OYSTERECOVER:
The Efficiency of Different Types of Oyster Spat Collectors for *Ostrea edulis*

Anneke van den Brink

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COV 2. B-1049 Brussels
Belgium

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P.O. Box 68
1970 AB IJmuiden
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 26
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 77
4400 AB Yerseke
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 59
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 57
1780 AB Den Helder
Phone: +31 (0)317 48 09 00
Fax: +31 (0)223 63 06 87
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 167
1790 AD Den Burg Texel
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 62
E-Mail: imares@wur.nl
www.imares.wur.nl

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Summary

The Oysterecover project is an EU project aimed at investigating the causes and possible solutions to the decline in the European flat oyster, *Ostrea edulis*. As part of Task 5.3 of Work Package 5 in the Oysterecover project a review of the efficiency of different spat collectors was conducted with the intention of recommending three collector types to be tested in the field. The ultimate aim of this task is to potentially identify a way to develop more efficient spat collecting techniques that may compensate for the lower survival rate of the oysters caused by the *Bonamia ostreae* parasite. The choice of three collector types chosen in this report for testing in the field was based on cost, collection success and user friendliness.

Five reports from studies comparing different spat collectors were reviewed with a total of 15 collector types tested. These were made of a range of material including plastic, clay, metal and shellfish shells. The collectors showed varying degrees of collection success, cost efficiency, amount of preparation required and ease of deployment, spat removal and storage.

In order to collect review spat collectors based on personal experience, a questionnaire was distributed to oyster farmers in Europe. Although this method was relatively unsuccessful (only five questionnaires were returned), personal communication with Dutch and French oyster farmers provided some feedback from a commercial perspective.

The three spat collectors ultimately selected were Chinese hats with a calcium coating, small mesh mussel stockings.

1. Introduction

The Oysterecover project is an EU project aimed at investigating the causes and possible solutions to the decline in the European flat oyster, *Ostrea edulis*. As part of Task 5.3 of Work Package 5, Deliverable D13 in the Oysterecover project a review of the efficiency of different spat collectors was conducted with the intention of recommending three collector types to be tested in the field. The aim of this task is to potentially identify a way to develop more efficient spat collecting techniques that may compensate for the lower survival rate of the oysters caused by the *Bonamia ostreae* parasite.

Various spat collector types are currently in use in Europe and being tested to collect the larvae of the European flat oyster, *Ostrea edulis*. The objective of these spat collectors is to provide a substrate for larvae to settle and recruit, thereby concentrating the number of oyster spat to a profitable quantity which can then be removed and reared in a hatchery. This also means that spat collectors must be affordable, user-friendly and efficient.

The efficiency of a collector is dependent on larval settlement and recruitment, so that the larvae can then be removed and grown elsewhere. The success of a collector is therefore influenced by several factors including geographic location, depth of the collectors in the water column, temperature and other fouling species (Burke *et al.* 2008 and Bataller *et al.*, 2006). Nevertheless, assuming all external factors remain equal, an efficient spat collector will collect a large amount of spat over the spawning season without an excess investment of time or money.

In this review studies found in the literature comparing spat collectors and the results of communication with oyster farmers are presented. These lead to a discussion of different collector types and a recommendation for the selection of three collector types to be used for field experiments.

2. Methods

The current study was conducted in three parts; a literature study, a stakeholder/sector survey and selection.

A literature search was conducted to find studies of oyster spat collectors and assemble a list of different types of material used. Each study is presented separately below and their evaluation varies according to the methods used, the results available and the information provided by the source documents. The results in these studies were then compared qualitatively, as each study compared collectors differently it was not possible to conduct a quantitative analysis.

A questionnaire (See Appendix 1) was also developed and circulated to the partners in the Oysterecover project to then be translated into their local languages and distributed to their local oyster fishers/breeders. The responses given by the fishers were then assembled and used to identify the commonly used types of oyster spat collectors, and their pros and cons from a commercial perspective.

A selection of three collector types were chosen based on the results from both the literature study and the questionnaire survey. These three collector types are recommended for further investigation and experimentation.

3. Literature research

A literature search produced five suitable reports of comparisons of the efficiency of different spat collector types. These are presented separately to provide an overall perception of different spat collectors. The results were then presented and discussed to develop a recommendation of the best spat collectors to test in the field. The studies analysed in this report include Kamermans et al. (2004) from the Netherlands, the Danish Shellfish Centre (unpublished) from Denmark, Bataller et al. (2006) and Freeman and Denny (2003) from Canada and Nalesso et al. (2008) from Brazil.

Study by Kamermans *et al.* (2004) - The Netherlands.

In the summer of 2003 several spat collectors were used to measure the recruitment of both the flat oyster, *Ostrea edulis* and the Pacific oyster, *Crassostrea gigas* in the Grevelingenmeer, The Netherlands on behalf of the local oyster fisheries. For this review the results were compared between the two species using the results for *C. gigas* as an indication of the extent that other fouling species may obstruct the recruitment of *O. edulis*.

Methods

The information for three types of spat collectors in the report was appropriate for the current review: Chinese hats, tubes and sacks of mussel shells (Figure 1).

'Chinese hats' were smooth pvc shallow conical discs with a diameter of 15.5 cm threaded onto a central rope to form long 'towers' of 21 'hats'. 'Tubes' were long rough plastic cylinders about 1.2 m long and with a diameter of 2.2 cm in groups of 35. Mussel shell collectors consisted of clean and empty mussel shells were placed in 5 L onion sacks. In this study, a 'collector' therefore refers to either a tower of 21 hats, a group of 35 tubes or 24 five litre sacks of mussel shells. All collectors were suspended in the water column attached to a rope tied between two poles. These collectors are all commercially available.

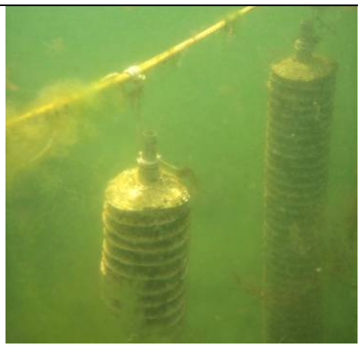
Chinese hates	 Photo: Anneke van den Brink
Tubes	 Photo: Anneke van den Brink
Sacks of mussel shells	 Photo: Pauline Kamermans

Figure 1. Chinese hats (top), tubes (centre) and sacks of mussel shells (bottom) similar to those used for spat collectors in Kamermans *et al.* (2004).

Collectors were placed in the water column at different times throughout the season, resulting in possible skewed results depending on the exact time of spawning. As the exact timing of spawning is unknown, this was not taken into account in the results.

<u>Spat per cm²</u>

Because the three spat collectors were considerably different in size and surface area, data for the Chinese hats and tubes, including the number of spat from both species settled on each collector, the surface area was initially re-analysed to produce a number of spat collected per cm².

The number of spat per cm² was calculated as:

Chinese hats:

$$n = x/377$$

where n is the number of spat per cm², x is the total number of spat found on each 'hat' and 377 is the surface area in cm² of each hat according to Kamermans *et al.* (2004).

Tubes:

$$n = x/829$$

where n is the number of spat per cm², x is the total number of spat found on each tube and 829 is the surface area in cm² of each tube according to Kamermans *et al.* (2004).

As there was no simple/direct method to calculate the surface area of the sacks of mussel shells, photographs taken at the time of the research done in 2003 of samples of mussel shells used were analysed using a size reference to determine the estimated length, width and height of the shells. This was only possible for shells in appropriate positions in each photograph. As it was not possible to take all necessary measurements of each shell in the photograph, the averages of each measurement was taken and used to calculate the estimated average surface area of the shell using the formula from Reimer and Tedengren (1996):

$$A = l \times (h^2 + w^2)^{0.5} \times \Pi/2.$$

Where A is the surface area, l is the length of the shell, h is the height of the shell, w is the width of the shell. Although this formula was used for the area of a whole, live mussel, it is not altered here as each half of the shell has both the inside and outside surface available for spat settlement.

In the report by Kamermans *et al.* (2004) mussel shells were used in 5 L sacks. An estimated 80-160 adult mussel half shells fit into 1 L (Aard Cornelisse pers. comm.), therefore a 5 L sack would contain 400-800 mussel shells. The average surface area of a mussel shell was multiplied by 600 (midway between 400 and 800) to give an estimated surface area for the whole 5 L sack of mussel shells.

The total number of oyster spat per 5 L sack of mussels was divided by the estimated cm² for the whole sack to give the average number of oyster spat fount per cm².

The average number of oyster spat per cm² was then compared between Chinese hats, tubes and sacks of mussel shells.

<u>Spat per collector</u>

To gain a more practical perception of the number of spat collected, the number of spat per collector was calculated. A collector is considered to be 21 Chinese hats, 35 tubes and 24 sacks of mussel shells so that all collectors were all of relatively similar total size. The average number of oyster spat per collector was multiplied by the number of collectors in each arrangement according to type. The average number of spat was then compared between collector types.

Results

The sampling season in 2003 was a remarkably successful spawning season for the Japanese oyster *Crassostrea gigas*. The data are therefore unlikely to be representative of the same period every year, but it does give an indication of an extreme case of settlement.

When comparing collectors by cm² tubes collected the highest average number of flat oysters (0.0067 per cm²) followed by Chinese hats (0.0044 per cm²), while mussel shells collected a much lower average number of flat oysters (0.0013 per cm²) (Figure 2).

In comparison, the Chinese hats collected the highest average number of Pacific oysters per cm² (6.31 per cm²) although the variation is comparatively high (±4.9). Tubes collected an average of 1.11 Pacific oysters and mussel shells collected 0.065 Pacific oysters per cm² (Figure 3).

The average ratio of flat oysters to Pacific oysters was highest for the mussel shells (0.28 flat to 1 pacific oyster) although the error bars were here also considerably wide (±0.02). Tubes collected an average of 0.008 flat to 1 pacific oyster) and Chinese hats collected only 0.001 flat to 1 pacific oyster (Figure 4).

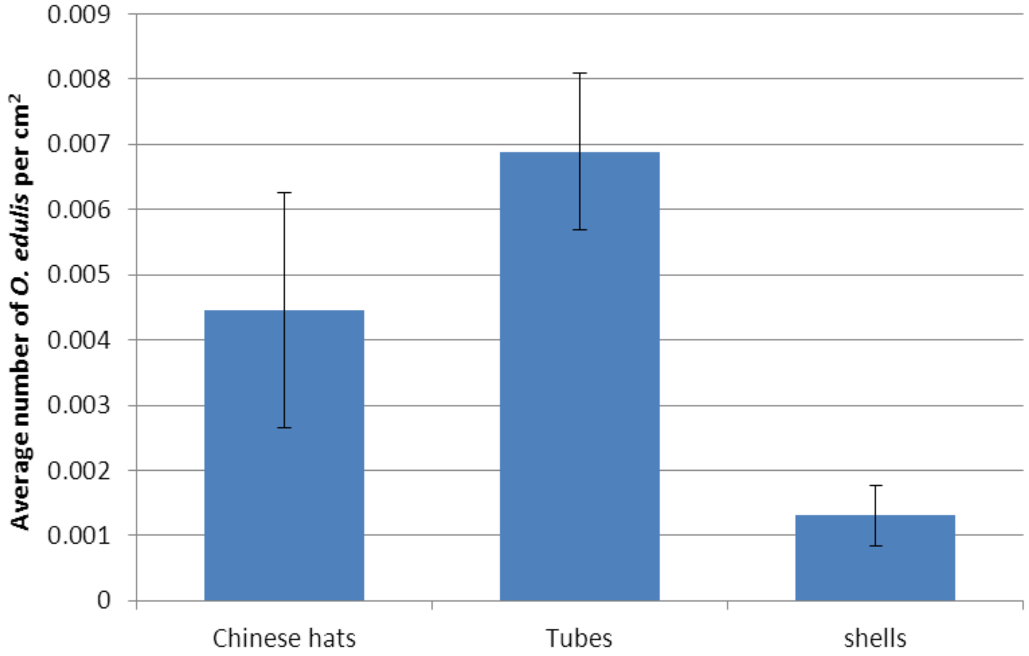


Figure 2. The average number of *O. edulis* collected per cm² on Chinese hats, tubes and mussel shells. Error bars are ±1 S.E.

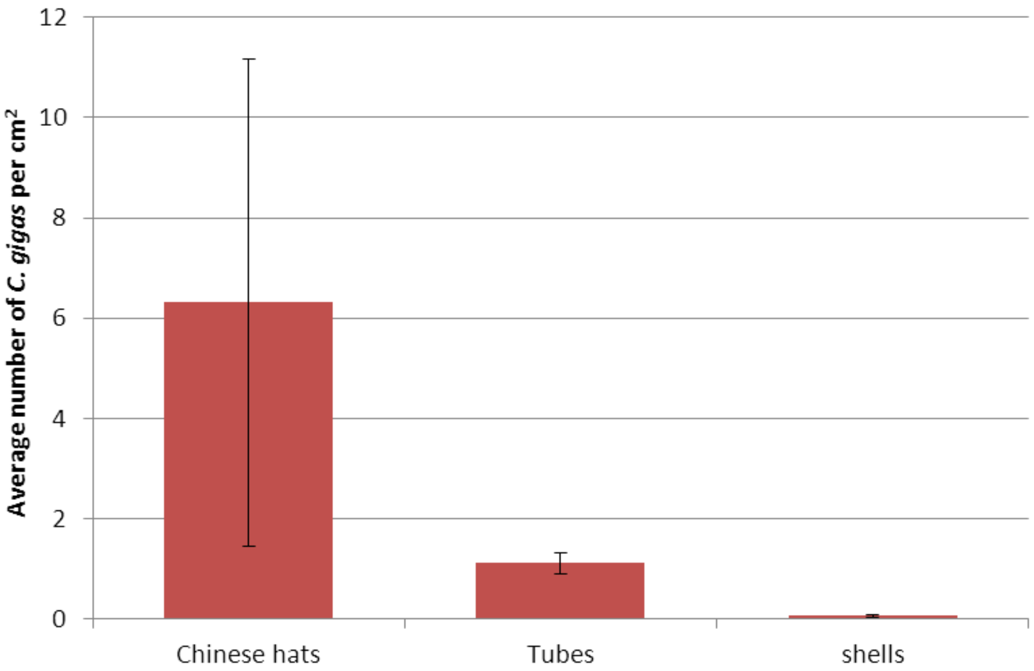


Figure 3. The average number of the Pacific oyster, *C. gigas*, collected per cm² on Chinese hats, tubes and mussel shells. Variation is ±1 S.E.

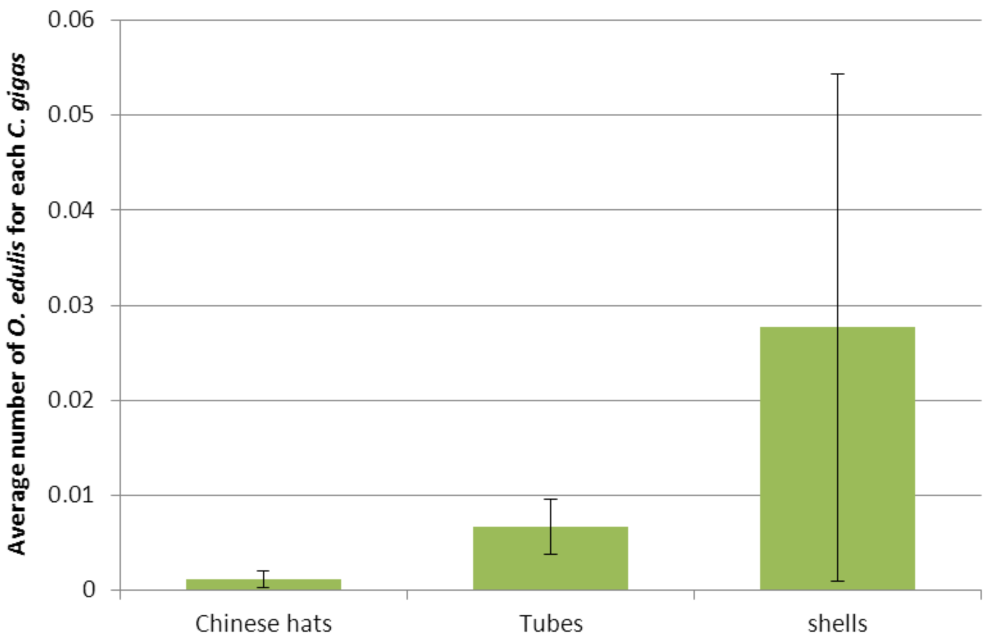


Figure 4. The average number of *O. edulis* for each *C. gigas*, collected per cm² on Chinese hats, tubes and mussel shells. Error bars are ±1 S.E.

While comparing the collectors using cm² is statistically correct, a comparison between collectors as a whole is considered a more practical approach to testing their overall efficiency.

The results of the comparison of collectors (21 Chinese hats, 35 tubes and 24 five litre sack of shells) were considerably different to the comparison per cm². The average number of flat oysters collected was highest for the mussel shells (604 spat) followed by the tubes (200 spat), while the Chinese hats collected the fewest (35 spat) (Figure 5). The difference in number of spat found on mussel shells between cm² and the whole collector may be explained by the uneven distribution of spat settling on the shells. Spat would be highly concentrated on the outer shells of the collector compared with the shells in the middle of the sack, therefore the average number of spat per cm² is likely to be misrepresentative of shells as collectors.

The average number of Pacific oysters collected was highest for the Chinese hats (49 975 spat) although the error bars were considerably wide (±38440). Mussel shells collected 26 296 Pacific oyster spat and tubes collected only 19 393 Pacific oyster spat (Figure 6).

The sacks of mussel shells collected more flat oyster spat for each Pacific oyster spat (0.032 flat to 1 Pacific oyster) than both the Chinese hats (0.001 flat to 1 Pacific oyster) and the tubes (0.011 flat to 1 Pacific oyster) (Figure 7).

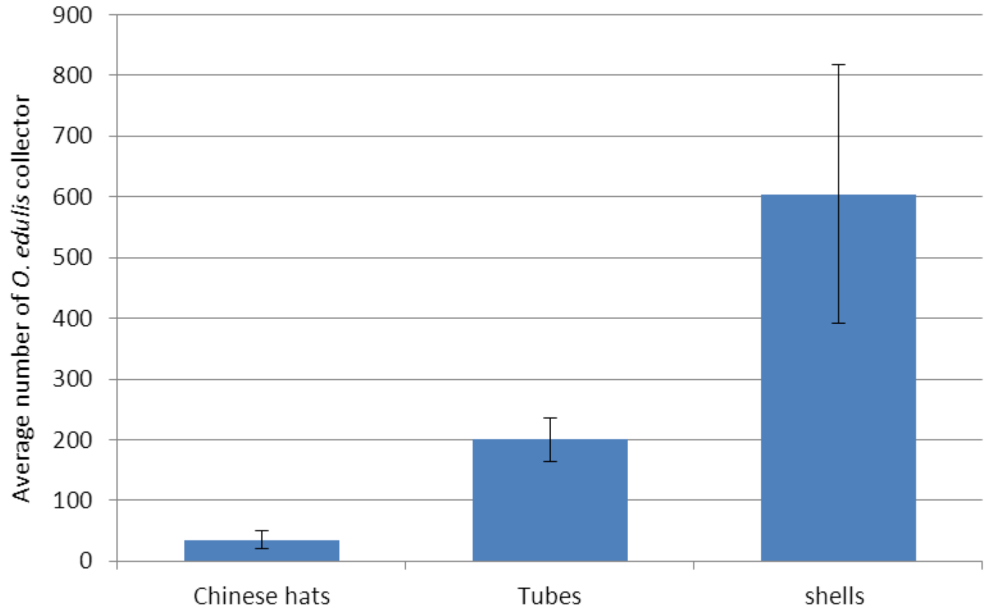


Figure 5. The average number of *O. edulis* per collector (21 Chinese hats, 35 tubes and 24 sacks of mussel shells). Error bars are ±1 S.E.

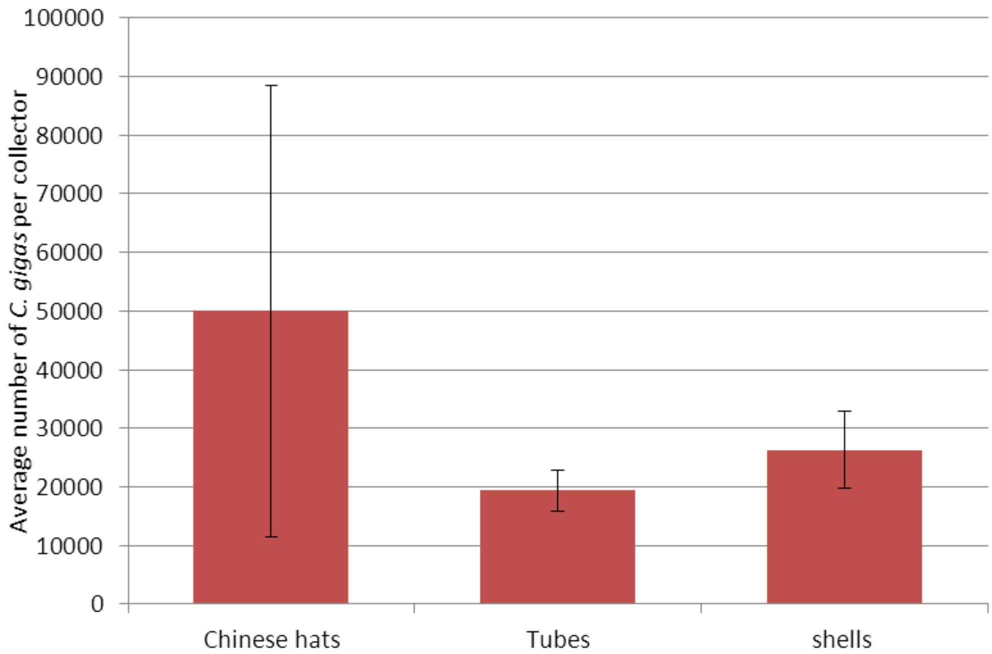


Figure 6. The average number of *C. gigas* per collector (21 Chinese hats, 35 tubes and 24 sacks of mussel shells). Error bars are ±1 S.E.

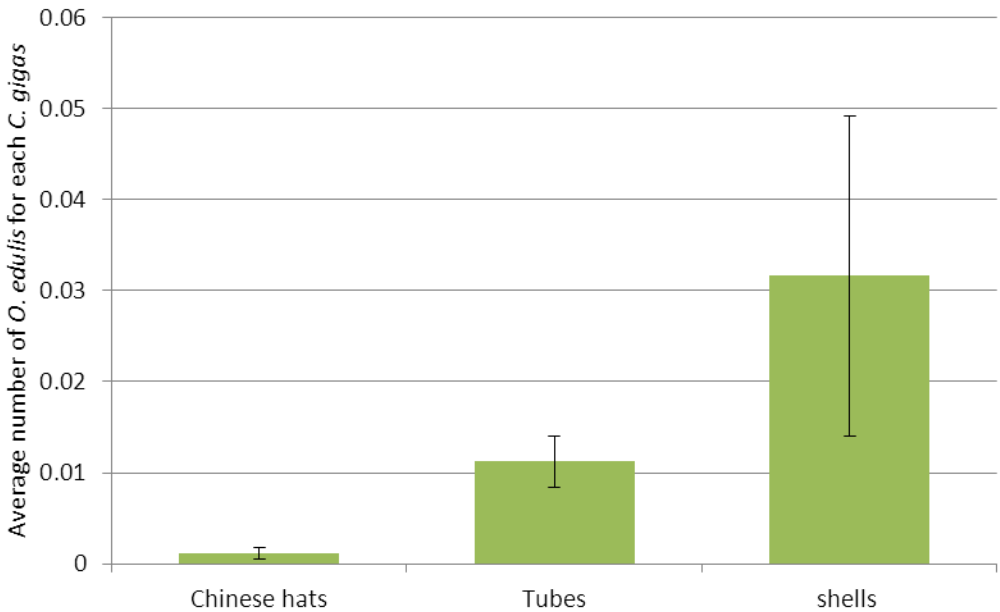


Figure 7. The average number of *O. edulis* for each *C. gigas*, per collector (21 Chinese hats, 35 tubes and 24 sacks of mussel shells). Error bars are ±1 S.E.

Study by the Danish Shellfish Centre (unpublished) - Denmark.

In 2010 the Danish Shellfish Centre (DSC) performed a field survey to identify suitable sites and appropriate settling substrate for oysters. The appropriate, currently unpublished data was used to compare different spat collectors is included in the present study.

Methods

Spat collectors were deployed at four locations in the Limfjord, Denmark; Nissum Bredning, Kaas, Venoe and Harre Vig all of which are known to be productive oyster areas or previously productive oyster areas. Due to very poor spat collection at Nissum Bredning and Kaas, only data from Venoe and Harre Vig was used in the analysis.

The DSC tested a tower of 10 Chinese hats, one shower loofa and two plastic dish sponges (Figure 8). (Sample sizes were thus too small for a meaningful standard error). Half of these were coated with lime, sand and cement, the other half were untreated.

In Kaas the collectors were hung in the water at 4 meters depth while at the other locations the collectors were placed at 2 meters depth near shore and 4 meters depth offshore. Chinese hats were only used at 4 m depth. The collectors were monitored from July to August and the number of spat found on the collector was recorded four times; on the 6th and 20th of July and the 3rd and 17th of August.

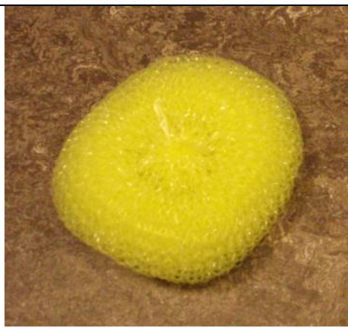
Shower loofa	 Photo: Carsten Fomsgaard Nielsen
Plastic dish sponge	 Photo: Carsten Fomsgaard Nielsen

Figure 8. Shower loofa (above) and plastic dish sponge (below) used as spat collectors in the study by the Danish Shellfish Centre.

Results

From the comparison between spat collectors in two locations in Denmark coated Chinese hats collected the largest average number of spat (3992). Untreated Chinese hats at 4 m depth collected much fewer spat than coated Chinese hats (1476) but still collected more than both coated and untreated shower loofas and dish sponges at both 2 and 4 m depth. Untreated shower loofas and dish sponges collected on average more spat at both 2 m (1432 and 717.5 spat respectively) and 4 m depth (618 and 635 spat respectiely) than coated shower loofas (134 at 2 m and 306 at 4 m) and dish sponges (324 at 2 m and 0 at 4 m). Untreated shower loofas collected more spat than dish sponges at both 2 and 4 m depth, while coated dish sponges collected more spat at 2 m depth (324) than coated shower loofas (134) (Figure 9). The number of spat per cm² could not be calculated as surface areas were not known.

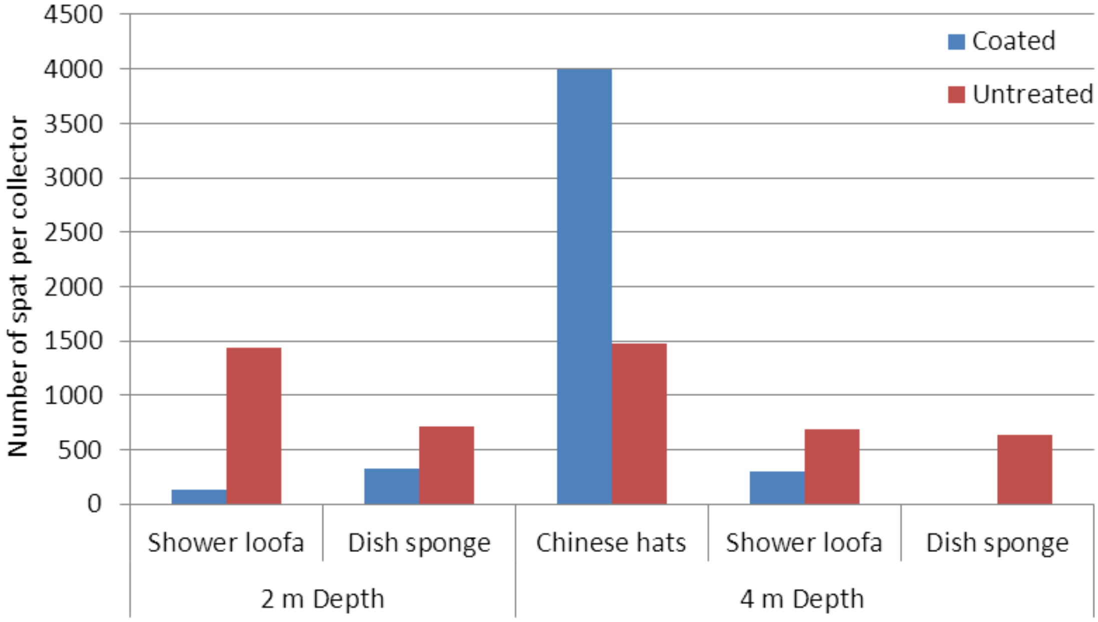


Figure 9. Average number of spat found on different types of collectors, some coated in lime, sand and cement and some left untreated, at 2 and 4 m depth from July to August 2010.

Study by Bataller *et al.* (2006) - Canada

An evaluation of different spat collectors for *O. edulis* was carried out by Bataller *et al.* (2006) on the Canadian Atlantic coast where the oyster was introduced, has now established and become a potential subject for culture.

Methods

Six different spat collectors were tested in triplicate, at two different depths and at three different sites. The collectors used were: Chinese hats, Vexar bags full of soft-shell clam shells, onion bags filled with pieces of Netron fabric, drain tubes, scallop shell strings and French tubes (referred to simply as 'tubes' in Kamermans *et al.* 2004). Although three replicates were used at each site and depth, only two were recovered as the third was used for another study. French tubes had no replicates. The size of each collector and the number of Chinese hats was not specified in the text. The Chinese hats and drain tubes were coated in a mixture of water, lime, sand and cement to provide a suitable substrate for the larvae.

The collectors were left in the water for three months over the spawning season (summer) and then recovered and brought to the laboratory where the number and size of collected spat was recorded.

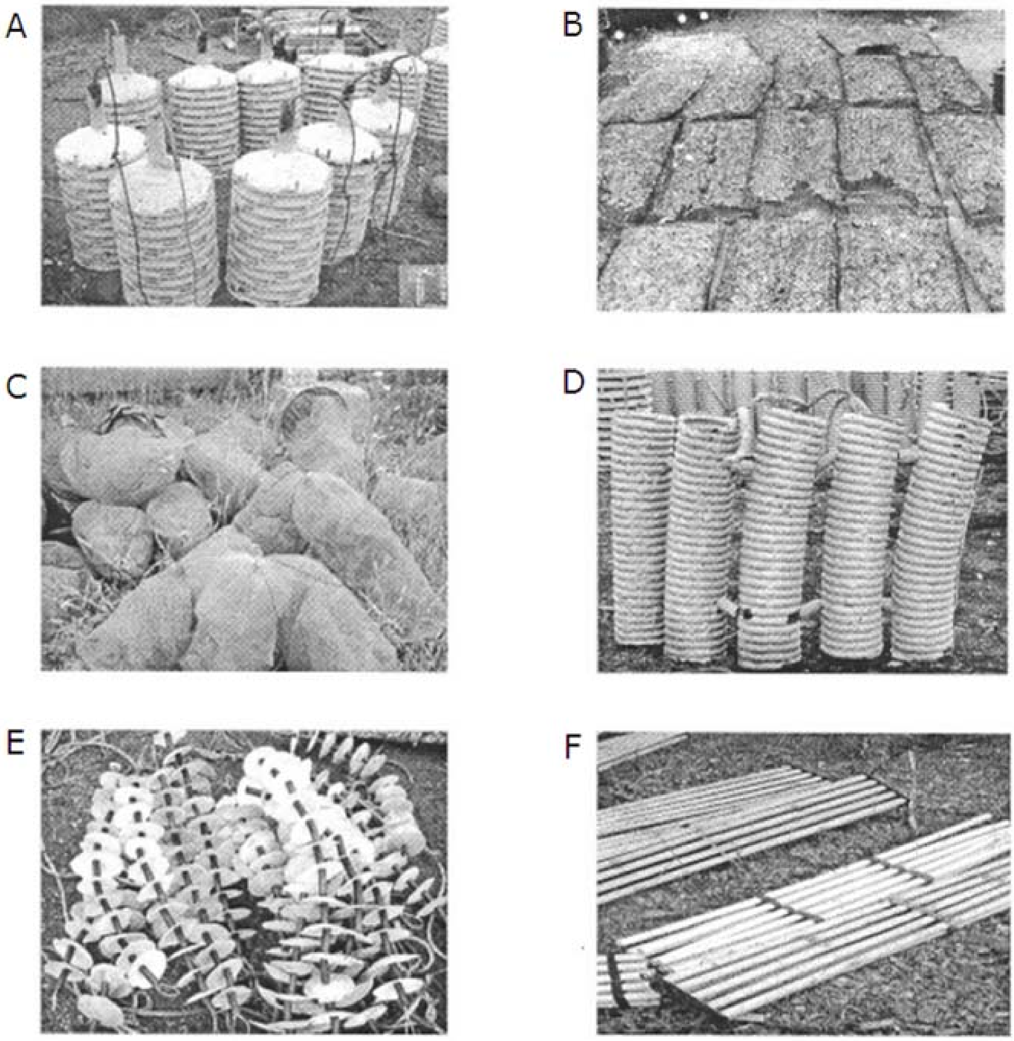


Figure 10. Collectors used in Bataller *et al.* (2006). A: Chinese hats, B: Vexar bags full of clam shells, C: Onion bags filled with pieces of Netron fabric, D: Drain tubes, E: Scallop shell strings, F: French tubes.

Results

From the comparison of spat collectors in Bataller *et al.* (2006), Chinese hats collected by far the most spat compared with the other collector used (Table 1). Bataller *et al.* (2006) report that they found spat on the Chinese hats as early as one week after deployment and suggested that these were the most effective spat collector of those they tested.

Table 1. The mean number of spat (n spat per collector) present on each type of collector for each site and depth in Bataller *et al.* (2006). Results are from two replicates except those with * which denotes only one replicate.

Depth	Site	Chinese hats	Vexar bag with clam shells	Onion bags with Netron fabric	Drain tubes	Scallop shell strings	French tubes
1.2 m	C	191 ± 20	16*	1 ± 0	0	2 ± 2	0*
	D	291 ± 66	37 ± 1	0	1 ± 0	4 ± 0	0*
	E	245 ± 43	41 ± 1	1 ± 0	2 ± 1	0	1*
1.8 m	C	203 ± 1	15*	0	3 ± 2	1 ± 0	1*
	D	304 ± 50	33 ± 1	0	5 ± 2	1 ± 0	3*
	E	314 ± 206	20 ± 4	0	2 ± 1	1 ± 0	2*

Study by Freeman and Denny (2003) - Canada

An analysis of the efficacy of various spat collectors for the oyster *Crassostrea virginica* was conducted in Gillis Cove, Breton Island, Nova Scotia, Canada in 2003. Although this study was focussed on a different oyster species than *Ostrea edulis*, with which this report is concerned, the success of spat collectors is assumed to be comparable for any oyster species. Species specificity is maintained by timing the deployment of the collectors to correspond with the differing spawning season of the oysters.

Methods

Seven different collector types were suspended from floating rafts and deployed in sets of two or three at seven different locations in the cove. Methods are detailed in Freeman and Denny (2003). The collectors were deployed in summer for approximately a month before they were retrieved and the size (as an indication of growth) and density of the collected spat was recorded.

The collectors used in the study are illustrated in Figure 11 and are described by Freeman and Denny (2003) as:

1. Shell Strings: Single scallop shells of an approximate average height of 12 cm had 1 cm diameter holes punched in their centres and were placed concave side down on 12-gauge vinyl-coated wire with spacers (-5 cm long) between them to support and separate the shells. The numbers of shells per collector ranged from 15 to 29 with a mean of 23. Shell String lengths ranged from 1.5 to 2.0 m. Suspension depth to the top shell of each collector was 0.30 m.

2. Chinese Hats: Standard oyster collection devices, these are perforated, plastic shallow cones, 0.34 m in diameter by 0.09 m high with a hole at the apex through which slides a 5 cm plastic pipe on which they are stacked, twelve "hats" per collector, with spacers between. These twelve-unit assemblages, each considered to be one collector, were first covered with a thin cement coating before being stacked on the pipe, then vertically suspended with 0.61 m of water above the top of each. A randomly selected collector was disassembled and the top, sixth and bottom (twelfth) "hats" were taken for spat sampling.

3. Veneer Rings: Two rings, 17.8 cm in diameter and made from 7.62 cm wide wood veneer, were suspended one above the other, 0.91 m below the surface to the upper ring after having been coated in cement and dried.

4. Large Mesh: Rolls of 5 cm plastic mesh were cut into strips approximately 54 cm wide by 125 cm long. These collectors could also be described as being 6 squares (or diamonds) wide by 16 long, were weighted by a small piece of cement attached to one end and vertically suspended from cross pieces on the rafts such that the upper part of the mesh was 0.61 m below the surface. Although machine manufactured, the "diamond to diamond" measurements across the material were inconsistent, as were those of the strands that formed each mesh. Overall mean mesh squares were calculated as 67 × 60.4 mm and strand were calculated as 5.1 mm wide. Omitting the bottom, incomplete row, the total surface area of one side of this collector (15 rows and 6 columns of "diamonds") was estimated to be 1,309.5 cm^2, and of one side of one mesh, inclusive of shared corners, 15.48 cm^2.

5. Small Mesh: Rolls of half-inch (10 mm) Vexar™ mesh were cut into strips approximately 125 cm long by 15 to 25 cm wide. As with Large Mesh collectors, these were weighted by a small piece of cement attached to one end and suspended in a similar fashion to the Large Mesh. Mesh and strand size were quite consistent throughout the material and the total surface area of one side of a collector of 15.2 cm width by 125 cm long (13 by 104 "squares" was estimated to be 1502.8 cm^2. The sampled area, which was one side of four contiguous squares (arranged 2 by 2) was 6.79 cm^2

6. Harps: As with Chinese hats, these are also traditional collecting devices but comprised of fourteen bands of flexible plastic held top and bottom by headers made of similar, but more rigid material. Each harp was comprised of 14 bands that were 9 mm wide by 44.5 mm long and spaced at 3.5 cm centred. This style of collector was suspended in the water with the bands vertical, the lower header inter-band spaces being filled with cement to ensure that the vertical position was maintained. The upper header was positioned 0.46 m below the surface, the lower header was then at 0.91 m.

7. Bolts: These were lengths of green, 5.2 mm diameter braided nylon cordage, weighted at one end with a metal bolt (hence the name) and suspended with 1.52 m of its length submerged.

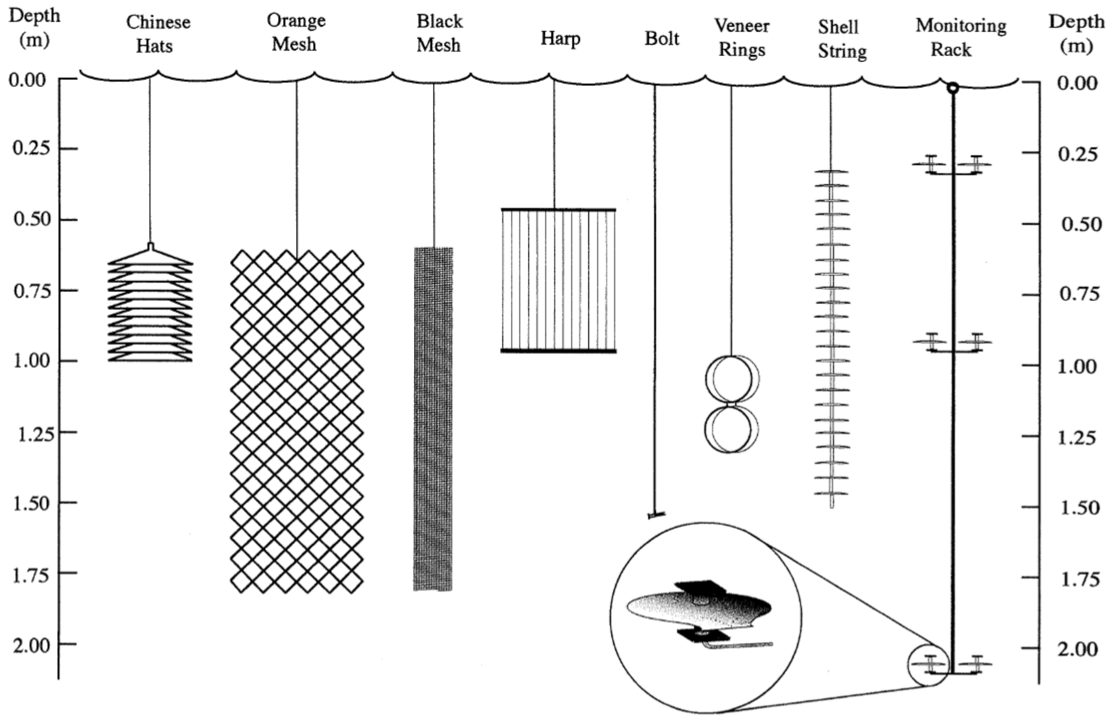


Figure 11. Approximate relative sizes, configurations and deployment depths of the collector types tested in Freeman and Denny (2003).

Results

The highest spat density was found on the shell strings (lower section), harps and bolts, while the lowest densities were found on the Chinese hats and Veneer rings (Table 2Figure 10).

Table 2. Mean spat densities (n per cm²) of *C. virginica* found on different collectors at different depth ranges as in Freeman and Denny (2003).

Collector	0.0-0.5 m	0.5-1.0 m	1.0 - 1.5 m	1. - 2.0 m	Average
Small mesh	-	2.112	2.178	2.898	2.396
Large Mesh	-	1.881	2.713	3.022	2.539
Shell stings (upper)	2.308	0.896	3.066	-	2.09
Shell stings (lower)	1.688	3.358	3.703	-	2.916
Bolts	1.771	3.088	3.382	-	2.747
Chinese hats (upper)	-	-	0.361	-	1.361
Chinese hats (lower)	-	-	1.194	-	1.194
Harps	-	-	2.802*	-	2.802
Veneer rings (outer)	-	-	1.877*	-	1.877
Veneer rings (inner)	-	-	1.671*	-	1.671

*Harps were set at depths between 0.46 and 0.9 m and Veneer rings at 0.91 m but are referred to at 1.0-1.5 m depth to enable analysis of all treatments at a more or less common depth.

Freeman and Denny (2003) came to several conclusions about the most efficient spat collectors. In their conclusions they stated:

1. The choice of which collector to use to maximise spat density would appear to lie among Shell Strings (SU, SL), Harps (H), Bolts (B) and Mesh (LM, SM). However,

given the logistic constraints of using scallop shells, the restricted surface area of Bolts, and the cost of manufacture and preparation of Harps, both Large and Small Mesh appear more attractive although they may fall below this set of four in terms of density collected. Furthermore, since the Small Mesh is much finer and has a greater surface area than that of Large Mesh, a sheet of the former will yield much more spat than a comparably-sized sheet of Large Mesh; so the choice based on density alone is probably between Harps and Small Mesh.

2. Analysis of shell lengths indicates that Small Mesh and Large Mesh yield the greatest growth of spat.
3. Further, the maintenance of and harvesting from Small Mesh is very simple - a flip or two of the mesh releases most of the spat - so should be preferred.
4. Shell Strings, Chinese Hats and Veneer Rings are much more difficult to work with and harvest from than Small Mesh or even Large Mesh; so these three collectors could almost be discounted on those grounds alone.
5. Storage space required for the various collectors favoured Bolts, Small Mesh and Large Mesh.
6. The use of Chinese Hat collectors, an industry standard, is not recommended because of initial cost, storage space required, labour and materials needed for preparation before use. Further, its spat-collecting efficacy is less compared with other less expensive and easier to use materials.
7. Overall, Small Mesh was shown to be the collector easiest to store, prepare for deployment and from which to harvest spat. The generally superior growth on Small Mesh, combined with the highest collection densities recorded, identified it as the most favoured collector in this study.
8. Over the limited range of depths studied, no depth effects for either Small or Large Mesh were noted.

Study by Nalesso *et al.* (2008) – Brazil.

In a study by Nalesso *et al.* (2008) four different spat collectors were tested and compared for the mangrove oyster *Crassostrea* spp. at five sites in the Benevente river estuary, Brazil. As with the study by Freeman and Denny (2003) (above), this investigation focussed on a different oyster species to *O. edulis* with which this report is concerned, but the results are assumed to be comparable with any oyster species.

Methods

Four different spat collectors were tested:

1. Oyster shells: ten oyster shells were drilled centrally and hung on a string.
2. PET bottles: ten half PET bottles, 3 cm apart, were hung on a string.
3. Car tyres: ten pieces of car tire (±10×25 cm) were drilled centrally and hung on a string 2 cm apart.
4. Tiles: three clay tiles (30×35 cm) were tied together with string and hung on a rope.

At each site three collectors of each type were suspended from approx. 1 m long ropes and tied to the roots of mangroves, rafts or mussel long-lines.

For one year the spat collectors were withdrawn from the water at regular intervals and replaced with new ones. The number of spat found on each collector was recorded and calculated per area of each collector type and compared between collectors. For more detailed methods, refer to Nalesso *et al.* (2008).

Results

Nalesso *et al.* (2008) reported that the most efficient collectors were those made of oyster shells and tile (collecting a mean of 0.20409 and 0.18868 spat per cm² respectively), while the PET collectors were the least efficient as they consistently collected the lowest number of spat (often fewer than 10 spat per collector), in spite of their large surface areas (Figure 12). They suggested that the smooth surface of the PET plastic inhibited larval settlement. However, the authors referred to other papers where high recruitment was found on PET bottles.

The authors also noted that the oyster shell collectors attracted the most fouling organisms including barnacles and algae which prevent oyster spat recruiting. These fouling organisms were found on other collectors but to a lesser extent.

Nalesso *et al.* (2008) found that PET collectors were advantageous because of the ease of spat removal due to the flexibility of the plastic and because they were reusable and recyclable. However they also noted that on both tile and tyre collectors, oyster spat of over 20 mm could be easily removed as early as three month after immersion of the collector. The removal of spat from the oyster shell collectors, however, was difficult and imposed restrictions on its use as the oysters produced were only suitable for the oyster meat market and could not be served to consumers in the shell.

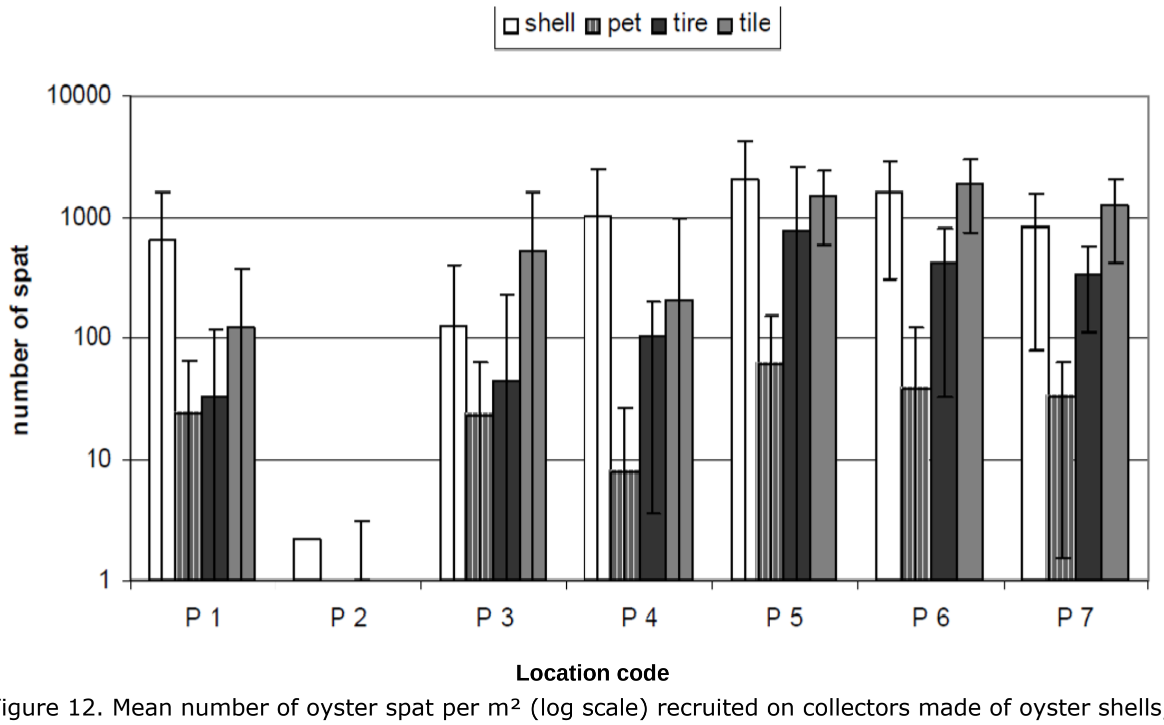


Figure 12. Mean number of oyster spat per m² (log scale) recruited on collectors made of oyster shells, PET bottled, car tyres and tiles as reported in Nalesso *et al.* (2008). P1-7 indicate different locations.

Practicality of collectors

Cost of equipment

The financial cost of the different spat collectors was compared as an important factor in determining the overall efficiency of the collectors. The estimated costs of each collector type tested in Kamermans *et al.* (2004) and the study by the DSC are compared in Table 3. Costs are provided per unit as well as for each group of collectors as used in the experiments. The number of spat collected is also shown, but should not be compared between the two studies due to unequal experimental conditions. The cost of the Chinese hats and tubes used in Kamermans *et al.* (2004) were taken directly from the invoice received following the purchase of the equipment at the time. The cost of the mussel shells was taken from the current cost for oyster farmers while the cost of the onion sack was estimated from probable current prices. The cost of the Chinese hats, shower loofa and dish sponge used in the study by the DSC were taken directly from the equipment costs incurred for the experiment although the cost of the coating is not included due to the unknown, but most likely negligible cost. It is difficult to directly compare costs due to the difference in size of each item and the various number in each collector group. While Dish sponges were the cheapest per unit at €0.60 each, Chinese hats, tubes and 5 L mussel shells are much larger in individual size.

Table 3. Financial costs and number of spat collected for each collector type used in studies by Kamermans *et al.* (2004) and the DSC. Prices are given both per item and per group of collectors as used in the experiments by Kamermans *et al.* (2004) and the Danish Shellfish centre. Mussel shells are given per 5 L unit. The number of spat collected for the shower loofa and dish sponge is given as the average between the two depths. C: coated with lime, cement and sand, U: untreated. Comparisons of number of spat collected should not be made between the two studies.

<table>
<tr><th>Study</th><th>Collector type</th><th>Cost per unit</th><th>Number of items in collector</th><th colspan="2">Total cost per collector</th><th colspan="2">Number of spat collected</th></tr>
<tr><td rowspan="4">Kamermans et al. (2004)</td><td>Chinese hats</td><td>€0.50</td><td>21</td><td colspan="2">€10.50</td><td colspan="2">35</td></tr>
<tr><td>Tubes</td><td>€1.00</td><td>35</td><td colspan="2">€35</td><td colspan="2">200</td></tr>
<tr><td>Mussel shells</td><td>€0.15</td><td>24</td><td>€3.60</td><td rowspan="2">€6.00</td><td colspan="2" rowspan="2">604</td></tr>
<tr><td>Onion sacks</td><td>€0.10</td><td>24</td><td>€2.40</td></tr>
<tr><td rowspan="3">DSC</td><td>Chinese hats</td><td>€1.20</td><td>10</td><td colspan="2">€12</td><td>C: 3992</td><td>U: 1476</td></tr>
<tr><td>Shower loofa</td><td>€0.60</td><td>1</td><td colspan="2">€0.60</td><td>C: 220</td><td>U: 1058</td></tr>
<tr><td>Dish sponge</td><td>€0.25</td><td>2</td><td colspan="2">€0.50</td><td>C: 162</td><td>U: 676</td></tr>
</table>

Although not quantitatively referred to in the text the following excerpts regarding costs are taken from the other referenced publications:

Bataller *et al.*(2006)
No information about cost was provided

Freeman and Denny (2003):
'Although relative costs of collector manufacture, purchase, preparation and use were not closely monitored in this study, the cost per unit of plastic mesh was among the lowest. Bolts were the least expensive in labour and material.'

Nalesso *et al.* (2008):
'All the collectors (strings of oyster shells, PET bottles, car tyres and clay tiles) utilized in this study can be made from recycled materials, thus lowering the costs for small farmers.'

Overall efficiency

The overall impression of efficiency of each of the 15 collector types tested in the above studies was also qualitatively compared using personal communication with Pauline Kamermans (from Kamermans *et al.*, 2004) and with Carsten Fomsgaard Nielsen (from the Danish Shellfish Centre) and others including Mathieu Hussenot from CRC Bretagne Nord, France. Comments were also taken directly from Freeman and Denny (2003) and Nalesso *et al.* (2008) (Table 4).

Table 4. Comments on the cost and labour intensity of the different spat collectors from various experienced consultants indicated as advantages (+), disadvantages (-) conditional features (±) and neutral features (•). No information specific to each collector type was provided by Bataller *et al.*(2006).

Collector	Comment	Source	Affiliation
Chinese hats	• Standard deployment time + Reusable (several times) + Relatively cheap (Table 3) + Commercially available	Pauline Kamermans	Kamermans *et al.* (2004)
Coated Chinese hats	• Standard deployment time + Spat easy to remove + High spat yield	Carsten Fomsgaard Nielsen	DSC
	• Standard deployment time - Machine required to remove spat - Can take time (approx. one month) to prepare if coated in lime as the collector need to dry on land before deployment	Mathieu Hussenot	CRC Bretagne Nord, France
	- Cementing and assembling is time consuming and labour intensive - Spat removal is labour intensive and can cause damage spat - Storage is inconvenient.	Freeman and Denny (2003)	Freeman and Denny (2003)
Shower loofa	• Standard deployment time. - Spat difficult to remove without causing damage - Spat removal is very time consuming (an estimated five times longer to remove the same number of spat than with Chinese hats). ± Cheap, but only on small scale (Table 3)	Carsten Fomsgaard Nielsen	DSC
Dish sponge	• Standard deployment time. - Spat difficult to remove without causing damage - Spat removal is very time consuming (an estimated five times longer to remove the same number of spat than with Chinese hats). ± Cheap, but only on small scale (Table 3)	Carsten Fomsgaard Nielsen	DSC
Tubes	- Machine needed for flexing tubes in order to remove the spat. - Still labour intensive + Reasonably high spat yield ± Cheap, but only on small scale (Table 3) + Commercially available	Pauline Kamermans	Kamermans *et al.* (2004)
Sacks of mussel shells	+ Easy to sow on bottom plots - Labour intensive - Shells are expensive depending on deployment method - Shells may be scarce in the future? - Shells cannot be re-used because they degrade.	Pauline Kamermans	Kamermans *et al.* (2004)

Collector	Comment	Source	Affiliation
Strings of scallop shells	+ Collects high densities of spat - Preparation is labour intensive - Removal of shells is difficult as scallop shells must be chipped around the oyster leaving shell behind - Shells not reusable - Storage is inconvenient	Freeman and Denny (2003)	Freeman and Denny (2003)
Harps	+ Collects high densities of spat - Preparation can be labour intensive (cementing) - High cost of manufacture + Spat removal is simple - Spat removal leaves small amount of cement attached to oyster. - Storage is inconvenient	Freeman and Denny (2003)	Freeman and Denny (2003)
Bolts	+ Spat removal is simple, requiring only a gloved hand to wipe the surface. + No pre-treatment necessary - Restricted surface area + Easy storage + Very cheap in labour and material	Freeman and Denny (2003)	Freeman and Denny (2003)
Small mesh	+ No pre-treatment necessary + Easy deployment + Density of spat collected is mid-range to high + Yielded the highest spat growth + Spat very easy to remove, requiring only manual bending to make spat simply pop off or a light brush with a gloved hand (easier with small mesh) + Long expected useful life + Easy storage + Cheap in labour and material + Larger surface area than large mesh so will collect more spat	Freeman and Denny (2003)	Freeman and Denny (2003)
Large mesh	+ No pre-treatment necessary + Easy deployment + Density of spat collected is mid-range to high + Yielded the highest spat growth + Spat very easy to remove, requiring only manual bending to make spat simply pop off or a light brush with a gloved hand - Spat removal not as easy as with small mesh + Long expected useful life + Easy storage + Cheap in labour and material - Smaller surface area than small mesh so would collect fewer spat	Freeman and Denny (2003)	Freeman and Denny (2003)

Collector	Comment	Source	Affiliation
Veneer rings	- Low yield of spat density and growth - Storage is inconvenient - Cementing is labour intensive and time consuming - Spat removal difficult, often requiring damage to the collector or spat	Freeman and Denny (2003)	Freeman and Denny (2003)
Strings of oyster shells	+ High yield in spat recruitment - Spat removal difficult - Preparation time consuming - Oysters often only suitable for meat market - Highest density of fouling organisms + Can be made from recycled materials, thus lowering costs and remains of calcium deposits provide suitable substrate for and attractant to spat	Nalesso *et al.* (2008)	Nalesso *et al.* (2008)
PET bottles	- Low yield in spat recruitment + Spat removal easy + Reusable and recyclable + Low density of fouling organisms + Can be made from recycled materials, thus lowering costs and remains of calcium deposits provide suitable substrate for and attractant to spat	Nalesso *et al.* (2008)	Nalesso *et al.* (2008)
Car tyres	• Average yield in spat collection + Spat removal easy - Preparation may be time consuming + Can be made from recycled materials, thus lowering costs and remains of calcium deposits provide suitable substrate for and attractant to spat	Nalesso *et al.* (2008)	Nalesso *et al.* (2008)
Clay tiles	+ Spat removal labour not intensive + Generally high yield in spat recruitment - Dispatching not labour intensive + Can be made from recycled materials, thus lowering costs and remains of calcium deposits provide suitable substrate for and attractant to spat	Nalesso *et al.* (2008)	Nalesso *et al.* (2008)
	- Difficult to use (deployment and retrieval) - Time consuming - Spat difficult to remove	Aard Cornelisse (pers comm.)	Oyster farmer, The Netherlands

4. Survey of Oyster Farmers

A general questionnaire was developed and circulated among oyster famers in the Netherlands, France, Denmark and Ireland. An extremely poor return of the questionnaires (three from the Netherlands and two from France) prevented a clear representation of the current state of affairs regarding spat collectors to be developed. The most common response to these questionnaires (from the Netherlands) was that spat collectors were not used by farmers at all. From France the responses indicated that mussel shells in net and Chinese hats were used and that roofing tiles had historically been in use, but were no longer used due to the expense of labour and lack of mechanisation.

Personal communication with oyster farmers in the Netherlands revealed that the suspending of collectors in the water column on a large scale is prohibited in several regions of interest, eg. due to the dangers presented to pleasure vessels in the area. Small scale experiments have been performed to demonstrate the efficiency. Instead, those who actively collected spat did so by scattering empty, loose mussel shells on the sediment and later gathering them up again using a dredge.

Further communication resulted in a suggestion to use 'mussel stockings'; empty mussel shells inside a long, thin plastic mesh 'stocking' with a 'spat collecting rope' through the middle (Figure 13). The rope provides stability to the structure and prevents the shells accumulating at the bottom. Oyster spat can then recruit onto a large surface area of mussel shells with minimal wasted volume. Since very recently these are being tested in the Oosterschelde in the Netherlands by the oyster growers to collect spat.

Spat collector rope for inside stocking	 http://www.itsaskorda.es/html/eng/productos/mejillon.htm
Mussel stocking ready for deployment	 http://www.youtube.com/watch?v=YkYtfCIp5ns

Figure 13. Mussel stocking used for oyster spat collection in the Oosterschelde, The Netherlands.

5. Discussion and Conclusions

Many types of oyster spat collector of varying size, material and efficiency have been used commercially or in experiments. Mussel shells are currently the spat collector used by oyster fishers in the Grevelingen, The Netherlands, due to the high number of oyster spat they collect. Unfortunately, these collectors have several draw backs. Mussel shells are most productive when a single oyster spat survives (a settlement of around 10) on each mussel shell, when using bottom culture techniques (this improves visual product quality) or multiple spat settle in substrate in the water column.(Marnix Poelman pers. comm.)This way the oyster simply grows attached to the mussel shell which will eventually break away. If more than one oyster grows on a mussel shell, they may crowd each other and become attached to each other as they grow, which is not desirable from a producer's perspective as these oysters may only be suitable for the oyster meat market (Nalesso *et al.*, 2008). Furthermore, mussel shells cannot be reused because they degrade as the oysters grow, and at close to €6 per 5 L sack, the cost of these collectors quickly becomes expensive. This is the fundamental reason why oyster growers in the Grevelingen, The Netherlands are seeking an alternative method to collect oyster spat (Pauline Kamermans pers. comm.).

However, communication with oyster farmers suggests that despite these drawbacks and the high cost of shells, the amount of spat collected is much higher than on any reusable collector. Furthermore, mussel shells are still currently the most cost efficient known method of spat collecting, as any artificial material has a much higher initial cost. The suggestion by experienced oyster farmers of using mussel stockings is therefore a valuable one, and is consequently proposed as a choice of collector to be tested Task 5.3 of the Oysterecover project.

An oyster spat collector from which the spat can be easily and safely removed and allowed to grow independently from an attachment as well as being reusable would be most efficient. This increases the chance that more oysters will be of regular shape and size and therefore more aesthetically pleasing to the consumer. Such collectors should also be able to be deployed more than once a season and last several seasons, increasing their efficiency and providing a more rewarding investment for fishers. Chinese hats are an industry standard in oyster spat collection (Freeman and Denny, 2003) and were tested in four of the five studies presented above. Although there are reports of extremely high fouling rates on Chinese hats (Aard Cornelisse, oyster farmer, The Netherlands pers. comm.), they were developed specifically for the purpose of efficient spat collection and have proven successful in doing so, particularly in France where their use is widespread. Chinese hats are then an obvious choice of collector to test in Task 5.3 of the Oysterecover project. Furthermore, because these have been tested in various studies (as shown above) and are widely used commercially, testing Chinese hats may also act as a type of control with which the other tested collectors can be compared; if another collector is shown to be more efficient than Chinese hats, it may be worth replacing them on a commercial scale. Communication with oyster farmers suggests that the calcium coating is necessary for the efficient use of these collectors so the calcium coating will be included in the planned field test.

Suggestions for the final spat collectors to test along with the mussel socks and Chinese hats are based on the studies presented above and their advantages presented in Table 4. The small mesh, as tested in Freeman and Denny (2003) appeared to be not only successful in collecting a mid-range to high number of spat, but it was cheap, reusable and user-friendly; easy to prepare, deploy, remove the spat and to store. Furthermore, in their study Freeman and Denny (2003) found that spat on the small mesh also yielded the highest spat growth of all the collectors they tested. For these reasons the small mesh is suggested as a collector to be tested in Task 5.3 of the Oysterecover project.

Although all collectors will probably collect a lot of fouling species along with the oyster spat, this is unfortunately most likely to be unavoidable. Therefore, the suggested spat collectors for Task 5.3 of the Oysterecover project are:

- Mussel socks
- Chinese hats with calcium coating
- Small mesh

6. Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 57846-2009-AQ-NLD-RvA). This certificate is valid until 15 December 2012. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

Report number: C0590/12
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The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Marnix Poelman
Researcher Aquaculture

Signature:

Date: 15th of August 2012

Approved: Birgit Dauwe
Head of Department Delta

Signature:

Date: 15th of August 2012

Appendix 1. Spat collector questionnaire

OYSTERECOVER
Work Package 5.3
Spat Collectors Questionnaire

Country:__________________________
Name: ___________________________
Company:_________________________

1. What type of spat collector(s) are used in your area now and historically?

Now	Historically	
		Mussel shells in cages
		Mussel shells in tubular nets suspended from frames
		Mussel shells on ropes
		Roofing tiles
		Slate tiles
		Plastic pipes
		PVC dishes covered with lime

		Other (please describe and illustrate below if possible)

____
____
____
____
____

Please sketch a diagram here

Please answer the following questions on a separate page for each type of spat collector.

Spat collector type: ____________________________________

2. How long has this collector been used?____

____

If it is no longer used, why is it not in use now?____

____

____

3. What materials and equipment are required for this collector? ____

____

____

____

____

4. What is the cost of materials and equipment for this collector? _____________________

____

____

____

5. How many man hours does using this type of collector usually require? (please indicate preparation time, deployment time, monitoring time and harvesting time).____

____

____

____

____

____

6. How long is this collector left in the water and what is the average number of spat per cm^2 collected by this collector during this time?_____________________________________

____

____

7. What are the pros and cons to this type of collector?

Pros____

____

____

____

____

____

Cons____

____

____

____

____

____

Thank you for your participation