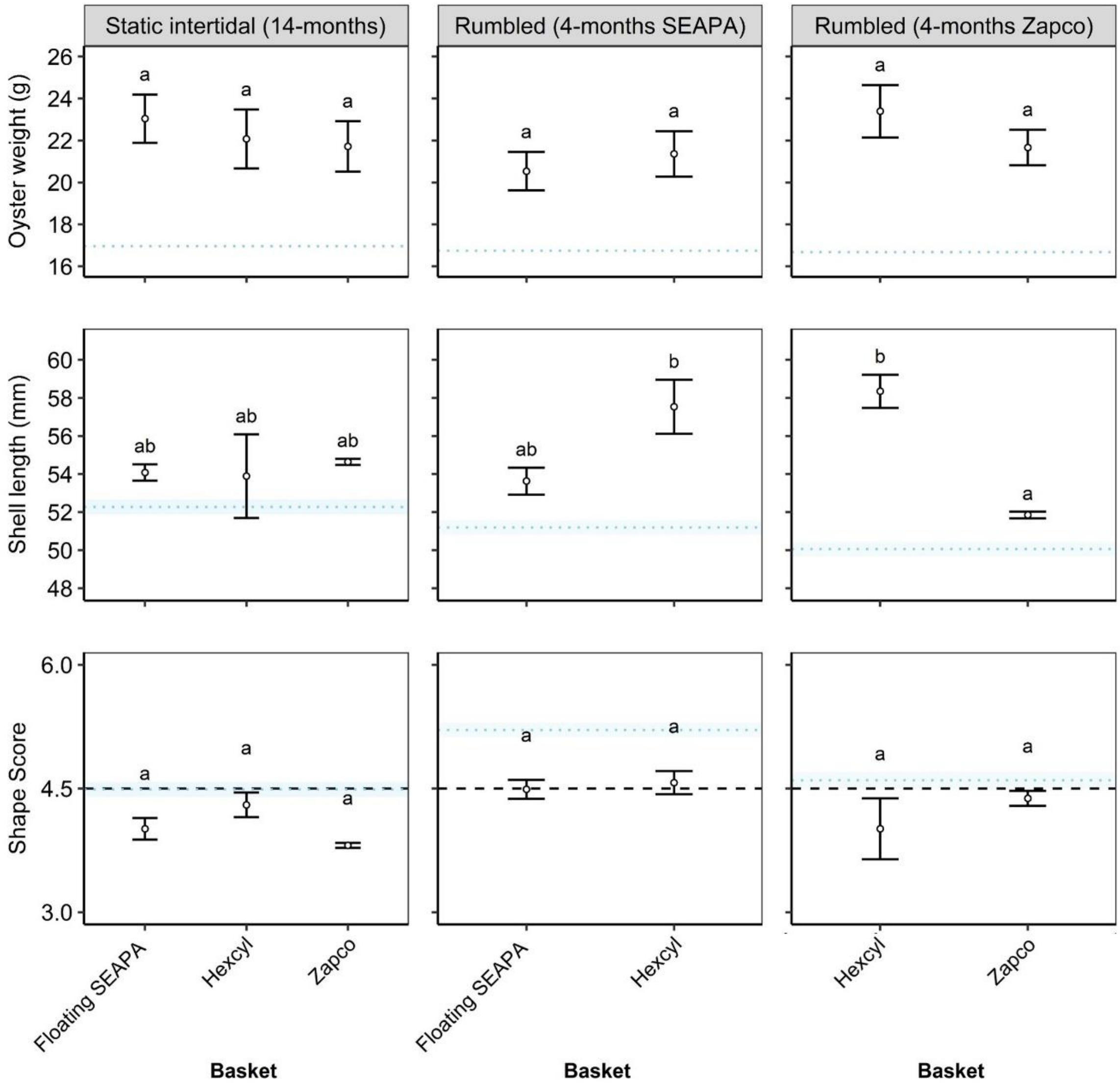

Figure 21. Mean weight per oyster ± SE, shell length ± SE, and shape score ± SE of cultivated *Saccostrea* A oysters in a 35mm size grade when on-grown in three baskets (Hexcyl, floating SEAPA, and Zapco tumblers) at Cossack intertidal site for 105 days. Oysters from three husbandry backgrounds (static intertidal baskets, rumbled in SEAPA baskets, or rumbled in Zapco tumblers) were used in the trial to determine optimum husbandry for this size class. The blue dashed line is the mean value at the start of the trial with a SE ribbon around it.

35mm gear trials – *S. echinata*

In Experiment 5, 35mm *S. echinata* oysters were split across several basket types and sites to determine if an optimum husbandry combination could be determined for both growth and shell shape development. Oysters that had been rumbled on the farm in floating SEAPA gear for the previous five months were also used in one treatment to determine whether the amount of time rumbled on farm influenced oyster development. A one-way ANOVA ($\alpha = 0.05$) determined that husbandry method significantly influenced the mean weight per oyster ($F_{5,15} = 12.91$, $p < 0.001$), shell length ($F_{5,15} = 6.16$, $p = 0.002$) and overall shell shape score ($F_{5,12} = 8.01$, $p < 0.001$).

Oysters deployed to the Flipfarm at Withnell Bay for five months increased in mean weight per oyster ($T = 14.75$, df = 2, $p = 0.004$), but there was no change in overall shell shape ($T = 0.36$, df = 2, $p = 0.75$) or length ($T = 1.25$, df = 2, $p = 0.34$, Figure 22). Mean shell length at this site was significantly less than oysters in Hexcyl, hanging SEAPA, and Zapco baskets ($p_{adj} = 0.005$, $p_{adj} = 0.006$, and $p_{adj} = 0.02$

respectively) at the Cossack intertidal site but no different to oysters in floating SEAPA baskets regardless of previous husbandry ($p_{adj} > 0.5$, Figure 22). *S. echinata* oysters gained the least amount of weight while at the Flipfarm at Withnell Bay with the mean weight of oysters at the site less than all oysters at Cossack intertidal site, except for those in a floating SEAPA basket ($p_{adj} = 0.34$)[2]. Deploying *S. echinata* to the Flipfarm at Withnell Bay at this stage in their grow-out did not benefit their overall shape or growth when compared to the Cossack intertidal site.

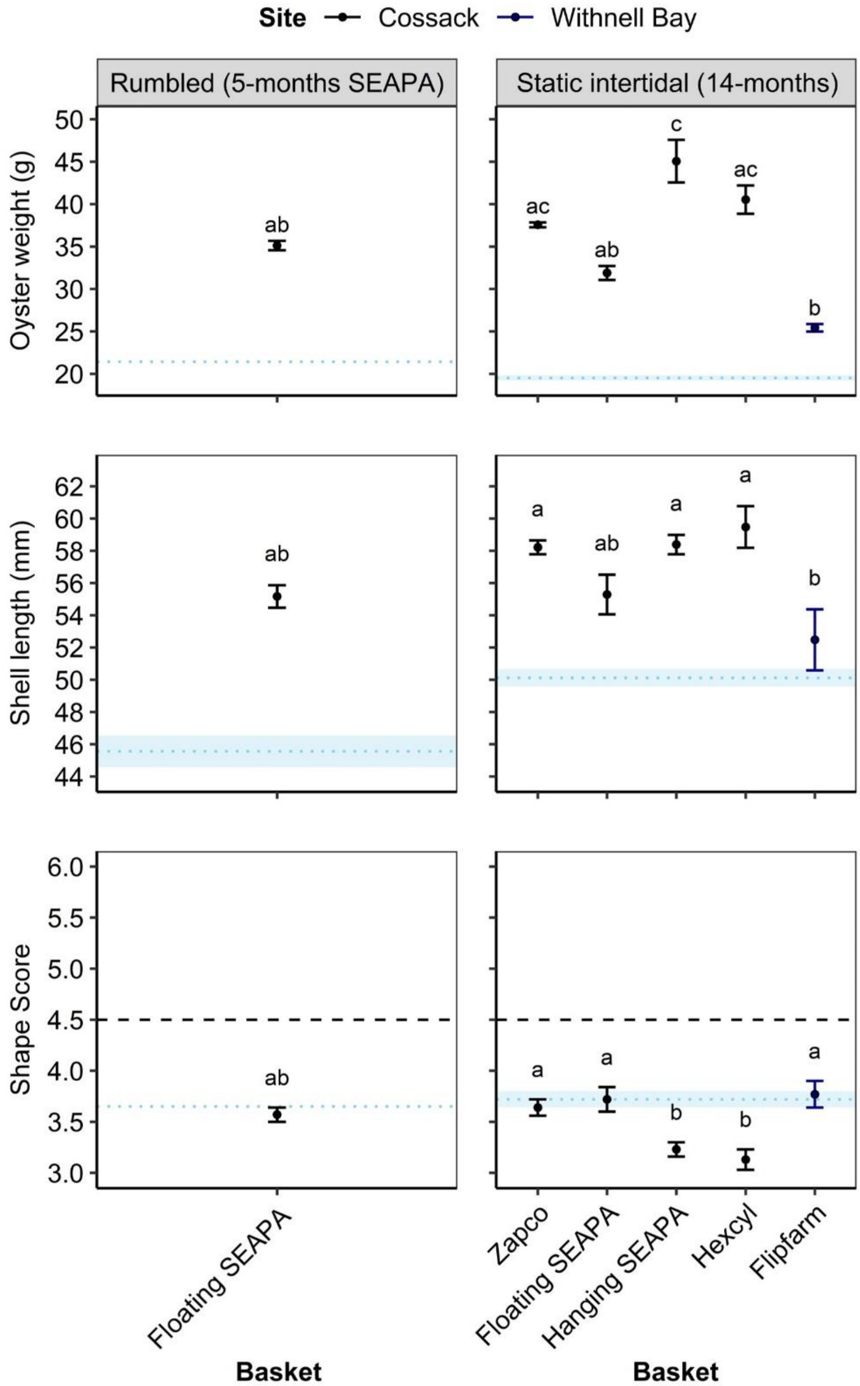

Figure 22. Mean weight per oyster ± SE, shell length ± SE, and shape score ± SE of cultivated *S. echinata* oysters in a 35mm size grade on-grown in one of seven baskets treatments at the Cossack intertidal and Withnell subtidal sites for 125 days. Treatments with the same letter assigned (within a growth metric)

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[2] The mean oyster weight of *S. echinata* oysters that had been in floating SEAPA baskets at Cossack for 10-months by the end of the trial was statistically the same, but only marginally ($p_{adj} = 0.06$).

indicate these means were not different from each other. The blue dashed line is the mean value at the start of the trial with a SE ribbon around it.

Dependent T-tests ($\alpha = 0.05$, $n = 3$) determined that all basket treatments at the Cossack intertidal site increased both oyster weight ($p < 0.006$) and length ($p < 0.02$) significantly except for the ex-static intertidal floating SEAPA baskets which did not increase mean length ($p = 0.06$) during this trial. Oysters in hanging SEAPA baskets gained significantly more weight than those in floating SEAPA baskets regardless of prior husbandry ($p_{adj} < 0.02$) but were not significantly heavier than oysters in Hexcyl and Zapco baskets at Cossack ($p_{adj} = 0.55$ and $p_{adj} = 0.19$ respectively). No differences in mean shell length were observed for any basket treatments at the Cossack intertidal site, with all increasing in length (Figure 22). Mean shape score of oysters in hanging SEAPA and Hexcyl baskets decreased during the trial indicating that the shells were getting deeper and wider. However, as shape scores were already low for this species (< 4.0) this result could indicate that height and width of the shells were not growing proportionally (making achieving a marketable oyster unlikely).

S*. echinata* oysters that had spent the previous five months rumbling in floating SEAPA baskets and were redeployed to these baskets again, did not differ significantly in mean oyster weight, shell length, or shape score from any other treatment (Figure 22). This is an interesting result, as moving the *S. echinata* oysters into floating SEAPA baskets reduced shell length and oyster weight during the 22mm gear trials, without improving shell shape score. Similarly, on-growing these oysters in this gear type for a further five months did not outperform any other gear type for weight gain, shell length or shape score.

It would appear that by this stage in the grow-out phase, the overall shell shape and dimensions of *S. echinata* oysters cultivated in static intertidal baskets were tracking well. Transferring oysters at this stage into buoyant gear types and rumbling them purely to improve shape score does not appear worthwhile and would come at the cost of improved weight and length. However, rumbling gear can improve oyster condition and reduce overcatch so may still be desirable depending on the intention for their use and production goals sought (see Overcatch section below).

Survival

An assessment of survival was made for *Saccostrea* A oysters by counting the number of live oysters and empty shells in all baskets at the conclusion of the 22mm gear trial (May 2022). Survival of *Saccostrea* A was higher than 85% for oysters deployed to the site from March 2021 (Table 13). At this time, oysters of 5mm size were deployed to Hexcyl baskets where they remained for nine months (until January 2022). Following this, the oysters were divided into different gear configurations, so the survival of *Saccostrea* A oysters in hanging Hexcyl baskets outlined in Table 13, should be considered a species performance indicator for 13 months at Cossack intertidal site and not a reflection of gear performance. Survival of 22mm oysters deployed to hanging and rumbled gear types at Cossack for four months between January – May 2022 was greater than 95% (Table 13).

Table 13. Survival (as of May 2022) of *Saccostrea* A oysters originally deployed to Cossack intertidal site in March 2021.

Duration at site	Gear (basket)	Gear duration	Survival (%)	Mortality per month (%)	Sample size (n)
13 months	Hanging Hexcyl	13 months	85.7%	1.1	1,025
	Hanging SEAPA	4 months	97.3%	0.7	940
	Rumbled Floating SEAPA		95.6%	1.1	1,317
	Rumbled Zapco tumbler		97.1%	0.7	861

Comparison of *Saccostrea* A growth at four sites

Baskets of 5–10mm *Saccostrea* A spat ($n = 4$) were deployed across four sites in July 2021 to assess differences in their growth. The sites were Flying Foam Passage, West Lewis, Cossack and Withnell Bay. Cossack and West Lewis were intertidal sites where baskets were exposed at low tide. Withnell Bay was a semi-subtidal site with a Flipfarm installation and Flying Foam Passage had both subtidal and intertidal lines installed.

The total weight (g) of oysters within the baskets was determined every one to four months depending on weather and staff availability. Average weight per oyster was calculated using the total basket weight and density. Oyster density of baskets occasionally needed to be reduced to allow space for oysters to continue growing. The same management practices were employed at all sites.

Oysters deployed to the intertidal site at Cossack grew larger than oysters at any other site. Within three months of deployment, the average weight of a *Saccostrea* A oyster at Cossack was 5.9g ± 1.7g. It took a further seven weeks to see a comparable mean weight at another site (Withnell Bay, 5.7g ± 1.4g). A Kruskal Wallis test (α = 0.05, n = 4) showed that the median weight per oyster at the conclusion of the trial was not the same at all sites (χ^2= 15.05, df = 4, p = 0.005). By the end of the trial, oysters at Cossack were, on average, two to seven times heavier than those grown at other sites (Table 14). The mean weight of oysters at Cossack was significantly greater than at all other sites, except Flying Foam Passage subtidal site. The oysters grown on the intertidal Flying Foam Passage farm were significantly smaller than those at Cossack and the Flying Foam Passage subtidal site, but not Withnell Bay and West Lewis, despite only putting on an average of 0.75g in 16 months. The mean weight of oysters at Withnell Bay Flipfarm did not differ from oysters on the subtidal Flying Foam Passage site or West Lewis intertidal site (Table 14).

Average oyster weight was similar at the intertidal site at West Lewis, the Flipfarm at Withnell Bay, and the subtidal site at Flying Foam Passage until May 2022 (~10 months) after which the average oyster weight at the subtidal Flying Foam Passage site increased beyond that at the intertidal West Lewis site (Figure 23).

Table 14. Mean weight (g) ± SE of *Saccostrea* A oysters grown at five sites in the Pilbara. Duration of deployment was different for each site and average weights differed significantly at the end of the trial. Statistical significance (sig) was determined via post-hoc Dunn test for multiple comparisons of groups (α = 0.05) following a significant Kruskal Wallis test.

Site	Type	Avg weight per oyster	Duration	Sig
Cossack	Intertidal	23.5 ± 4.9	13 months	a
Flying Foam Passage	Subtidal	11.1 ± 3.0	16 months	ab
Withnell Bay	Subtidal	7.8 ± 1.6	11 months	bc
West Lewis	Intertidal	7.7 ± 2.6	17 months	bc
Flying Foam Passage	Intertidal	3.2 ± 1.0	16 months	c

To confirm the oyster weight trends seen in the time series data above, a two-way, repeated measures ANOVA (α = 0.05, n = 4) was conducted at three-time intervals for each site (start, January 2022, and final measurements). The data was confirmed to be normally distributed (except for the final weight measurements from Withnell Bay after a basket was lost in May 2022, n = 3, p = 0.02) and without outliers.

There was a significant interaction between site and duration of deployment ($F_{8,44}$ = 15.95, p <0.001). Post-hoc comparisons were used to analyse the effect of site on the mean weight per oyster during the three deployment times on the farm. Considering Bonferroni adjusted p-values (p_{adj}), the simple main effect of site was not significant at the start of the experiment (p_{adj} = 1). This was expected as oysters were homogenised across treatments to achieve equal weights at deployment. The main effect of site became significant in January 2022 (6 months, p_{adj} < 0.001) and at the conclusion of the trial (or final measurement) for each site (p_{adj} < 0.001). The main effect of site was not significant for Flying Foam Passage intertidal (p_{adj} = 1), but was for Cossack (p_{adj} < 0.001), Flying Foam Passage subtidal (p_{adj} = 0.003), and Withnell Bay (p_{adj} = 0.005). West Lewis intertidal site was only just considered significant (p_{adj} = 0.045).

Pairwise comparisons further indicate that the mean weight per oyster was significantly different between oysters at the Cossack and Flying Foam Passage intertidal sites for both the middle-point and conclusion of the trial (p_{adj} = 0.002 and p_{adj} = 0.019, respectively). The mean weight per oyster was also different between Cossack and West Lewis in January 2022 (p_{adj} = 0.003), however not at the conclusion of the trial (p_{adj} = 0.236). No other differences in mean weight per oyster were significant at any site for either the January 2022 measurements or at the end of the trial, despite clear trends emerging (Figure 23). Within site differences across the three-time intervals were significant for Cossack, Flying Foam Passage subtidal and Withnell Bay indicating the mean weight per oyster continued to increase during their deployment on the farms (see Table App B.1).

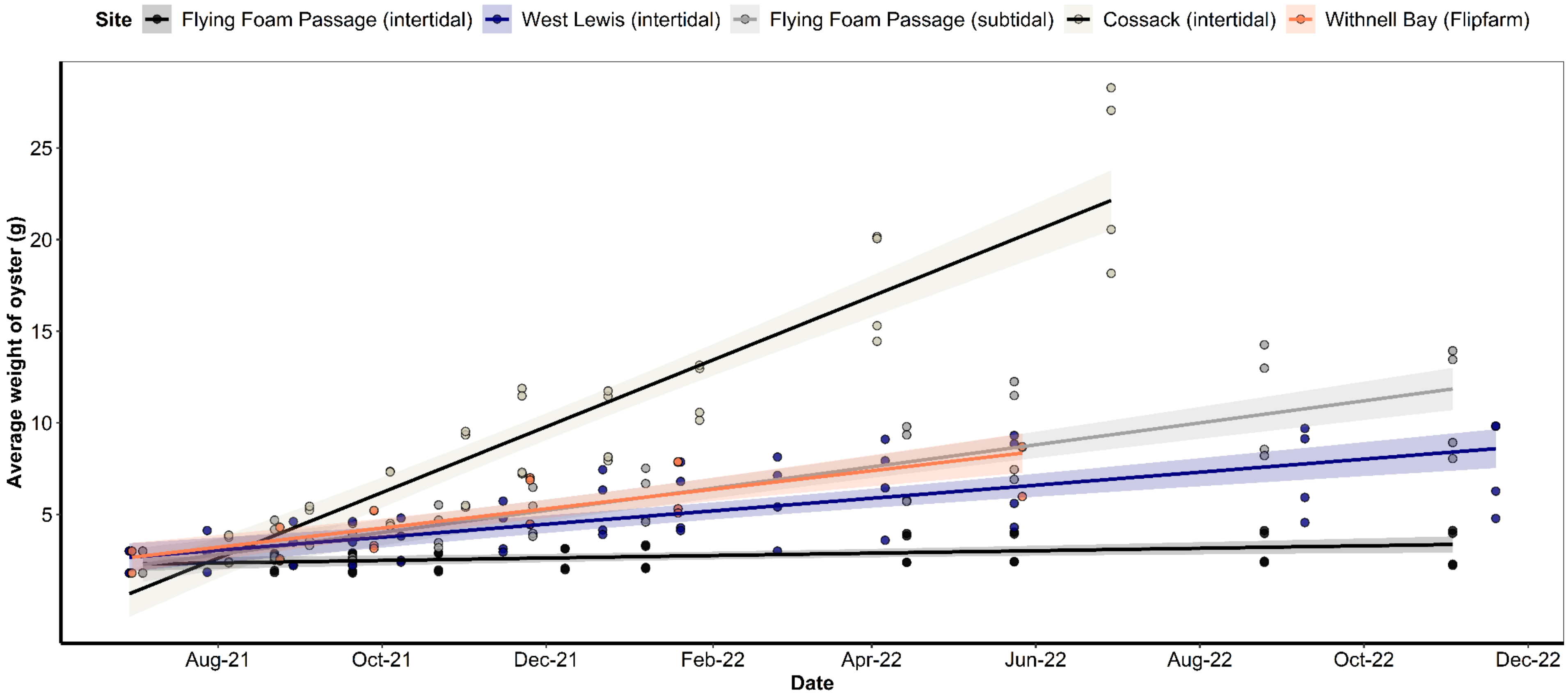

Figure 23. Average weight of *Saccostrea* A oysters grown at four Pilbara sites (Flying Foam Passage, Withnell Bay, West Lewis, and Cossack) varied greatly depending on site and farm type. A linear model of growth over time has been fitted for each site with 95% confidence ribbons.

Condition

Saccostrea A

Mean weight of oyster meat of *Saccostrea* A oysters increased significantly over the 106 days of the finishing trial (Figure 24). A three-way ANOVA ($\alpha = 0.05$) showed there was no significant interaction between prior husbandry techniques, basket type or density of oysters in the baskets in terms of mean meat weight of *Saccostrea* A oysters ($F_{1,16} = 0.01$, $p = 0.92$). There were also no significant two-way interaction effects between prior husbandry and basket type ($F_{1,16} = 0.08$, $p = 0.78$) or density and basket type ($F_{1,16} = 0.04$, $p = 0.85$), or any simple main effects of these three factors ($p > 0.17$) by the end of the trial. Any combination of densities and basket type was therefore equally as effective at increasing meat weight in this species regardless of prior husbandry techniques (Figure 24).

Meat condition (the proportion of meat mass to whole shell weight) increased for all oysters that had previously been rumbled in floating SEAPA baskets for four months ($p < 0.016$). Of the stock that had never been rumbled, only the low density, floating SEAPA baskets showed a significant increase in meat condition ($T = 12.98$, $df = 2$, $p = 0.006$). There was a significant two-way interaction effect between basket type and density ($F_{1,16} = 8.05$, $p = 0.01$), and a simple main effect of both basket type ($F_{1,16} = 38.7$, $p < 0.001$) and prior husbandry techniques ($F_{1,16} = 237.7$, $p < 0.001$). There was a statistically significant simple main effect of basket type for high stocking densities with both previously rumbled ($F_{1,16} = 34.9$, $p < 0.001$) and static-only stock ($F_{1,16} = 9.95$, $p = 0.06$), but no significant effect for low stocking densities regardless of prior husbandry ($p > 0.09$).

For all basket and density combinations, stock that had previously been rumbled had a higher mean meat condition than their static intertidal counterparts (Figure 24). Previously rumbled stock re-deployed into rumbling gear had higher meat condition scores than those that were switched back to a static Hexcyl basket, although this was only significant in the case of the high-density treatment ($p < 0.005$). As there were no differences between mean meat weight of any treatments, differences in meat condition are more likely to have been caused by differences in shell and overcatch weight.

To account for this weight bias due to overcatch oysters, the meat condition score was recalculated after applying a correction factor to the total oyster weight[1]. This confirmed that the presence of overcatch disproportionately understated the meat condition values for all treatments (). *Saccostrea* A oysters that had never been rumbled prior, showed an increase in meat condition from between 6.2% - 7.3% once overcatch was accounted for. Previously rumbled stock's meat condition was also between 3.4% and 4.2% greater once overcatch was accounted for. This shows the importance of managing overcatch.

S. echinata

Independent T-tests ($\alpha = 0.05$) were used to assess the impact of density on meat weight and condition within the finishing trial. Condition measurements (meat weight and meat condition) did not differ between the two densities within the same site, basket and prior husbandry treatments ($p > 0.37$). The density treatments were then pooled for further analysis. Mean meat weight of all treatments and sites increased over the 106-day trial, except for the hanging SEAPA baskets at Flying Foam Passage where stock had never been rumbled ($T = 0.46$, $df = 10$, $p = 0.17$). While meat weight of this treatment appeared to increase slightly over 106 days, it did not differ significantly from the start of the trial (Figure 25). Mean meat condition did not change significantly over the course of the trial for most treatments except for both the previously rumbled and static-only hanging SEAPA basket treatments at Cossack site ($p = 0.006$ and $p < 0.001$ respectively), which lost meat condition (Figure 25).

Husbandry techniques did not increase meat condition of *S. echinata* over the 106-day finishing trial. Some treatments lost meat condition, while others maintained or only slightly improved condition over the course of the trial. It is likely shell or overcatch weight increased relative to oyster meat during this trial. When the same overcatch adjustment was applied to *S. echinata* as described above, meat condition for oysters at Cossack intertidal site increased from between 4.0% to 5.7% and 1.8% to 2.5% for those at Flying Foam Passage ().

[1] An adjustment factor was applied to the total shell weight of each treatment to account for the percentage of the total weight that could reasonably be attributed to overcatch instead of the cultivated oyster of interest. The adjustment factors used are shown in Table App B.2 of Appendix B.

Table 15. A percentage of meat weight per whole oyster weight (meat condition) was calculated in oysters with overcatch on their shell. The account for the fact that this would cause a reduction in true meat condition of the cultivated oyster given there were big differences in overcatch between sites and treatments, an overcatch adjustment factor was applied to the whole oyster weight to standardise by the mean overcatch percent (see Table App B.2 for these values).

Species	Site	Prior Husbandry	Gear type	Density	Meat condition (%)	
					With overcatch	Adjustment for overcatch applied
Saccostrea A	Cossack	Static intertidal (14 months)	Floating SEAPA	High	8.95 ± 0.58	15.33 ± 0.99
				Low	8.62 ± 0.17	14.78 ± 0.28
			Hexcyl	High	7.20 ± 0.19	14.07 ± 0.37
				Low	7.63 ± 0.40	14.90 ± 0.78
		Rumbled (4-months SEAPA)	Floating SEAPA	High	13.75 ± 0.29	17.33 ± 0.36
				Low	13.04 ± 0.45	16.43 ± 0.56
			Hexcyl	High	10.49 ± 0.31	14.12 ± 0.42
				Low	12.16 ± 0.53	16.36 ± 0.72
S. echinata	Cossack	Static intertidal (18 months)	Hanging SEAPA		7.56 ± 0.17	13.28 ± 0.29
		Rumbled (9-months SEAPA)	Hanging SEAPA		9.24 ± 0.21	13.62 ± 0.30
			Floating SEAPA		10.52 ± 0.16	14.53 ± 0.22
	Flying Foam Passage	Static intertidal (18 months)	Hanging SEAPA		9.24 ± 0.22	11.76 ± 0.28
		Rumbled (9-months SEAPA)	Floating SEAPA		10.77 ± 0.34	12.55 ± 0.39
					11.21 ± 0.42	13.62 ± 0.51

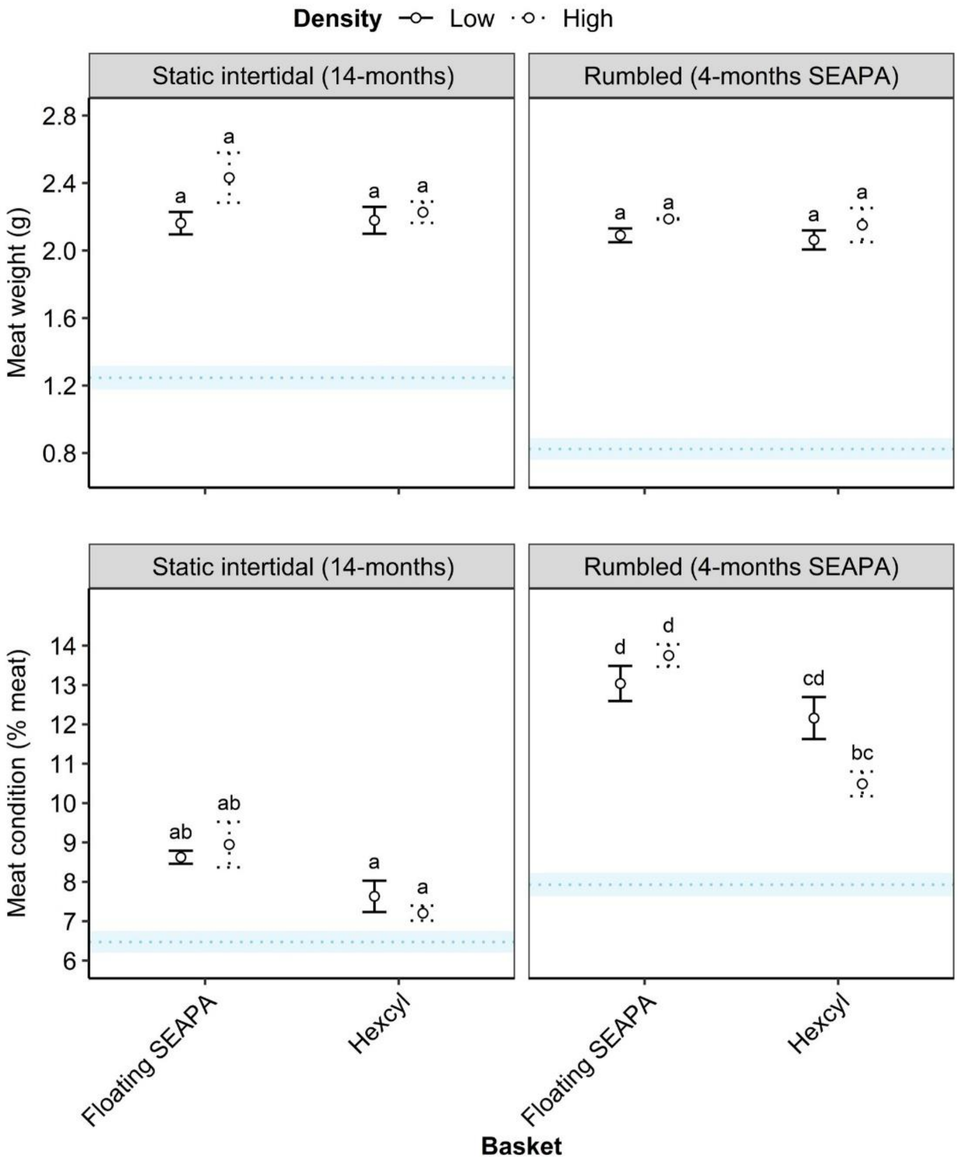

Figure 24. Mean meat weight and meat condition (percentage meat weight) of *Saccostrea* A oysters with two stock husbandry histories (static intertidal or rumbled) deployed to Cossack intertidal site in static hanging or rumbling (floating) SEAPA baskets at two densities (low and high) for 106 days. Data points with the same letters have statistically similar means.

Previous studies have shown buoyant gear systems similar to those used in this study result in slower growth (shell height), deeper cups, heavier shell, greater meat weight, and lower biofouling than static gear (Leavitt et al., 2017). Similar trends were found in our trials except for an increase in meat weight in rumbling gear types. By the end of our field trials, the oysters had not yet achieved a marketable weight. *Saccostrea* A meat weight was between 2–3g by the end of the trial, whereas a cocktail size (45–55mm) Sydney rock oyster would go to market with 7g of meat weight (Ryan, 2008). Rankin et al. (2018) reported meat condition scores of Sydney rock oysters between 20–30% while the *Saccostrea* A oysters in our Pilbara trials had achieved about half this meat condition by the end of the trial. Meat weight of *S. echinata* oysters was higher than *Saccostrea* A at 3–4.5g, but this was still about half the marketable meat weight of Pacific oysters at 9.0g (Ryan, 2008). It is important to note that our trial took place between May and September, with an average water temperature off the Pilbara coast of 28.0°C ± 0.27°C and the lack of condition in our tropical rock species compared to Pacific and Sydney rock oysters could be seasonal rather than due to other factors tested in our trials. Additionally, *S. echinata* grown in the Pilbara is outside of its natural range and the cool season temperatures of the Pilbara may have impacted its ability to condition up.

The two WA tropical rock species investigated in our trials will continue to be grown in the Pilbara until they have reached marketable size and condition. The field trials have shown that buoyant gear produces a different product to static gear. Static gear promotes growth parameters in both species, however buoyant gear helped to reduce overcatch, improve meat condition and optimise shell shape (when aiming for a score of 4.5). Farmers should therefore aim to find an optimum balance between the fast growth rates associated with static gear and the lower overcatch (and therefore labour), deeper shell cups and higher meat condition associated with buoyant gear.

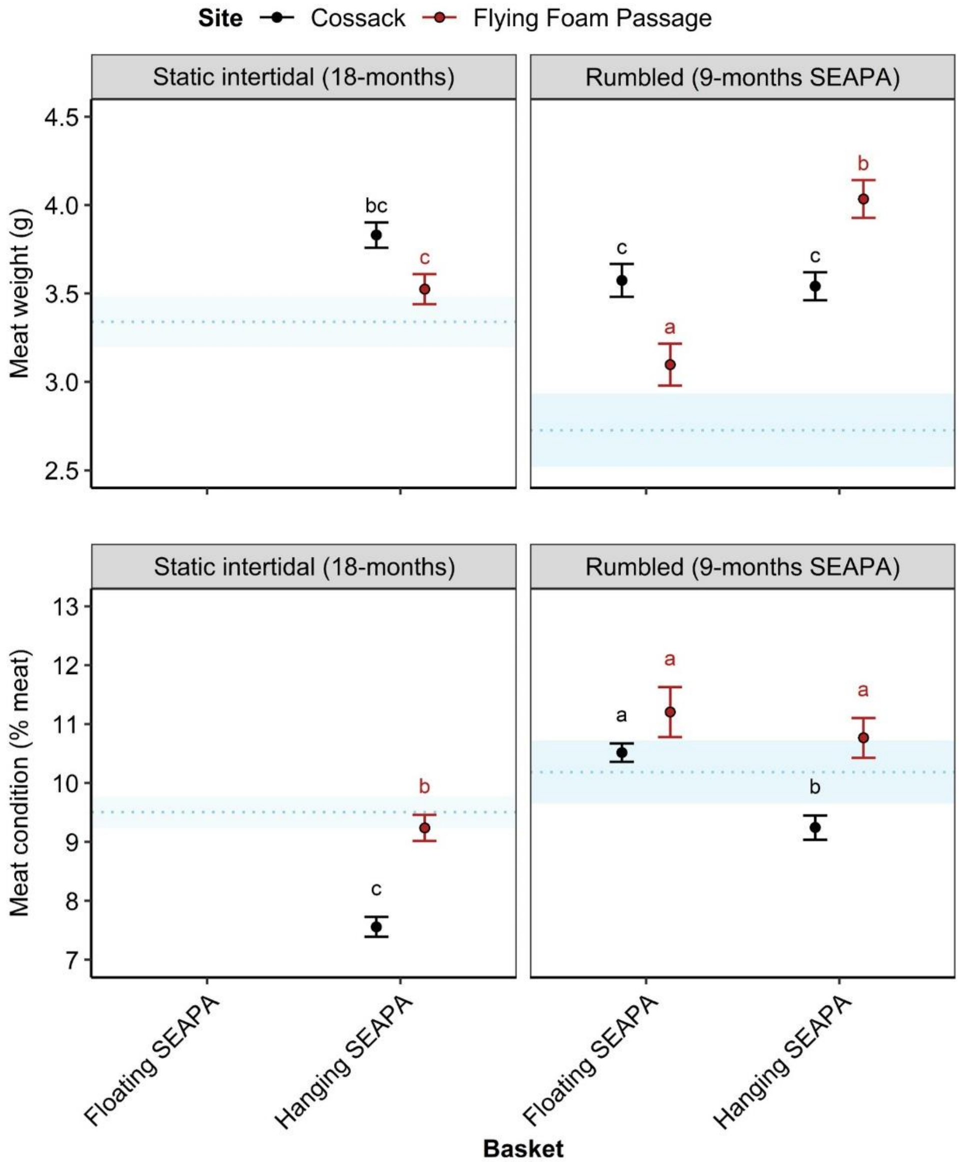

Figure 25. Mean meat weight and meat condition (percentage meat weight of whole oyster adjusted for overcatch) of *S. echinata* oysters with two stock husbandry histories (static intertidal or rumbled) deployed to either Cossack or Flying Foam Passage intertidal sites in static hanging or rumbling (floating) SEAPA baskets for 106 days. Data points with the same letters have statistically similar means.

Kimberley grow-out

A small number of *S. echinata* oysters (n = 267) were grown at an intertidal site in Cone Bay for 13 months from December 2020 to January 2021, despite challenges establishing farm sites in the area (see Site setup section). Total survival over this period was 61.1% and oysters reached an average length of 52.4mm ± 0.58mm and weight of 29.5g/oyster. The highest average weight of an *S. echinata* oyster at any of the Pilbara sites in January 2021 was 22.3 g/oyster with an average length of 50.12mm ± 0.55mm. The average shape score of the Kimberley oysters was 3.76 ± 0.10 indicating good cup development with a slightly wider profile (Figure 26).

Figure 26. *S. echinata* oysters grew well at an intertidal site in Cone Bay over 13 months, reaching 50mm length and developing a favourable cup shape.

The growth and performance of *S. echinata* oysters was significantly better in the Kimberley than in the Pilbara, however the trials were not set up for direct regional comparison. The Pilbara trials were stocked at higher densities than the Kimberley trials which likely gave a growth advantage to the Kimberley stock. However, Pilbara stock spent an additional nine months at site and while there was negligible overcatch on Kimberley oysters, an average of 20% of oyster weight in the Pilbara trials was attributed to unmanaged overcatch. In addition, the Kimberley stock were rumbled in Zapco tumblers early in their deployment, while Pilbara stock were grown only in hanging intertidal baskets, which may have resulted in a greater shell weight for Kimberley stock. It is nonetheless interesting to note the potential of *S. echinata* as an aquaculture species when grown in its natural geographical range.

Overcatch

Overcatch is a type of fouling where 'pest' oysters settle and grow on cultivated oysters. Overcatch oysters can be the same species as farmed oysters or recruit onto the farm from nearby populations of wild oysters. It is also possible for farmed oysters to spawn, creating their own overcatch offspring. Managing overcatch on oyster farms is an important consideration as it increases labour requirements and compromises the marketability of farmed oysters (Cox et al., 2012). Both species, *S.echinata* and *Saccostrea* A experienced a high degree of overcatch at the Cossack intertidal site (Figure 27 and Figure 28), particularly on the bottom shell (Figure 29).

Figure 27. Growth of overcatch oysters was more prolific on cultivated *S. echinata* oysters at Cossack intertidal site when grown in static gear types (hanging intertidal Hexcyl). The rumbling action on oysters when grown in buoyant gear (floating SEAPA) helped reduce the prevalence of overcatch.

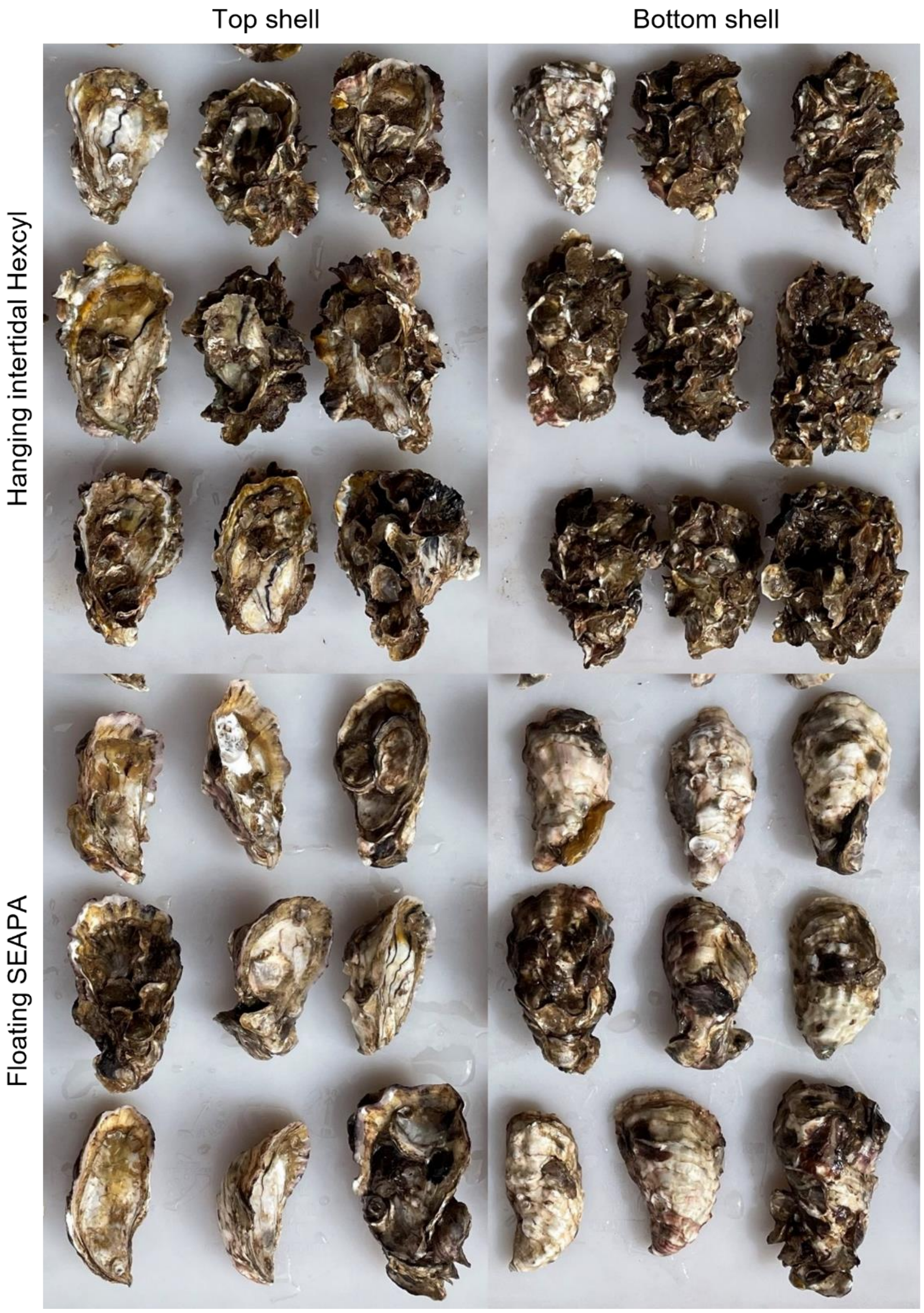

Figure 28. Growth of overcatch oysters was more prolific on cultivated *Saccostrea* A oysters at Cossack intertidal site when grown in static gear (hanging intertidal Hexcyl). The rumbling action on oysters when grown in buoyant gear (floating SEAPA) helped reduce the prevalence of overcatch.

Figure 29. Cultivated *S. echinata* with overcatch oysters on its top and bottom shells.

Tumbling action to mitigate dominance of overcatch

A sample of oysters (n = 10) was taken from each basket at the end of the finishing trial (Experiment 6: Finishing trials). The whole weight of the cultivated oysters was measured along with any overcatch still intact. All overcatch was then removed with oyster knives and the cultivated oyster reweighed. The weight of overcatch was calculated as the difference between these two measurements. To standardise for differences in the size of cultivated oysters, the proportion of overcatch on each cultivated oyster was then calculated:

$$\text{Overcatch proportion} = \frac{\text{Overcatch weight}_{(g)}}{\text{Cultivated oyster weight}_{\text{overcatch removed (g)}}}$$

Any value over 1.0 indicates that there was more overcatch (by weight), than farmed oyster.

A two-way ANOVA ($\alpha = 0.05$) was conducted to determine if there was a significant interaction between prior husbandry techniques and basket type for *Saccostrea* A oysters deployed to the Cossack intertidal site over 106 days. There was no significant interaction between these two factors ($F_{1,31} = 4.02$, $p = 0.24$), however the main effect of both basket type ($F_{1,31} = 11.7$, $p = 0.002$) and prior husbandry techniques showed a significant impact on the mean proportion of overcatch on cultivated oysters. Pairwise comparisons showed that rumbling oysters in a floating SEAPA basket for four months prior significantly reduced the mean amount of overcatch on *Saccostrea* A oysters ($F_{1,31} = 140.8$, $p < 0.001$), regardless of whether they then spent another 3.5 months in a hanging intertidal (Hexcyl) basket or remained in a floating SEAPA basket for the same time ($p = 0.39$, Figure 30). Oysters that had never been exposed to a rumbling gear type (static intertidal oysters in Hexcyl baskets) had proportionally more overcatch than those that spent the final 3.5 months on the farm in a floating SEAPA basket ($p = 0.01$).

A one-way ANOVA[2] ($\alpha = 0.05$) determined that prior husbandry techniques and basket type influenced the mean proportion of overcatch on *S. echinata* oysters deployed to a finishing trial at Cossack intertidal site ($F_{2,14} = 35.57$, $p < 0.001$). Post-hoc Tukey's tests showed that *S. echinata* oysters that had never been rumbled, had a greater mean proportion of overcatch than those that had been rumbled in floating SEAPA baskets for the previous nine months ($p_{adj} < 0.001$, Figure 30). For oysters that had been previously rumbled, there was no significant difference in the mean proportion of overcatch between those that were then switched to a static intertidal basket (Hanging SEAPA) and those that remained in floating SEAPA baskets ($p_{adj} = 0.16$).

Farmers can therefore be confident that modifying husbandry techniques and using different gear types will help with the management of overcatch of both *Saccostrea* A and *S. echinata* oysters in northern WA. Once overcatch has started to colonise the shells of cultivated oysters, rumbling baskets should be used to prevent overcatch during spawning season and to reduce the dominance and establishment of overcatch. Rumbling gear types should be used relatively early in the grow-out phase (~22mm) to minimise the amount of overcatch, particularly for *Saccostrea* A oysters. While there was a trend towards less overcatch on oysters that remain in rumbling gear for longer, this was not significant. Therefore, since static gear

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[2] A FF two-ANOVA could not be conducted as there were no stock from static intertidal husbandry put into floating SEAPA's for this species.

types tend to promote better growth metrics in oysters, a combination of rumbling and static gears should be used depending on the production goals sought.

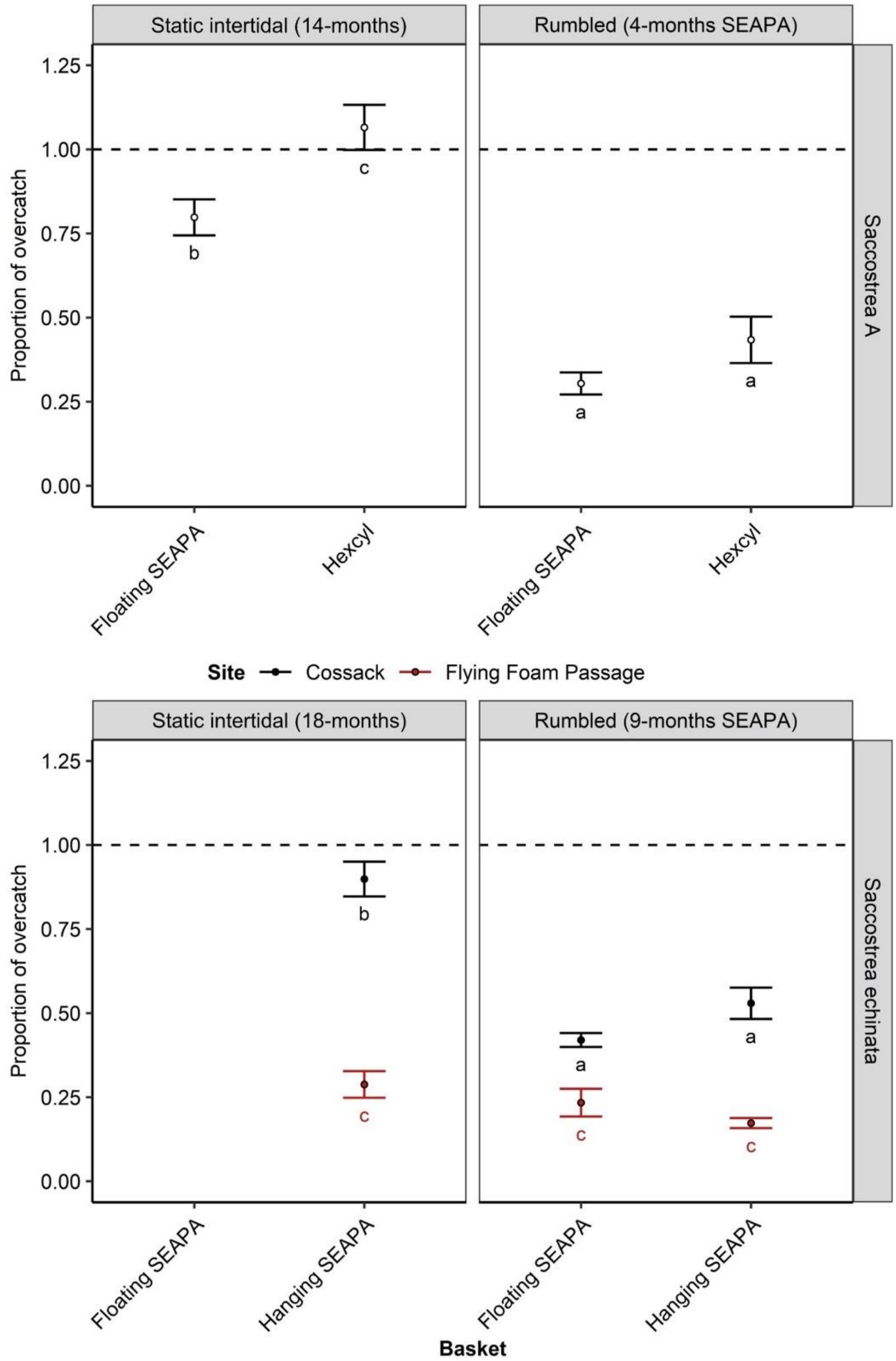

Figure 30. Mean proportion of overcatch colonising farmed *Saccostrea* A (empty dot) and *S. echinata* (filled dot) oysters at the Cossack intertidal site (black lines). Overcatch was greater in stock that had never been rumbled in a buoyant gear type. Mean proportion of overcatch on *S. echinata* oysters was also greater at the Cossack site than the Flying Foam Passage intertidal site (red lines). Mean proportions greater than one (---) indicate the weight of overcatch was higher than the farmed oyster itself. Within each species comparison, data points with the same letter indicate no significant difference in means.

A two-way ANOVA ($\alpha = 0.05$) was used to determine the influence of site on mean proportion of overcatch for *S. echinata* oysters deployed at either the Cossack intertidal or Flying Foam Passage intertidal sites. There was a significant interaction between site and the combination of basket and prior husbandry ($F_{2,27} = 15.4$, $p < 0.001$). There was a statistically significant difference in mean proportion of overcatch between basket and prior husbandry at the Cossack site ($F_{2,27} = 41.5$, $p < 0.001$), but not at the Flying Foam Passage site ($F_{2,27} = 2.23$, $p = 0.13$). Prevalence of overcatch was much less on *S. echinata* oysters deployed at the Flying Foam Passage intertidal site. It is unclear if this was because the overcatch did not continue to grow while at Flying Foam Passage, or if overcatch was somehow removed while at the site. Moving oysters between growing and/or harvest sites could therefore be another effective way to manage overcatch.

Impact of overcatch on shape score measurements

A repeated measures ANOVA (α = 0.05) showed there was a significant interaction between removing overcatch on *S. echinata* oysters and the combination of basket type and prior husbandry ($F_{2,28}$ = 1.96, p = 0.01). Removing overcatch had a significant impact on the mean shape score for *S. echinata* that were in rumbling gear (floating SEAPA) for more than 12 months ($F_{4,1}$ = 51.7, p = 0.006), switched from rumbling gear after nine months back into a static intertidal gear for three months ($F_{5,1}$ = 21.4, p = 0.012), and in static intertidal gear for 21-months ($F_{5,1}$ = 274, p <0.001). The magnitude of this change was greater for stock that had never been rumbled or rumbled less. This aligns with the overcatch weight data above that showed these oysters had a greater proportion of overcatch on them and therefore once removed, were most likely to experience the greatest change in overall shell dimensions (Figure 31). Removing overcatch brought *S. echinata* oysters closer to the ideal shape score of 4.5 indicating this species was growing a well-rounded and cupped shape at the Cossack intertidal site.

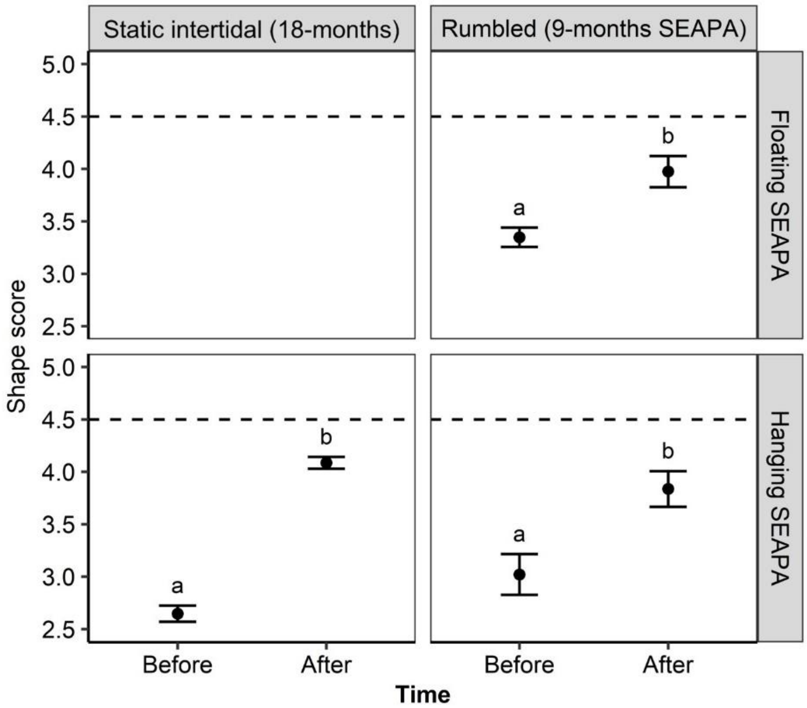

Figure 31. Mean shape score of *S. echinata* oysters at the Cossack intertidal site. Mean shape improved once overcatch was cleaned from oysters regardless of basket type (floating or hanging SEAPA) or prior husbandry techniques (static intertidal or rumbled). Farmed oysters were narrower and flatter once overcatch was managed. The dashed line represents the ideal shape score of 4.5.

For *Saccostrea* A oysters, there was a significant interaction between prior husbandry techniques and removing overcatch ($F_{64,1}$ = 4.37, p =0.041) and the simple main effect of removing overcatch ($F_{64,1}$ = 61.50, p < 0.001). Post-hoc pairwise comparisons confirmed that there was initially a difference in the mean shape score of previously rumbled oysters and those that had never been rumbled (p_{adj} = 0.005), however once overcatch was removed, there was no longer a difference (p_{adj} = 0.88). This trend was also seen with *S. echinata* oysters and reflects the impact of overcatch on shape score. Oysters in both floating SEAPA and Hexcyl baskets improved in shape score once overcatch was removed, regardless of prior husbandry techniques. Initially, all treatments had oysters with a similar shape score (3.91 ± 0.16 to 4.71 ± 0.18), however once overcatch oysters were removed, cultivated oysters were narrower, and flatter than originally measured (5.23 ± 0.25 to 5.65 ± 0.26, Figure 32).

The mean shape score of oysters that were never rumbled was significantly higher than oysters in floating SEAPA baskets for this trial (Figure 32). Oysters that had never been in rumbling gear (static intertidal stock in Hexcyl baskets) had significantly narrower, flatter shells than stock in floating SEAPA baskets. Unlike *S. echinata*, removing overcatch from *Saccostrea* A rendered the oyster shells further from the ideal shape score of 4.5 (Figure 32) and more work is therefore required to deepen the cup of this species.

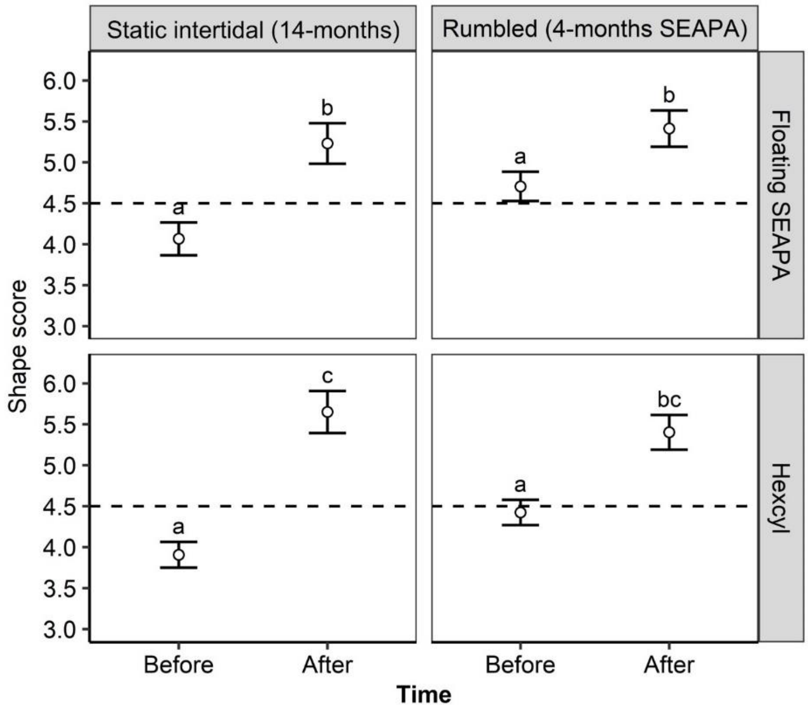

Figure 32. Mean shape score of *Saccostrea* A oysters at the Cossack intertidal site. Shape score improved once overcatch was removed, regardless of basket type (floating SEAPA or Hexcyl) or prior husbandry techniques (static intertidal or rumbled). Initially, all treatments had a similar shape score, however once overcatch oysters were removed, the remaining oysters were narrower and flatter. Oysters that had never been in rumbling gear (static intertidal stock in Hexcyl baskets) had significantly narrower, flatter shells than stock in floating SEAPA baskets. Means with the same letter are not significantly different. The dashed line represents the ideal shape score of 4.5.

Removing overcatch once established

Management and removal of overcatch and biofouling is one of the most time-consuming and labour-intensive components of oyster farming. Once overcatch and other fouling species have settled on cultivated oysters they are very challenging to remove. Previous work on overcatch management in Australia has predominately occurred on east-coast Pacific and Sydney rock oysters that live under cooler conditions than tropical rock oysters. Rock oysters in the Pilbara experience little mortality when emersed for short periods at low tide as air temperatures approach high 40°C temperatures. A traditional method to manage overcatch airtime by leaving oysters out the water for several days. Repeated airing of oysters can kill off overcatch when they are still small. Another method then utilised for larger cultivated oysters is ‘cooking’ them at 80°C for up to three seconds to kill any overcatch living on cultivated shells. While this does not always kill the cultivated oyster, it does cause a degree of mortality and deconditioning to farmed oysters. This method is generally used when missed the window to use less risky methods such as airing as the overcatch are now larger and more established. It was also hypothesised that tropical rock oysters may be hardier than cooler-climate oysters and therefore more able to tolerate ‘cooking’ at smaller sizes.

To assess the tolerance of tropical *S. echinata* to ‘cooking’, 16–22mm hatchery-bred oysters with overcatch (mean weight = 8.7g, n = 9) were brought back from the field after about eight months and immersed in freshwater at either 23°C (control), 60°C, 70°C, or 80°C for 10–40 seconds. Immediately following the exposure period, the oysters were placed back in 22°C seawater. The proportion of dead vs. live overcatch and the survival of cultivated hatchery oysters (or hosts) were assessed six days later.

For *S. echinata* spat, immersion in 60°C freshwater killed 100% of overcatch when sustained for 40 seconds, however this also killed 25% of the cultivated oysters the overcatch was living upon. Host survival of 89–100% was achieved at this temperature in 10–30 seconds exposures, however the amount of overcatch that was successfully killed was also reduced, making it an ineffective treatment. Increasing the temperature to 70°C and 80°C degrees resulted in 96–100% of overcatch being killed for all durations, except the 10 seconds at 70°C treatment. However, host survival was reduced to between 22–78%, again making these treatments ineffective for managing overcatch. By comparison, when much larger broodstock underwent similar ‘cooking’ trials host survival was 100% while overcatch mortality was 61–100%.

Size of the host oyster is therefore an important factor when using ‘cooking’ treatments to manage overcatch. At 16–22mm, the overcatch on *S. echinata* oysters can be reduced with a 30 second 60°C or 10 second 70°C treatment. However, there is not much room for error (+10 seconds) and the sample size here was small, so these treatments may not translate to a large-scale commercial operation. Overcatch on 16–22mm farmed oysters in the Pilbara is problematic with overcatch continuing to grow and become more established the longer the issue is unmanaged. Overcatch should be addressed as early as possible while cultivated oysters are small. Alternative methods such as cold-shock (Cox et al., 2012), emersion (extended airtime), basket rotation and selection, and manual removal should be considered.

Further Research

The tropical rock oyster field trials in the Pilbara and (to a lesser extent) Kimberley have demonstrated that both *Saccostrea* A and *S. echinata* are promising aquaculture products for operators in northern WA. Due to disruptions throughout the project, oysters were not deployed to site long enough to reach market size and quality, and therefore commercial partner Maxima Rock Oyster Company Pty Ltd will continue to grow these oysters following the conclusion of these trials. Given the promising results seen in the Kimberley and that this region is *S. echinata's* natural habitat, further trials should be attempted in this region once spat can be secured and sites can be serviced more reliably.

Such productive, warm waters bring substantial overcatch and biofouling issues. Once further batches of tropical rock oyster spat can be secured, the mitigation and management of overcatch and biofouling in northern WA needs further investigation. Developing strategies to prevent overcatch (e.g., understanding seasonality and spawning windows and breeding triploid oysters) and manage overcatch once it has established (eg. air drying or freezing) would greatly reduce the manual labour associated with physically removing overcatch from cultivated oysters.

S. echinata were approaching marketable size and shape and so market research is now required to understand the size, shape, condition, quality, and taste preferences for this species in northern WA. Similarly, the largest *Saccostrea* A oysters were approaching the maximum size that they have been observed at in the wild. Therefore, it is important to determine the maximum size achievable under farming conditions. Once product is available for sale, industry should focus on understanding market demand for tropical rock oysters and explore a range of logistic and business models in a northern WA context. Tropical rock oyster farming is a low-trophic aquaculture commodity that lends itself to a range of business models from farmgate tourist sales, community-based farming in remote areas (e.g., Dampier peninsula), up to large scale operations. It is important to continue to find suitable sites for growing oysters in northern Australia and develop industries around traditional owner-operated sites.

Further work needs to be done by government in securing reliable and regular sources of spat for industry to continue to explore opportunities in tropical rock oyster farming in northern WA. Government should support further trials in northern WA with existing and new proponents in a range of sites to better define optimal farming conditions.

Appendix A Design specifications for ocean-based nursery systems

Floating Upweller System (FLUPSY)

The overall dimensions of each FLUPSY unit was 1500mm x 1500mm x 900mm and 40kg.

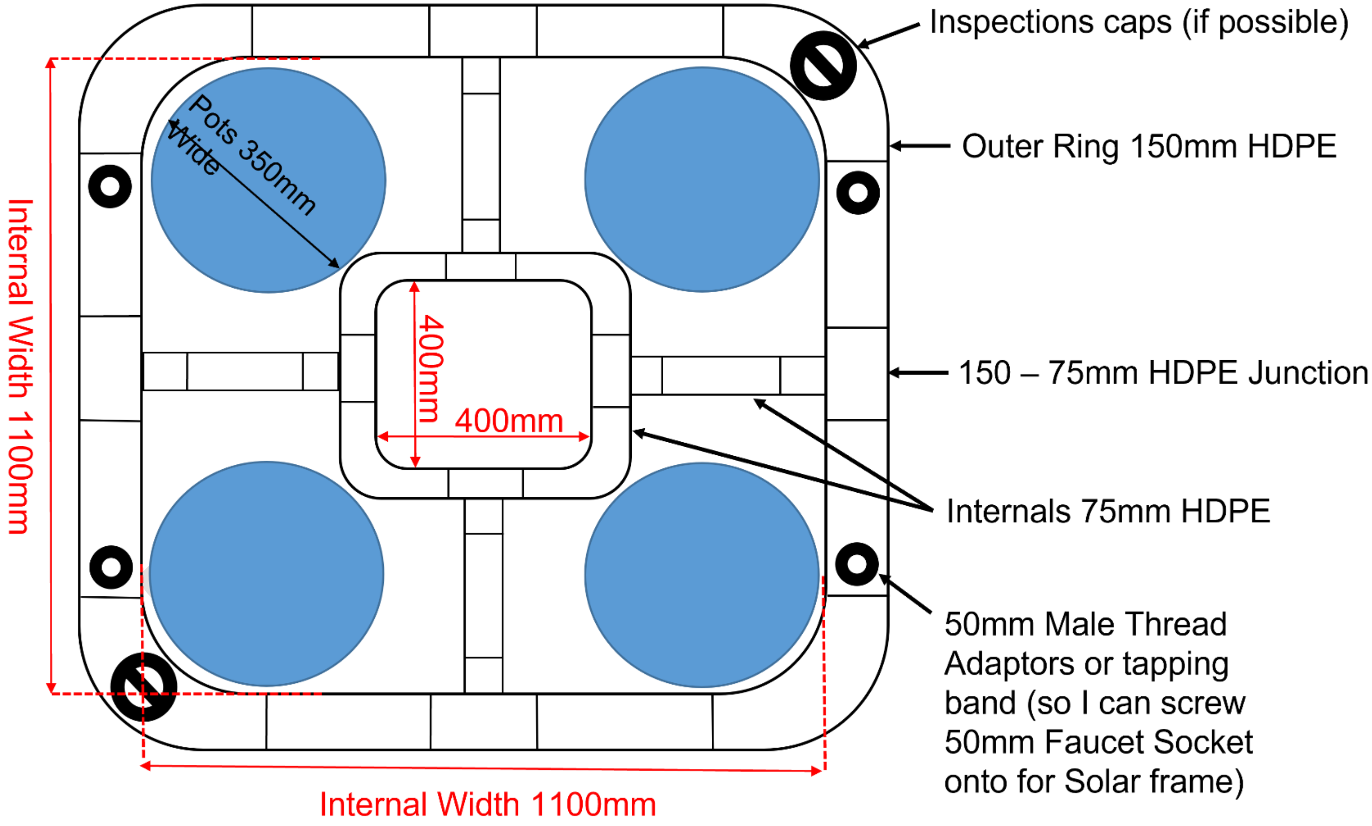

Figure App A.1 Dimensions of the solar floating upweller system used in ocean-based nursery trials in the Pilbara.

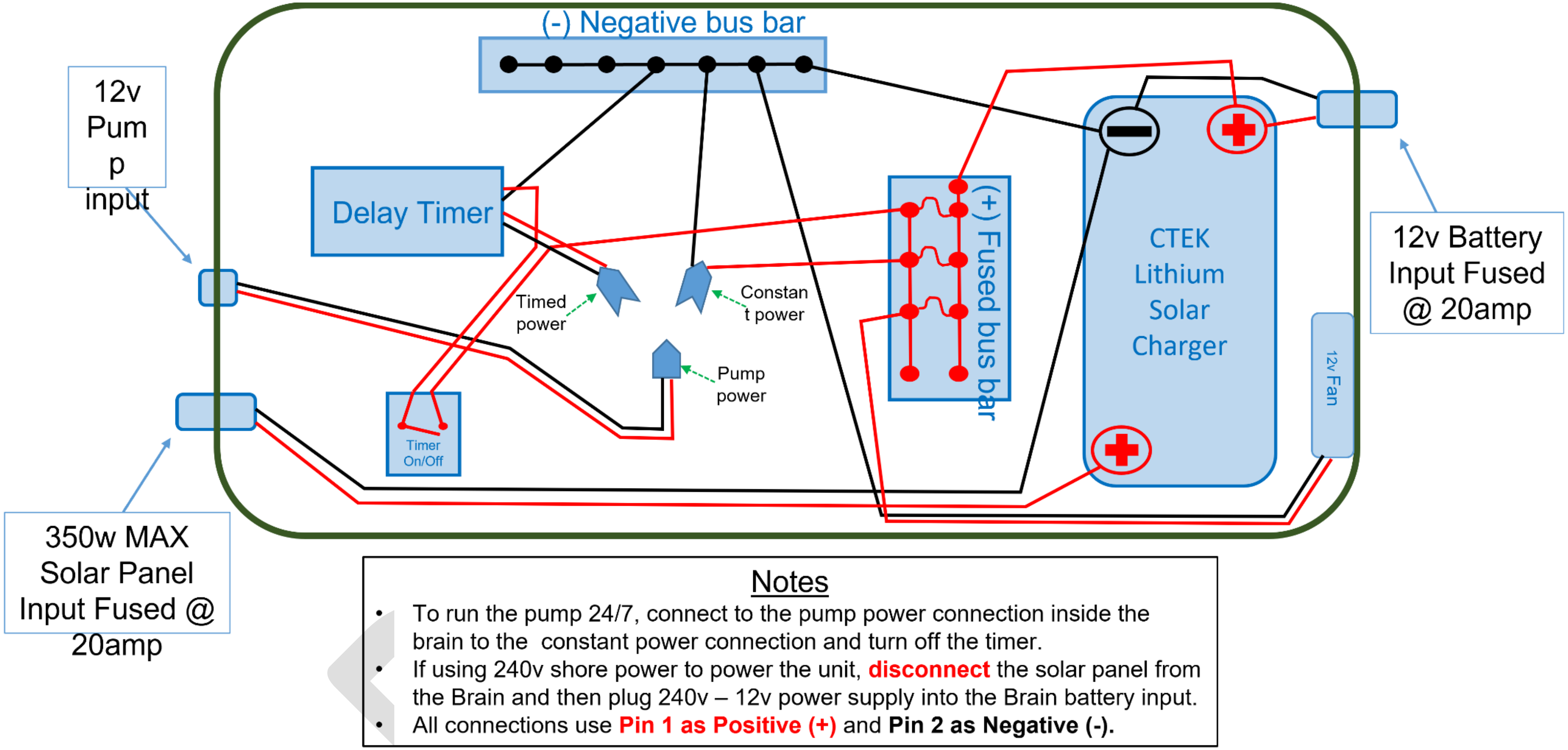

Figure App A.2 Schematic diagram of the 'electrical brain' that controlled the pump and contained the solar powered-battery on the solar floating upweller system used in ocean-based nursery trials in the Pilbara.

Figure App A.3 Image of FLUPSY's electronic brain housed in waterproof pelican case.

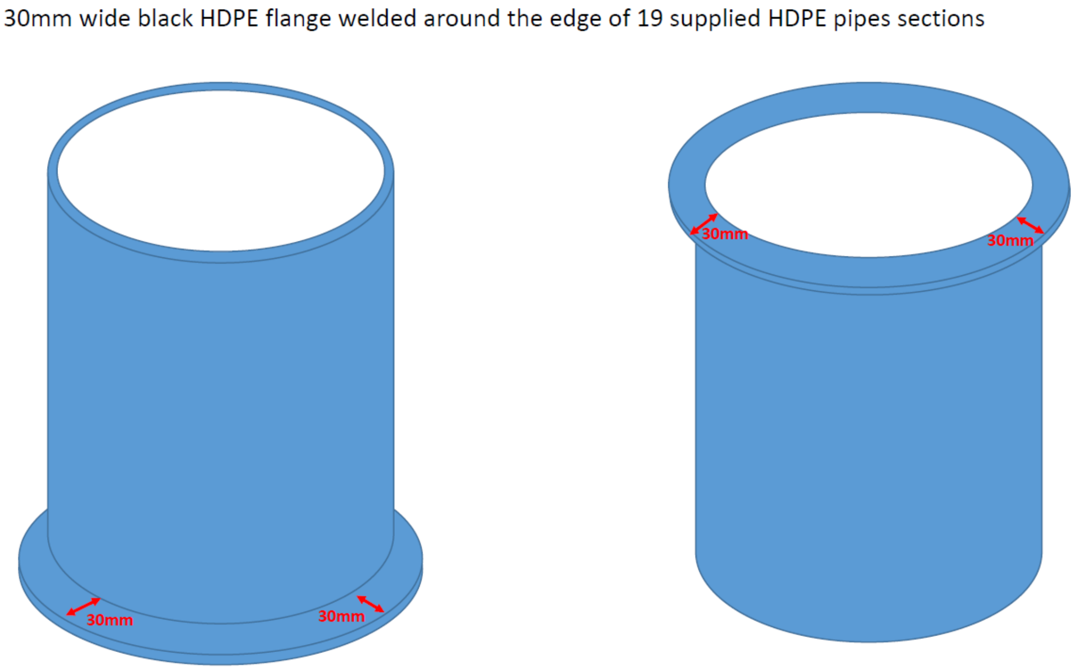

Figure App A.4 Diagram of the high-density polyethylene spat pots that fit into the solar FLUPSY frame.

Spat tray dimensions

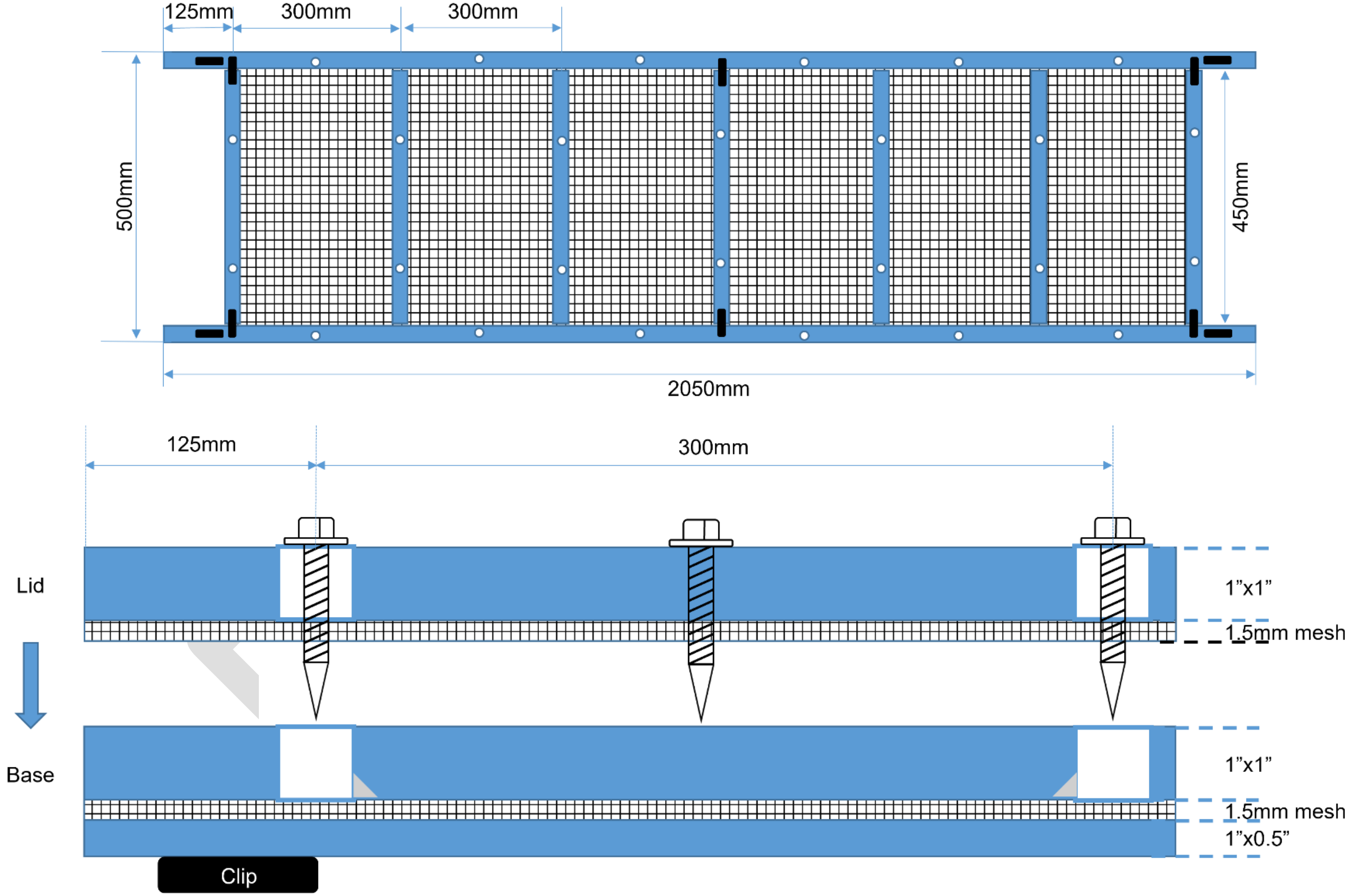

Figure App A.5 Dimensions of spat trays that were fitted with 1.4mm oyster mesh and deployed to the long line at Cossack intertidal site.

Appendix B Statistics

Growth of Saccostrea A at Pilbara sites

Table App B.1. Statistical output from post-hoc pairwise comparisons (following two-way repeated measures ANOVA) of the mean weight per *Saccostrea* A oyster at five sites in the Pilbara for three-time intervals (start, January 2022, and at the conclusion of the trial).

Site	Comparing time interval		Statistic	df	p	$p_{adjusted}$
Cossack (intertidal)	Start	Jan-2022	21.0	3	<0.001	<0.001
	Jan-2022	Conclusion	6.98	3	0.006	0.018
	Start	Conclusion	9.94	3	0.002	0.007
Flying Foam Passage (intertidal)	Start	Jan-2022	13.7	3	<0.001	0.003
	Jan-2022	Conclusion	2.74	3	0.071	0.214
	Start	Conclusion	4.29	3	0.023	0.07
Flying Foam Passage (subtidal)	Start	Jan-2022	8.75	3	0.003	0.009
	Jan-2022	Conclusion	6.09	3	0.009	0.027
	Start	Conclusion	7.40	3	0.005	0.015
Withnell Bay (Flipfarm)	Start	Jan-2022	9.67	3	0.002	0.007
	Jan-2022	Conclusion	15.8	2	0.004	0.012
	Start	Conclusion	10.4	2	0.009	0.028
West Lewis (intertidal)	Start	Jan-2022	5.61	3	0.011	0.034
	Jan-2022	Conclusion	0.87	3	0.451	1
	Start	Conclusion	3.26	3	0.047	0.141

Overcatch adjustment factors for meat condition calculations

Table App B.2. The amount of overcatch on the shells of cultivated oysters varied greatly between treatments and sites and therefore the average percentage of overcatch was calculated for each treatment and an adjustment factor applied to the total oyster weight taken for oysters measured for condition samples.

Species	Site	Prior Husbandry	Gear type	Average amount of overcatch (%)	Adjustment factor
Saccostrea A	Cossack	Static intertidal (14 months)	Floating SEAPA	41.7	0.417
			Hexcyl	48.8	0.488
		Rumbled (4-months SEAPA)	Floating SEAPA	20.7	0.207
			Hexcyl	25.7	0.257
S. echinata	Cossack	Static intertidal (18 months)	Hanging SEAPA	43.1	0.431
		Rumbled (9-months SEAPA)		32.1	0.321
			Floating SEAPA	27.6	0.276
	Flying Foam Passage	Static intertidal (18 months)	Hanging SEAPA	21.5	0.215
		Rumbled (9-months SEAPA)	Floating SEAPA	14.2	0.142
				17.7	0.177

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