Master's thesis

Comparison Study of the Use of Video Surveying Techniques and Dive surveys in Estimating King Scallop (*Pecten maximus*) Populations in the Inshore Waters of Devon, United Kingdom.

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Declaration

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

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Abstract

King scallops *(Pecten maximus)* are an important national marine resource to the United Kingdom, and the fishery is now the third most valuable in Britain, worth an estimated £49.8 million in 2010. Stock assessments are an important aspect of successful fisheries management, however little is currently known about the state of the UK scallop stocks. The traditional method of using dredges for king scallop stock assessments has been reported to have low efficiency and can be destructive. With closed fishing areas and scallop enhancement having an increased potential as a way forward in fisheries management in certain areas, there is a need for non-destructive methods of surveying with an increased efficiency. This thesis aimed to investigate the suitability of different methods for carrying out king scallop stock assessments in the inshore waters of Devon, United Kingdom. A pyramid frame camera system based on Dr Stokesbury's SMAST sampling pyramid was compared with a towed flying camera system and dive surveys. The results indicated that the most appropriate method for king scallop stock assessments is the towed flying camera system. This method can cover a large area in a short time period at different depths, and king scallops are more detectable with the oblique angle of the camera. Although the pyramid frame was not suitable for king scallop stock assessments, it may be appropriate for use in other marine habitat assessments to advise in the management of Marine Protected Areas.

This thesis is dedicated to my late Gran, Phyllis Venus whom always supported my education, and without her this masters may not have been possible. Thank you for all your support and I hope I've made you proud. I would also like to dedicate this to my parents for all their support and for never giving up on me.

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Acronyms

UK- United Kingdom

Defra- Department for Environment, Food and Rural Affairs

nm- Nautical mile

EMS- European Marine Site

US- United States

IFCA- Inshore Fisheries and Conservation Authority

CEFAS- Centre for Environment, Fisheries and Aquaculture Science

MPA- Marine Protected Area

ICES- International Council for the Exploration of the Sea

EU- European Union

IPA- Inshore Potting Agreement

SAC- Special Areas of Conservation

cSAC- Candidate Special Areas of Conservation

SPA- Special Protection Areas

SCI- Site of Community Importance

SI- Statutory Instrument

GPS- Global Positioning System

NTZ- No Take Zone

MCZ- Marine Conservation Zone

RIB- Rigid Inflatable Boat

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Thank you all for making this possible.

1. Introduction

Over the last 30 years in the United Kingdom (UK), scallops have become an important national resource creating a valuable fishery. In 2010, the UK landed 30,700 tonnes of *Pecten maximus* (king scallops) worth an estimated £49.8 million making it the third most valuable fishery in Britain. Although this is an important fishery little is currently known about the state of the stock. There are signs of decline in some areas of the UK, but landings data suggest most stocks are at a healthy level (Defra, 2011).

The main method for the capture of king scallops in the UK is by “Newhaven” dredges, which are fitted with a spring-loaded tooth bar that rakes the seabed (Boulcott et al, 2012). It has been reported that scallop dredges are the most damaging of fishing gear; causing physical disturbance and changes to the structure of benthic communities; along with impacts on target and non-target species (Hall-Spencer & Moore, 2000; Boulcott & Howell, 2011; Craven et al, 2012; Hinz et al, 2011; Beukers-Stewart, 2009). The level of these impacts varies depending on environmental factors. In order to minimise damage there are management measures in place through European and National legislation, and local byelaws.

Vessels greater than 15 metres are controlled at European level by the Western Waters effort regime Council Regulations (EC) No 1415/2004 which sets out maximum levels of annual fishing based on kW days. Scotland, Wales, Northern Ireland and the Isle of Man have set a maximum number of dredges on vessels outside the 6 nautical mile (nm) line, however outside 6 nm in English waters there are no restrictions on the harvest scallops other than the need to have a licence, a minimum landing size, and a number of gear specifications under the Scallop Fishing Order 2004. Within 6 nm there are a number of byelaws to restrict or prohibit access to larger vessels, and manage the fishing for scallops by the inshore fleet, and through hand collection, including curfews, closed seasons and spatial restrictions (McMinn, 2013; Defra, 2011; Beukers-Stewart, 2009).

An increase in spatial restrictions are currently coming into place for fishing activities, including scallop dredging, through a number of European and UK lead Marine Protected Areas including European Marine Sites (EMS). In 2012 Defra announced a revised approach for the management of commercial fisheries in EMSs with an objective to ensure that all existing and potential commercial fishing activities are managed in accordance with Article 6 of the EC Habitats Directive (JNCC.gov.uk, 2013).

With more spatial restrictions being put in place, possibly leading to the displacement of scallop fishing vessels, and with the potential for crashes in wild scallop stocks there is a need for management measure to maintain a stable fishery. One method which is used in different locations around the world is scallop enhancement, with or without rotational closed areas. Enhancement of scallop beds is the releasing of cultured juvenile scallops at higher than normal densities (Brand et al, 1991; Bell et al, 2006; Laing, 2002). This has been highly productive with the most successful case being in Japan, where enhancement and closed areas has produced a four-fold increase over the historical maximum catch (Bell et al, 2006). Across Europe, enhancement is currently carried out at a small scale but may play a more important role in the future and there are a number of funded projects to develop this management (Brand, 2006a).

Stock assessments are needed to monitor the health of scallop populations both on natural beds, enhanced, and closed beds. Stock assessments are carried out using a number of different survey methods. The most common method is by scallop dredge, however this has low efficiency of approximately 13% to 30% (Cryer & Parkinson, 2004; Dare et al, 1994; Mason et al, 1979; Chapmen et al, 1977). Due to low efficiency and the environmental considerations of using dredges in protected, closed, and enhanced areas there is a need for non-destructive survey methods. Other methods used for scallop surveys around the world include dive surveys, bottom towed cameras and other non-invasive camera systems. One of these methods is the SMAST sampling pyramid which was developed in 1999 in the US by Dr Stokesbury. This is used for stock assessments on the Georges Bank and the Mid-Atlantic Bight in the US (Stokesbury et al, 2010). This non-destructive method has been successful for the US scallop fishery and this study aims to apply this method to English inshore waters.

The Devon and Severn Inshore Fisheries and Conservation Authority (IFCA) has funded this study in order to use the results to inform future management of scallop resources in their district. The Devon and Severn IFCA is one of ten IFCA’s around England which replaced the Sea Fisheries Committees in April 2011 under the Marine and Coastal Access Act 2009. The Devon and Severn IFCA is funded by eight local authorities. The IFCA approach is to ensure delivery of statutory duties and to be guided by the governments Marine Policy Statement. The district of the Devon and Severn IFCA (figure 1) has 1314 km of coastline and covers a 3306km² area of sea. The district has two sea boundaries, the southern boundary stretches from Lyme Regis to the border with Cornwall and the northern boundary includes the Severn Estuary and runs from Countisbury Cove as far as Maisemore Weir to Chepstow including Lundy Island. The area of inshore waters managed by the IFCA extends to 6nm or the boundary with Welsh Territorial Waters in the north of the district, and sea fisheries resources in estuaries that are within the district. The vision of Devon and Severn IFCA is to:

"Lead, champion and manage a sustainable marine environment and inshore fisheries, by successfully securing the right balance between social, environmental and economic benefits to ensure healthy seas, sustainable fisheries and a viable industry" (Devon and Severn IFCA, 2013).

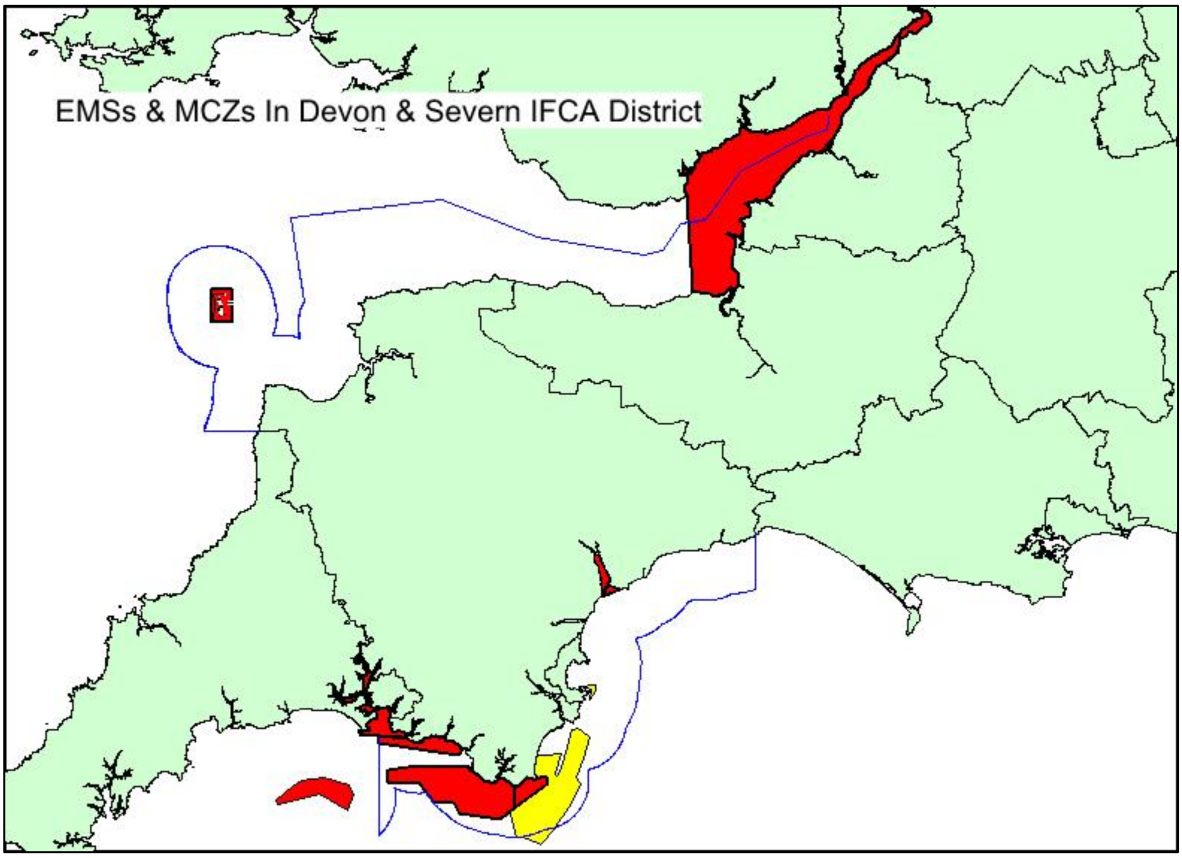

Figure 1Devon & Severn IFCA district including EMS & MCZ (Devon & Severn IFCA, 2013)

1.1 Aim of the Study

The aim of this study is to test video survey methods in order to find which method, if any, is most suited for *Pecten maximus* (king scallop) stock assessments in the inshore waters of Devon. The pyramid frame based on the SMAST frame will be tested along with a “flying array” underwater video camera system and diver surveys. Densities of king scallops observed with each method will be compared, along with operating procedures in order to find which, if any of the methodologies are most appropriate.

This report has been broken down into a number of chapters. Chapter two gives an overview of *Pecten maximus* and the UK fishery, current and possible future management along with the methods that are currently used to survey different scallop stocks around the world. Chapter three outlines the research rationale and aims of the study, chapter four explains the methodology used, chapter five gives the results of the study, chapter six discusses the results, outlines limitations of the study and makes future recommendations and lastly chapter seven gives conclusions to the study.

2. Literature Review

2.1 Scallops- *Pecten maximus*

2.1.1 Biology

Scallops belong to the family *Pectenidae*. There are two common species of scallops in British waters; the king scallop (*Pecten maximus*) and the queen scallop (*Aequipecten opercularis*) (Franklin et al, 1980a). This paper focuses on the former species, *Pecten maximus*.

Pecten maximus is a bivalve mollusc commonly known as great scallop, giant scallop, escallop, Coquille St.Jacques, and for the purpose of this paper, the king scallop. The lower right valve of the scallop is convex and off-white in colour and the upper left valve is flat and reddish-brown. Both are marked with up to 17 distinct radiating ribs. Sessile invertebrates, such as barnacles and tube worms often grow on the shells (Gibson et al, 2001) (figure 2). Maximum shell size varies with most being <150mm at the widest part of the shell. They reach reproductive maturity at a minimum size of 60mm and are fully mature at 3-5 years, living up to 20 years (Marshall & Wilson, 2009; Beukers-Stewart, 2009; Tang, 1941).

The king scallop is a simultaneous hermaphrodite with the gonad containing a creamy-coloured testis and an orange-coloured ovary (figure 3). Fertilisation occurs externally with either the sperm or the eggs being released first into the water column where the fertilisation takes place. Spawning usually takes place during the spring and summer, although this can vary in geographical ranges. Reproductive success and recruitment are influenced by a number of factors, including the amount of stock available at reproductive maturity, environmental conditions, and suitable settlement habitat availability (Franklin et al, 1980a; Beukers-Stewart, 2009). Spawning is synchronized with other nearby scallops in order to increase chances of cross-fertilization (Franklin et al, 1980a). Once fertilized a planktotrophic veliger larva develops which is free living in the water column and filter feeds on phytoplankton. Larval life depends on temperature and food availability, with genetic factors playing a role. The larvae is mixed within the plankton and is carried by currents for 3-8weeks before settling and attaching by byssal thread to available substrate, usually on substrates such as bryozoans and hydroids that provide an erect, silt-free, surface (Brand, 2006a). They remain attached until they reach between 4-13mm in length and then detach and settle on the seabed. Once detached, the king scallop has movement which is small and localised. This is achieved by "swimming" or "jumping", which is usually a behaviour seen as an escape mechanism. The scallop has three reactions to disturbance; closing the values, a jumping recreation that propels the scallop hinge foremost, and a more vigorous swimming reaction that propels the lower edge forward (Brand, 1991; Brand, 2006a). This movement is achieved by powerful water jets from the mantle cavity, generated by shell adductions (Marshall & Wilson, 2009). Many of these responses are chemosensory, and reactions to fishing gear and divers are triggered by light, water currents or vibrations (Baird 1958; Minchin & Mathers, 1982; Brand, 2006a). These escape reactions are only suitable for short distances and the scallop fatigues quickly. Young scallops swim readily, whereas adult scallops only move when they are disturbed and do not migrate. Therefore distribution is reliant on larval dispersal (Brand, 2006a).

The king scallop is a filter feeder pumping water through a filter in the gill chamber to remove particulate organic matter and phytoplankton (Franklin et al, 1980a). The recessed scallops orientate to water currents which is thought to help them feed more efficiency and imposes rhythms of feeding and digestion, phased with the tidal cycle (Brand, 2006b). The scallop has a number of eyes around the shell margin, each of which can process images (Wilkins, 1991). The king scallop has a number of predators including large crabs, cephlapods and a range of starfish, most commonly *Asterias rubens* (Oppegård, 2004, Brand, 2006b).

2.1.2 Distribution and Habitat

The distribution range for king scallops is from Norway to the Atlantic coast of Spain, at depths of up to100m. Settlement is on sediment, usually made up of fine sand or gravel and sometimes mud (marine species ID, 2013). The distribution within scallop beds has been described as patchy (Baird & Gibson, 1956; Mason, 1983). This spatial distribution has been rarely investigated using methods appropriate for the study of biological patterns. There have been a number of surveys to estimate king scallop densities in various locations around the UK including Mason et al, 1979; Franklin et al, 1980b; Murphy, 1986; Wilson & Brand, 1995. From these surveys it can be said that king scallop densities are rarely found at one scallop per m² and are more typically 0.1-0.01 scallops per m² on good fishing grounds (Brand, 2006, Rees & Dare, 1993).

The king scallop is usually found recessed into shallow depressions in the seabed, with the upper flat valve level or slightly below the sediment. The scallop recesses by jetting water from the mantle cavity forcing the scallop downwards. This process can take 2-20 minutes depending on the sediment type. Sediment which is disturbed during the process then settles onto the scallop providing protection from visual predators (Brand, 2006a).

Figure 2. King scallops (Parkhouse, 2013.

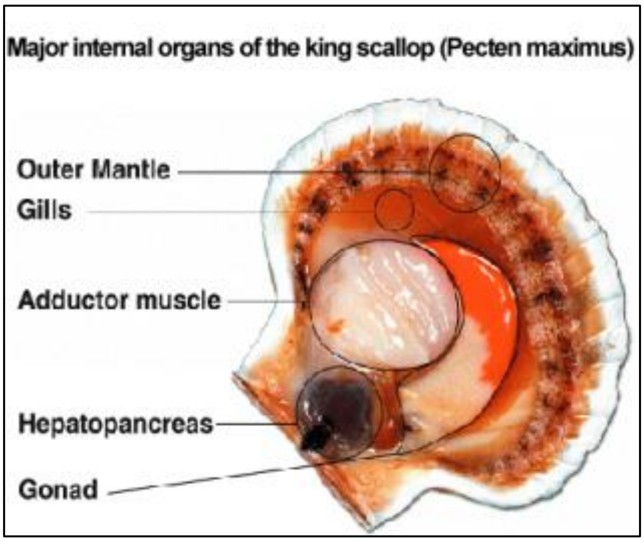

Figure 3. Scallop internal organs (food.gov.uk, 2002).

2.2 Scallop Fisheries in the United Kingdom

Scallops have been exploited by humans for millennia (Beukers-Stewart, 2009). However commercial scallop fisheries in Europe have grown rapidly in the last 40 years, with the main fisheries for king scallops being the UK and France (figure 4) (Beukers-Stewart, 2009). The UK scallop fleet is split into two components made of smaller vessels between 8 and 15m in length, and a fleet of larger vessels more than 15m in length, some up to 37m in length. The smaller vessels fish with fewer dredges and typically operate within 6 miles of the shore and are considered the inshore sector. Their catch is traditionally landed into local markets on a daily basis. The inshore fleet display a greater sensitivity to changes in stock levels (Beukers-Stewart, 2009; Defra, 2011). The larger vessels are based offshore and can operate for four to five days at a time with some vessels being more nomadic, fishing all around the UK coastline. However, the largest vessels in the fleet are only allowed to fish at full capacity in English waters due to fisheries restrictions in Scottish, Northern Irish and Welsh waters and most recently restrictions around the Isle of Man (Defra, 2011).

During 2010 the UK king scallop fishery landed 30,700 tonnes of scallops, worth an estimated £49.8million, and it is the third most valuable fishery in Britain after Nephrops (*Nephrops norvegicus*) and Mackerel (*Scomber scombrus*). Approximately 60% of the scallops landed are exported into Europe, mostly to France (Dobie, 2013). There is a westerly distribution of king scallop fisheries in the UK, with the main fisheries being concentrated in the eastern and western English Channel, the Irish Sea, and off the west and north-east coasts of Scotland, with Scottish boats accounting for approximately half of the UK catch (Beukers-Stewart, 2009).

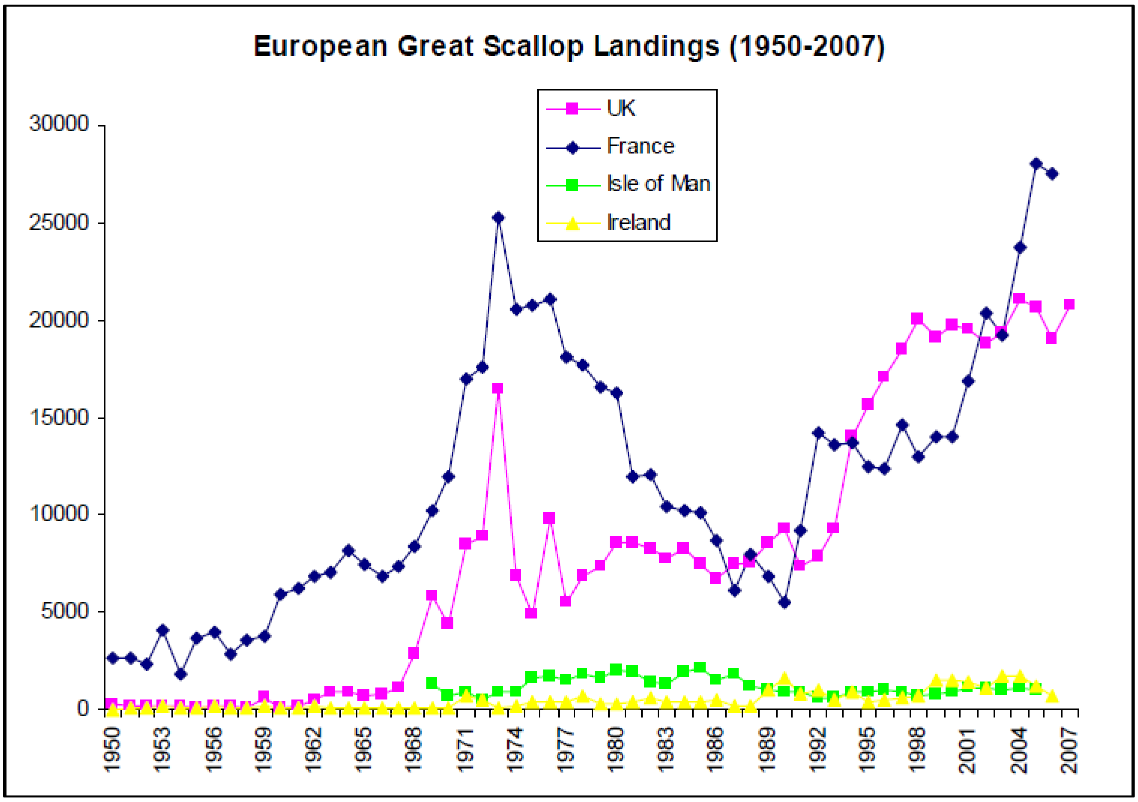

Figure 4. Latest king scallop landings in Europe by country and year (Beukers-Stewart, 2009).

In 2009 there were 318 UK scallop vessels, approximately 239 of which spent time in English waters. The Under 10m fleet consists of 117 vessels, the 10-15m fleet 86 vessels and the over 15m fleet 115 vessels. The catch from the over 15m fleet made up 78% of the total landed into the UK in 2009 (Defra, 2011).

The main method of capture for the king scallop in the UK is by dredge. This is normally a "Newhaven" type dredge, fitted with a spring-loaded tooth bar so that it can pass over hard ground. The teeth can flex backwards allowing them to pass over harder ground without snagging and breaking, and improving catch efficiency (Boulcott et al 2012; Boulcott & Howell, 2011). The tooth bar is made up of eight or nine teeth up to 11cm long, which allow the scallops to be raked up from their recessed position in the seabed (Bradshaw et al 2001). Behind the tooth bar is a mesh bag made up of nylon upper or chain mail with a mesh size of 100mm to allow undersized scallops out and a steel lower section with a mesh of 80mm designed to retain the scallops. There are between 2 and 22 dredges, roughly 75cm in width, attached per side to a towing bar with rubber wheels on each end designed to roll along the seabed (figure 5 & 6). The amount of dredges towed by UK vessels depends on local regulations and vessel size. There is low catch efficiency with this gear of between 5% and 40% for legal sized scallops, depending on the seabed and operating conditions (Beukers-Stewart, 2009; Beentjes & Baird, 2004; Cryer & Parkinson, 2004).

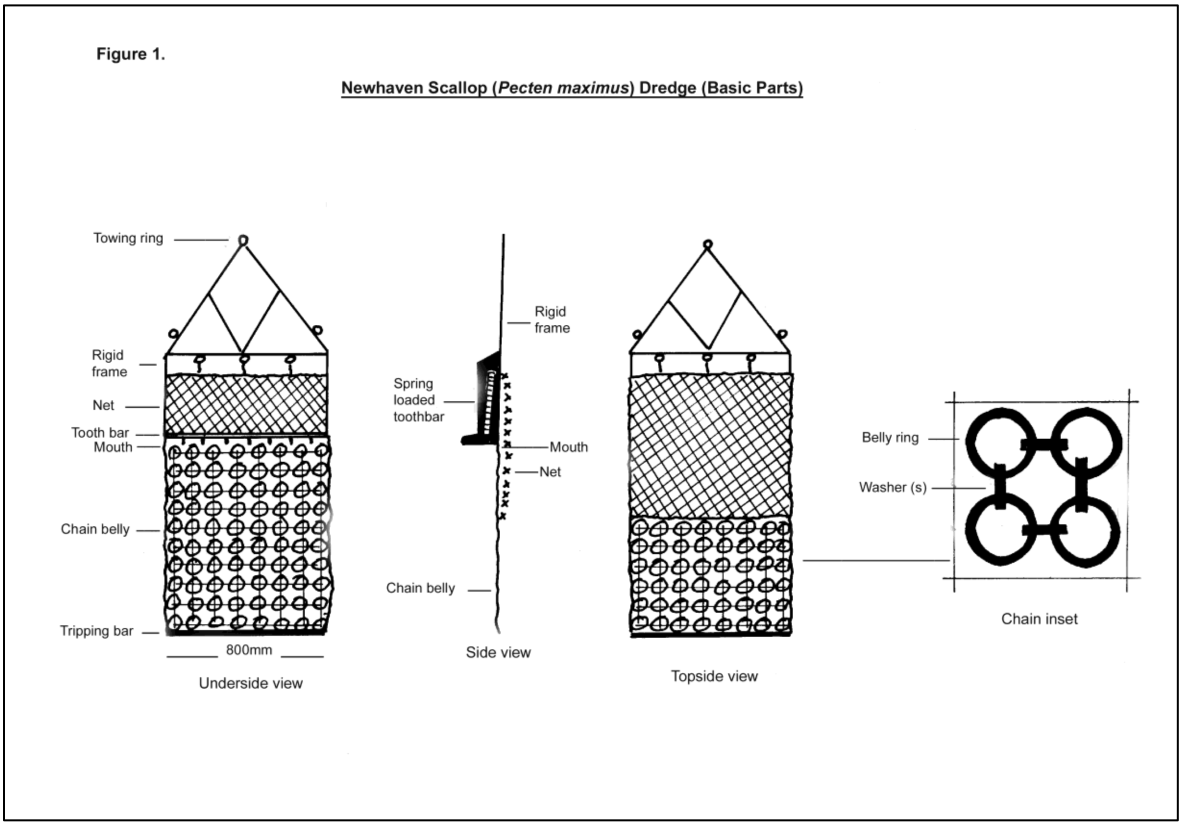

Figure 5 Schematic of Newhaven dredge (Hughes, 2009)

Figure 6. Newhaven dredge being recovered after tow (Beukers-Stewart, 2009).

King scallops are also hand-collected by divers. This is a more artisanal fishery compared to dredging and only accounts for a small percentage of total scallop production in the UK. Most scallop diving is carried out in Scotland where in 2003 this method made up 4.7% of scallops landed. Other areas of the UK where hand-collection occurs are parts of the South West; it is rare elsewhere in the UK (Beukers-Stewart, 2009). Hand-collection is typically done in shallow areas of depths of less than 40m, which tends to be rockier and away from dredge fisheries, and larger scallops are targeted (Boulcott et al, 2012).

A third method of king scallop production is cultivation. In 2011 only 10 tonnes of scallops were produced by cultivation in the UK, worth £31,000 (Cefas, 2013). Of this total, 9 tonnes was produced in Scotland, mostly on the west coast. Cultivation of scallops in the UK mainly uses wild-caught seed; however there has been an increase in spat produced in hatcheries in Europe (Laing, 2002; Beaumont & Gjedrem 2007). Wild caught larvae are collected using monofilament nylon mesh bags suspended in the water column on weighted ropes (Laing, 2002). Once the spat reach a size of 20-30 mm, they are ready for on-growing. This is done in suspended nets, such as pearl nets and lantern nets. As the scallops grow the amount of scallops in each compartment of the nets are reduced in order for them to have space to grow. In the UK, the scallops are then moved to the seabed once they reach 50-60 mm until they reach commercial size and are ready for harvest (Laing, 2002; Beaumont & Gjedrem 2007).

2.3 Effects of Scallop Dredging

It has been reported that demersal fishing gear, especially those that penetrate the substrate such as scallop dredges, may be the most damaging to benthic communities (Hall-Spencer & Moore, 2000; Boulcott & Howell, 2011; Craven et al, 2012; Hinz et al, 2011). The Newhaven dredges which are used in UK scallop fisheries are the most damaging of the scallop dredges, due to the long teeth which penetrate deeply into the seabed (Beukers-Stewart, 2009). Dredging for scallops can cause physical disturbance and changes to the structure of benthic communities in a number of ways (Jenkins et al, 2001, Hall-Spencer and Moore, 2000). The effects can be on the target species and the wider environment.

Physical impacts come from scraping and ploughing. This can cause destruction to the bedforms, and biological impacts come from the removal or scattering of non-target benthic species, and damage to the target species (Craven et al, 2012; Dale et al, 2011). Sessile organisms and epifauna, such as erect bryozoans, sponges and anemones which live on substratum, are long lived, and slow growing are most likely to be negatively impacted on by dredges (Hinz et al, 2011). It has been reported that such damage can be reversed over time with fishing closures. An example is Lyme Bay MPA which excluded towed demersal gear, including scallop dredges, from 206 km^2 of sensitive reef habitat. Within three years of the closure seven of the 13 indicator species showed positive responses for species richness, total abundance and assemblage composition (Sheenan et al, 2013).

Scallop dredges can cause homogenization of sediments and the seabed topography by penetrating, mixing and flattening the sediment. This mixing reduces spatial heterogeneity in benthic communities, altering the density of mega fauna and therefore affecting recruitment in a population (Collie et al, 2000; Craven et al, 2012; Kaiser et al, 2002; Beukers-Stewart, 2009). The gear can remove and move large numbers of stones and boulders from habitats, along with breaking up the integrity of reefs, which causes a loss of suitable substrate for certain epifauna species causing a reduction in biodiversity. Effects of dredging on soft sediment include the removal or re-suspension of sediment, which can then smoother sessile marine life in the vicinity (Beukers-Stewart, 2009, Bradshaw et al, 2001). Large amounts of re-suspended sediment can reduce the survival of bivalves by inhibiting their movement behaviour, and fish from clogging of the gills (Mercaldo & Goldberg, 2011). The removal of the sediment can change nutrient cycles and carbon flux by exposing anaerobic sediments (Kaiser et al, 2002; Beukers-Stewart, 2009).

Along with the effects on the wider environment scallop dredging can have negative impacts of target and non-target species including post-fishing mortality of species which come into contact with the gear, especially the teeth of the dredge. These can cause damage to the scallop shells along with non-target species (Bradshaw, 2001; Beukers-Stewart, 2009). Fatal damage can vary from 2% to more than 20% depending on the fishing grounds for captured and non-captured undersized scallops (Beukers-Stewart, 2009). Along with fatal damage to discarded scallops, there is evidence of a reduced predator escape response in discarded juvenile scallops, this is coupled with an influx of predators and scavengers taking advantage of the damage caused (Craven et al, 2012, Shephard et al, 2008; Bradshaw, 2001). It has been seen that sediment re-suspension from dredging can have a number of effects including a negative impact on feeding efficiency in scallops and on the behaviour and growth of scallops as well as smothering of benthic communities (Szostek et al, 2013). The growth and survival rate of juvenile scallops in heavily fished areas is lower than that of areas protected from fishing. The reduction in the survival of juvenile scallops can have an effect of the population due to the inability of the year class reaching the age to breed or recruit into the fishery (Beukers-Stewart, 2009).

The degree of these impacts varies depending on a number of different environmental conditions and there are a number of legislations to manage the fishery and minimise any impacts.

2.4 UK Scallop Management

At a European level UK scallop vessels greater than 15m in length are controlled by the Western Waters effort regime Council Regulation (EC) No 1415/2004, which sets out the maximum levels of annual fishing based on kW days. This was developed in 1995 to avoid an increase in fishing effort when Spain and Portugal joined the Common Fisheries Policy. The UK has been allocated a total of 3,315,619 kW days in Area VII and 1,974,425kW days in Area VI of the ICES areas (figure 7). This is a fixed allocation and does not change by year. Days at sea may be traded between countries if a member state has exhausted theirs, which occurred in the UK in 2011 (McMinn, 2013).

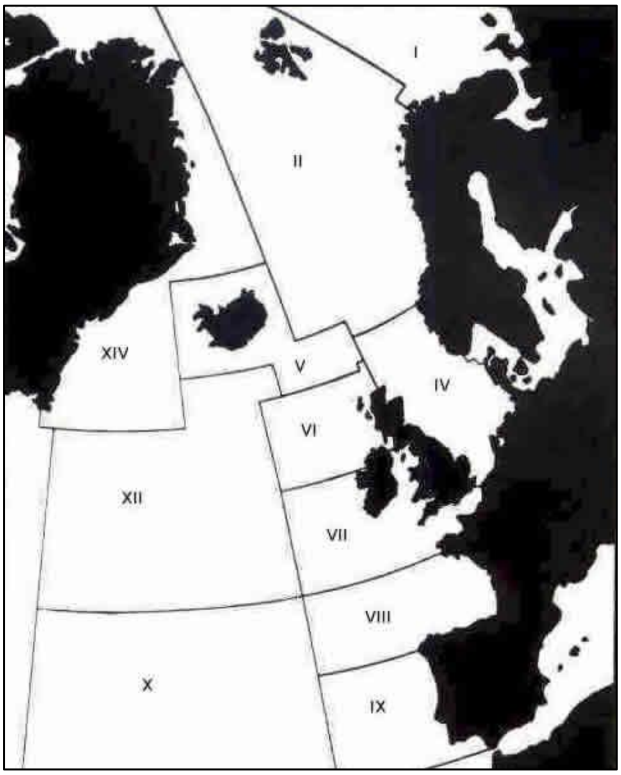

Figure 7. Map illustrating the ICES areas (mba.ac.uk, 2013).

There are management measures affecting larger vessels in place in UK water to maintain the small scales fleets, which rely on a sustainable fishery for scallops in inshore waters. In English waters to the 6 nm line, the Inshore Fisheries and Conservation Authorities (IFCA) have introduced byelaws to restrict or prohibit the access of large scale vessels. Outside of 6 nm, there are currently no English national measures in place to restrict the scallop fishery. In Scottish waters, there is the Prohibition of Fishing for Scallops (Scotland) Order 2003 which prohibits the use of vessels with more than 14 dredges per side. Northern Ireland, Wales and the Isle of Man also have similar measures in place. This means the largest scallopers are only allowed to fish at full capacity in English waters outside the 6nm line (Defra, 2011).

To operate within the commercial fishery a UK vessel must have a licence appropriate to its size, engine power and the type of fishing that is being carried out. At a national and EU level there are no restrictions for the total catch of scallops. The fisheries are mainly controlled by minimum landing sizes which are set by Council Regulations (EC) 850/98. ICES area Vlla and Vlld have a minimum landing size of 110 mm, while all other areas have a minimum landing size of 100mm. Under the Scallop Fishing Order 2004 all dredges used for scalloping must:

- Have a frame not exceeding 85 cm in width
- Include a fully operational spring loaded tooth bar and belly bar
- Not contain any attachments to the dredge
- Not contain a diving plate or similar device
- Have a total weight not exceeding 150 kg (McMinn, 2013).

If a dredge measures 80 cm or more in breadth it should not have more than 8 rows of belly rings hanging from the belly bar or more than 9 teeth. If it is less than 80 cm in length it should have no more than 6 rows of belly rings hanging from the belly bar or more than 6 teeth on the tooth bar. Dredges used must follow certain specifications concerning the internal belly ring diameter (≥75 mm), top net mesh size (≥100 mm), tooth number (<10) and tooth spacing (≥75 mm). Throughout the UK, there are different gear controls and in England byelaws are set by the Inshore Fisheries and Conservation Authorities (IFCAs). Closed season and curfew systems are common management measures put in place by IFCAs. (McMinn, 2013; Beukers-Stewart, 2009).

Hand-collection of scallops by recreational and commercial diving has fewer regulations. However, minimum sizes and closed seasons and spatial restrictions apply to both dredges and divers. Commercial divers are subject to the Health and Safety at Work Act 1974 and the Diving at Work Regulations 1997 (hse.gov.uk, 2013).

2.4.1 Devon and Severn IFCA Management

The study locations for this research project fall under Devon and Severn IFCA byelaws. These include closed season, spatial restriction, method restriction and size restriction and are as follows:

- No person shall fish for or take any scallop from a fishery on any day before 0700 local time and after 1900 local time.
- No person shall remove from a fishery any scallop (*Pecten maximus*) during the months of July, August and September each year in parts of the Devon and Severn IFCA district.
- A limited bye-catch of 10 dozen scallops per day will be permitted for vessels engaged in trawling.
- No person shall use in fishing for scallops any dredge except one fitted with a spring loaded tooth bar and with a mouth which does not exceed 85 cm width overall.
- Where rings are used in the construction for the retaining bag for a dredge, these shall not be less than 75 mm measured across the inside diameter. Where net is used in the construction of a retaining bag for this dredge it shall have a minimum mesh size of 100 mm. no person shall obstruct or otherwise reduce the size of the ring or net mesh of the retaining bag by any method.
- The total number of dredges used by any vessel shall not exceed 12 at any one time.
- Where multiple dredges are used, the length of the tow bar, including attachments, shall not exceed 5.18 metres.
- No vessel shall use more than two tow bars at any one time.
- No person shall remove from a fishery any escallop measuring less than 100mm across the broadest part of the flat shell.

On 1st January 2014, the Devon and Severn IFCA Mobile Gear Permit Byelaw came into action. This byelaw requires vessels using towed gear, other than those less than 7 metres using a net with a mesh size of less than 31 mm to fish for sand eels, to have a permit. This byelaw controls access of vessels using bottom towed gears to Marine Protected Areas. There are a number of areas closed to demersal towed gear under the conditions of the permits; including the locations the surveys took place at Start Bay (figure 8) and Torbay (figure 9).

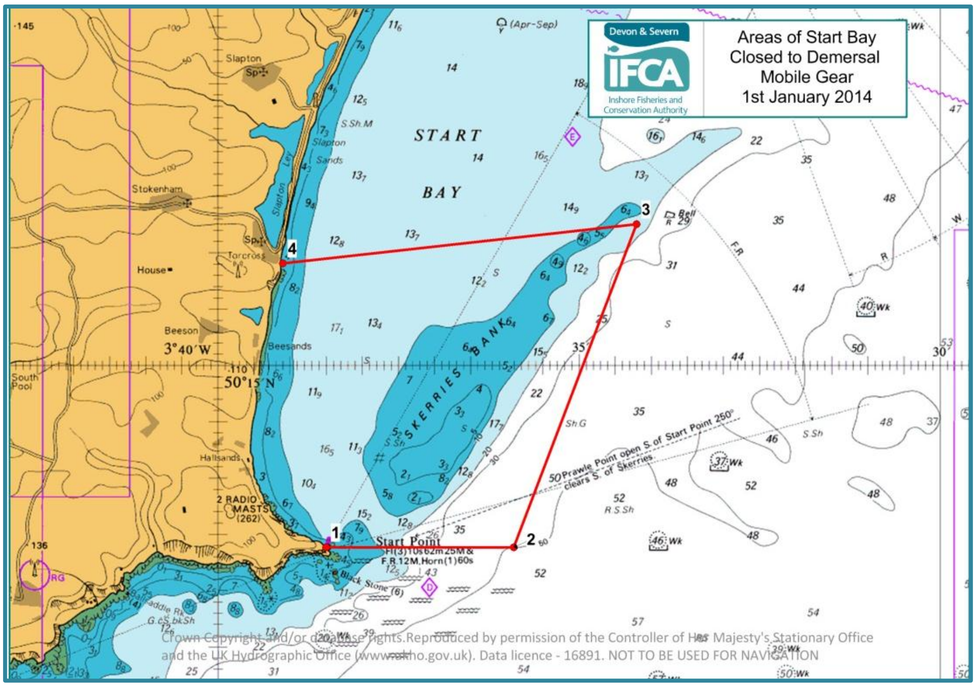

Figure 8. Start Bay area closed to demersal mobile gear (Devon and Severn IFCA, 2013).

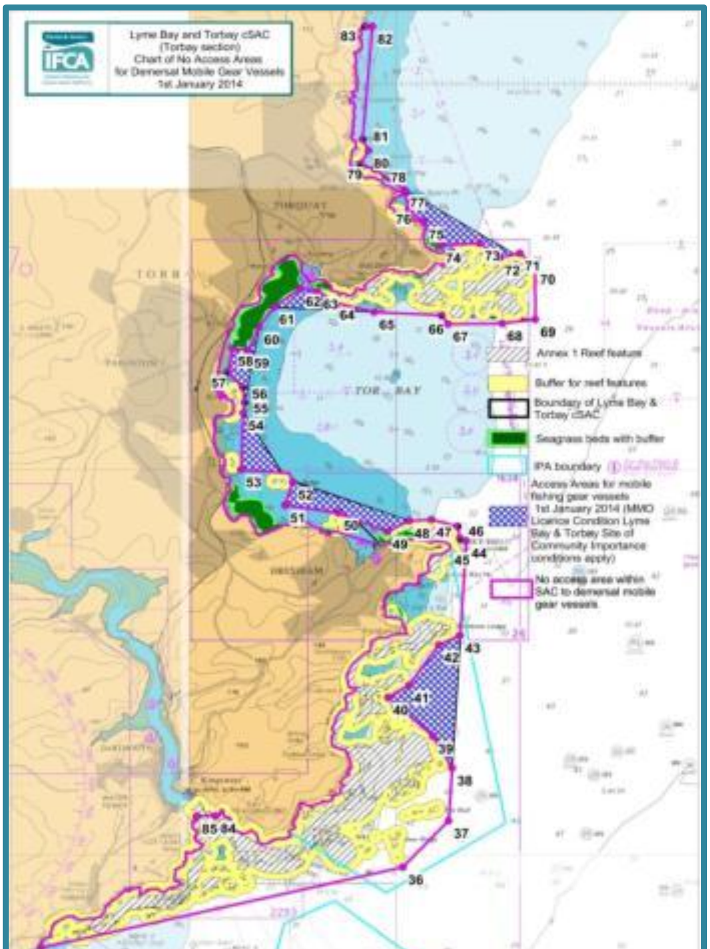

Figure 9. Torbay cSAC area closed to demersal mobile gear (Devon & Severn IFCA, 2013).

There are a number of other spatial restrictions in place which manage scalloping, along with other fishing activities, in the Devon and Severn IFCA district including, the South Devon Inshore Potting Agreement, European Marine Sites and other marine protected areas.

2.4.2 Inshore Potting Agreement

The Inshore Potting Agreement (IPA) started as a number of voluntary gear restriction zones in Start Bay, Devon, in 1978. It was established by fishers in order to reduce conflict between mobile and static fishing gears. There have been a number of changes over the years and in 2002 Defra legislated the towed gear exclusion to enhance protection and further reduce gear conflict. The area covered by the IPA is 478.4km² with 349.7km² for static gear only and 73.2km² shared between towed and static gear on a seasonal basis (figure 10) (Sweeting & Polunin, 2005; Blyth et al, 2002).

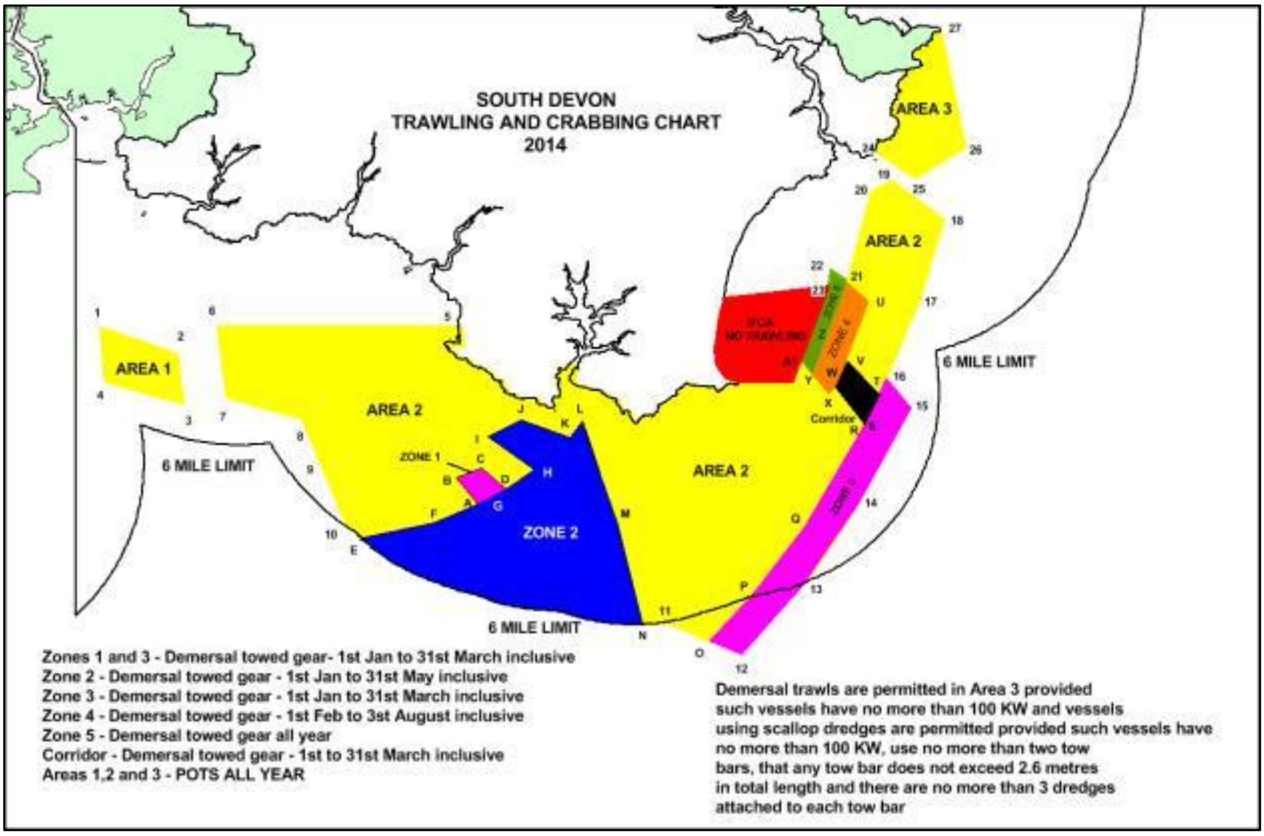

Figure 10. IPA Chart 2014 showing the zones where potting and trawling can and cannot take place (Devon & Severn IFCA, 2014).

2.4.3 European Marine Sites

European Marine Sites (EMS) are Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) which are protected under the EC Habitats Directive and EC Birds Directive. The Habitats Directive aims to promote the maintenance of biodiversity of natural habitats and wild species listed on the Annexes to the Directive. The SAC and SPA are the statutory designation and the EMS is the management units. Management measures are being put in place to protect European habitat features listed on Annex I and protected species listed on Annex II from certain potentially damaging activities occurring in the EMS. In 2012, Defra announced a revised approach to the management of commercial fisheries in EMS's. The objective is to ensure that all existing and potential commercial fishing activities are managed in accordance with Article 6 of the Habitats Directive (mmo.org.uk, 2013; JNCC.gov.uk, 2013).

The Devon and Severn IFCA has six EMS sites within their district. These are the Severn Estuary EMS, Lundy SAC; Exe Estuary SPA, Plymouth Sound and Estuaries EMS, Start Point to Plymouth Sound and Eddystone cSAC and Lyme Bay and Torbay cSAC.

The survey locations are within the vicinity of two of the EMS's; Start Point to Plymouth Sound and Eddystone cSAC and Lyme Bay and Torbay cSAC. Lyme Bay and Torbay cSAC is now classified as a Site of Community Importance (SCI) and part of the site is protected with a Statutory instrument (SI). The cSAC is designated for bedrock reefs, stoney reefs, biogenic reefs and submerged or partially submerged sea caves and is split into two areas; Mackerel Cove to Dartmouth and Lyme Bay reefs, the survey locations relate to the former (figure 11). The SI is located within the Lyme Bay part of the cSAC. In 2008, a 60 square mile area of Lyme Bay was closed to mobile fishing under this SI, The Lyme Bay Designation Area (Fishing Restrictions) Order 2008. This was in order to protect nationally important reefs (Pearce, 2013). The Torbay part of the cSAC covers the area from Mackerel Cove to Dartmouth and has been designated to protect the bedrock reef, biogenic reef and sea cave features and the related flora and fauna those features support. The bedrock in the area is highly vulnerable to physical damage and biological disturbance caused by demersal towed fishing gears (JNCC.gov.uk, 2013).

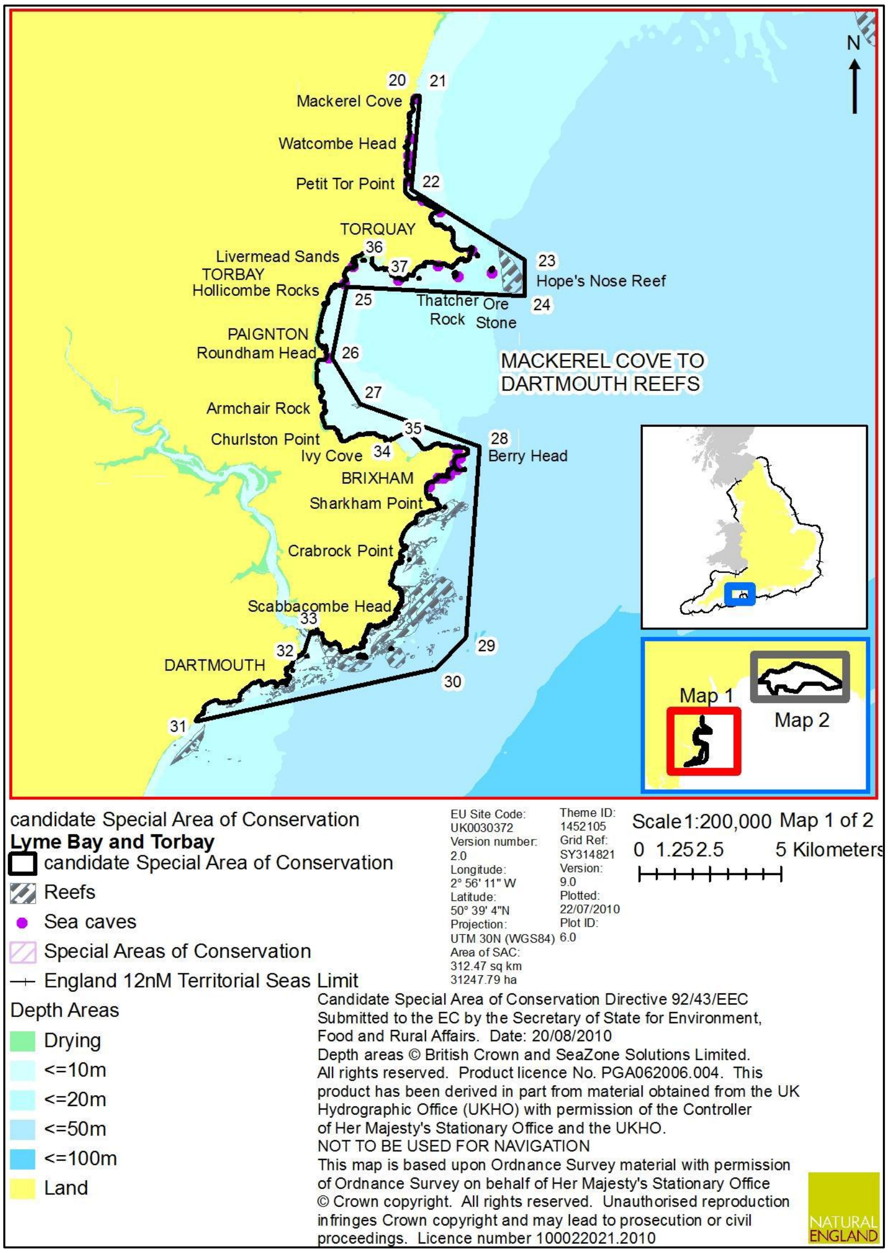

Figure 11. Map of the Torbay EMS (Natural England, 2013).

In order to bring in management measures to fulfil Defra's revised approach to commercial fisheries within EMS and meet the conservation objectives for the EMS's Devon and Severn IFCA has developed management of fisheries through a Mobile Fishing Permit Byelaw. This prohibits the interaction of damaging gear types on sensitive reef features. The byelaw therefore restricts scallop dredging over and close to the reef features within EMSs within the district. Figure 12 shows the scalloping effort in 2010, this is sightings per unit effort. The greatest effort is shown in deep red and the lesser effort in pinks (Devon & Severn IFCA, 2010).

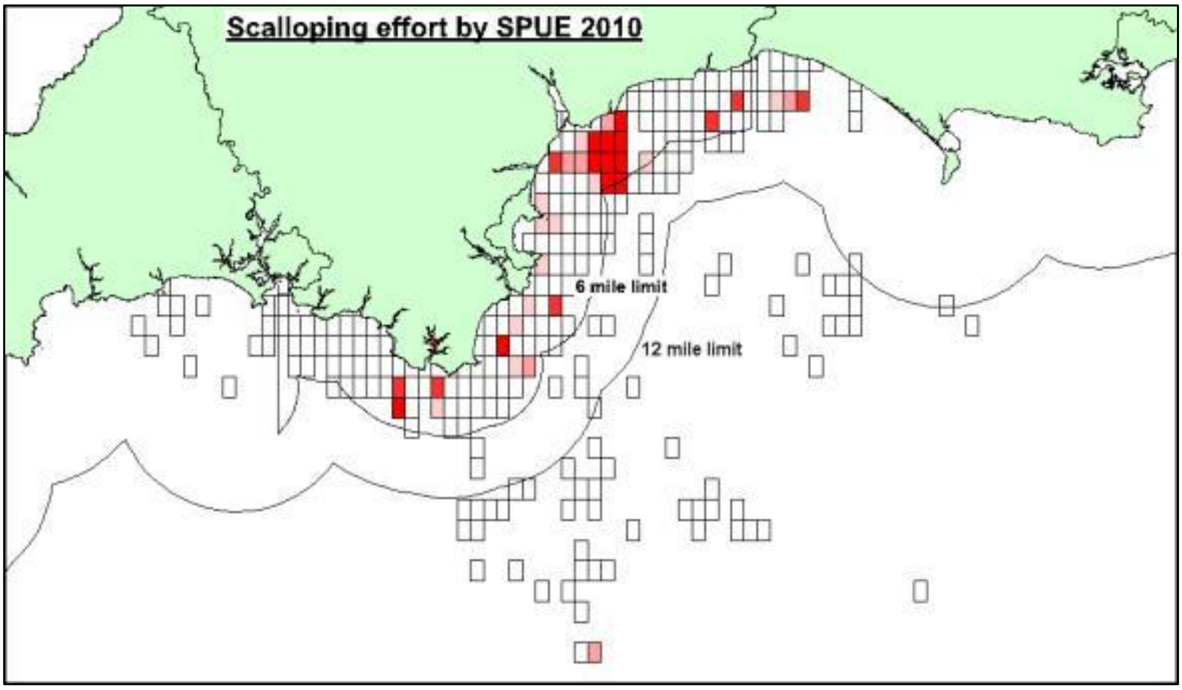

Figure 12. Scallop effort data from sighting per unit for South Devon 2010 (Devon & Severn IFCA, 2010.)

2.5 Enhancement

Enhancement of scallop beds is the releasing of cultured juvenile scallops at higher than normal densities to overcome recruitment limitations. These juveniles can come from wild-caught spat or hatchery produced spat which are on-grown (Brand et al, 1991; Bell et al, 2006; Laing, 2002). Enhancement, along with closed areas, is becoming an increasingly popular way to manage scallop fisheries around the world. This type of management has been highly productive in countries such as Japan, China, New Zealand and the USA (Beukers-Stewart, 2006; Dao et al, 1999). The most successful example of stock enhancement comes out of Hokkaido, Japan, which has a consistent annual harvest of ~300,000 t p.a. of *Patinopecten yessoensis*. This is a four-fold increase over the historical maximum catch (Bell et al, 2006). This success is down to effective juvenile production and management of the harvests, which is funded and conducted by the fishers themselves (Bell et al, 2006). Rotational closures, alongside enhancement, have been successful in other countries such as Tasmania and New Zealand, where this type of management has maintained a stable fishery and sustains full-time fishermen (Brand, 2006a).

Currently across Europe, including the UK, scallop enhancement is only carried out at a small scale, with under 500t being produced. However this may play a more important role in the future (Brand, 2006a). In the UK, stock enhancement has been carried out on a small scale successfully along with closed areas off the Isle of Man. An area of 2 km^2 was closed to fishing in 1989 and expanded by 1 km^2 in 2003; in 2008 another area was closed. The 2003 and 2008 areas were enhanced with juvenile scallops from a hatchery in the Isle of Skye, Scotland. (Beukers-Stewart, 2006; Beukers-Stewart, 2009; Brand, 2006a). The area closed in 1989 saw an exploitable biomass of 8.0 times greater than the adjacent fishing grounds by 2004. Results have shown that the enhancement has aided in the recovery of scallops populations in the closed area (Beukers-Stewart, 2006).

The need for future development in enhanced scallop fisheries may arise from an absence of natural stock, depletion of wild stock through fishing mortality, increased areas being closed to fishing for environmental protection reasons such as EMS's and displacement of scallop fishing activity due to these closures. There are a number of well-funded projects to develop this type of management of scallop fisheries in the UK (Brand, 2006a). There has been increased interest within the Devon and Severn IFCA district for scallop hatcheries and scallop stock enhanced fisheries (Clark, pers.comm, 2014).

2.6 Survey Methods for Scallop Stocks

Scallop dredging is currently the most common method of surveying for assessing scallop populations. This is done using the same method as the fishery, using Newhaven type dredges to simulate commercial practice. King dredges are used for king scallops and smaller queen dredges can be used to catch undersized king scallops for the analyses of age and size structures of populations (Lambert et al, 2012). Typically GPS coordinates are taken at the start and end of each tow to calculate the area surveyed using tow length and dredge width; this is then used to calculate abundances and biomass. Scallops are usually measured, weighed and aged using growth rings with this type of survey. Surveys carried out by scallop dredge need to be corrected for sampling efficiency (Cryer & Parkinson, 2004).

Although the most common method of assessing scallop population is by scallop dredge, the efficiency of this gear is often unknown and this could mask population measures (Stokesbury et al, 2010). There have been many reviews of scallop surveying methods around the world and efficiency and size selectivity problems of scallop dredges are well-documented. Beukers-Stewart et al (2001) found that the efficiency of Newhaven spring-toothed dredges, which are used for king scallops, was significantly lower for king scallop <90mm shell height than for larger animals (Rosenkranz & Byersdorfer, 2004). Chapmen et al (1977) found that spring loaded dredges in Scotland were about 13% efficient for scallops close to the minimum legal size, and fixed tooth-bar dredges were about 20% efficient. Commercial dredges, used in biomass surveys for stock assessment, have been found by Dare et al (1993, 1994) to have an average efficiency for scallops close to minimum landing size was approximately 30% and lower for very large scallops and very small scallops. Similar results were found by Mason et al (1979) who found the efficiency to approximately 20% (Cryer & Parkinson, 2004).

Other factors that can make scallop dredging unsuitable for surveying are environmental considerations and restrictions in certain areas. Other methods used for these assessments include dive surveys, bottom towed cameras, and other non-invasive camera tows.

A study was carried out by Mason et al (1982) comparing the use of dive, dredge, and towed video camera surveys for carrying out distribution and density studies for king scallops. They found that compared to divers, dredges recovered 18% of scallops in their path and 36.3% of scallops were observed using the camera system. Dive surveys were the most effective in recording the highest number of scallops, but these surveys are limited by area covered and restricted by water depth. They also found that divers tended to select areas with high local densities with diver estimates of up to 8 scallops per m^2 being recorded. Unlike the small area that the divers can cover, camera surveys can cover a larger area, operate in deeper water and give information on large scale patchiness in scallop distributions. However, Hall-Spencer et al (1999) concluded that camera surveys can underestimate the density of recessed scallops because they can be difficult to pick out on the screen (Brand, 2006a).

2.6.1 Camera Tows

Towed camera systems have been used in a number on scallop surveys in the UK and abroad. This is typically done using a sledge mounted with a video and/or still camera which is towed along the sea bed filming and/or taking photos. Researchers from Bangor University used this method for a Welsh water scallop survey in 2012 (Lambert et al, 2012). A sledge mounted with video and still cameras was towed over 25 sampling stations, at a speed of approximately 0.5knots for a period of 30 minutes, to collect real time records of scallop abundances. Start and end positions of each tow were recorded from the point the sledge had visibly reached the sea floor to the point when the sledge lifted off the ground during hauling. Digital stills were taken every 10 seconds, along with the constant filming of the seabed. Scallop densities were then estimated from both the stills and the video footage and a comparison was made of the density estimates from the two methods. This was a trial run for the towed camera equipment in this region; results from the survey are leading them to improve their sampling devices for future use in the area (Lambert et al, 2012).

Another example of cameras being used to estimate scallops densities comes from a video survey carried out in the eastern Gulf of Alaska by Rosenkranz and Byersdorfer (2003). A towed sled was again used, equipped with two flood lights and a small digital camcorder that was aimed downwards with a slight tilt forward of ~3° from a height of 1.15m. A total of 135 stations were sampled, covering 124,223m² of seabed with a total count of 12,000 scallops. Tows were 15 minutes long as this was the maximum time they found viewers could concentrate fully on reviewing the footage. Unlike the survey carried out in Welsh waters, the Alaskan survey did not have a live feed and the crew were unaware of problems that may have been occurring during filming, this lead to lost survey time. They found from the results of the survey that video surveys are a viable method for assessments of Alaska's scallop stocks and there are plans to continue using this method to survey the three main scallop fishing areas in Alaska on an annual rotating basis (Rosenkranz & Byersdorfer, 2003).

2.6.2 Dive Survey

SCUBA Diving is another method for carrying out scallop density and abundance surveys. This type of method gives greater efficiency, but does have limitations including; being restricted by depth, low spatial coverage and a high cost (Katsanevakis, 2005).

Dive surveys are often carried out using transects. These are typically line transects or circular search transects. Divers can take counts of scallops and measure them while on the seabed. There are examples of different dive surveys being used in different countries including New Zealand, Greece and the UK.

In New Zealand, circular search sweep survey methods are used for scallops' abundance in the Coromandel recreational fishing areas annually. Using a buoyed line as the centre of the circle, the divers attach a sweep rope to the centre line and use this to mark out a 5m and 8m circle radius to sweep for the scallops. Scallops are collected as the divers make their sweep and are brought to the surface to be measured. An efficiency of 100% is assumed for the dive searches (Williams, 2009).

In the Mediterranean, line transects were used in a marine lake. At different depths a 200m line was deployed, marked every 1m and every 5m. The divers moved along the line and all scallops were recorded and measured for shell height and length in situ (Katsanevakis, 2005).

In the UK, line transects were carried out by a pair of divers at Lundy Island over a number of years. This was carried out in order to assess the effectiveness of achieving the conservation goals of the Lundy No Take Zone which was established in 2003. The transect was 10m by 3m, this distance was measured using a tape attached to a shot line and the width was measured using a pipe which had the measuring tape attached to the centre. All scallops within the 3m by 10m transect were counted and measure in situ (Hoskin, 2009).

2.6.3 SMAST Sampling Pyramid

The SMAST sampling pyramid was developed in 1999 by Dr Stokesbury and his team in a cooperative with scallop fishermen. This technique has been used in the US since 1999 and in 2003 the scallop fishing industry requested the video survey covered the entire scallop resource in the US waters, based on the footprint of the 2002 fishery. This work was carried out between 2003 and 2011 and covered the scalloping areas on Georges Bank and the Mid-Atlantic Bight. The video survey uses quadrat techniques based on scuba diving studies. The aim was to provide spatially explicit, accurate, precise, absolute estimates of sea scallop (*Placopecten magellanicus*) density and size distribution. A mobile video recording system, which is compatible with any scallop vessel wheelhouse layout, is used for the sampling pyramid which is deployed and hauled using an electro-hydraulic winch. The sampling pyramid can support four cameras and eight lights (Stokesbury et al, 2010). For the 2003-2011 project, stations were positioned on a 5.6km by 5.6km grid, with the sampling pyramid making four drops at each station. The pyramid had two vertically placed cameras at a height of 700-1575mm above the pyramids base to provide quadrats of 0.788m² and 3.235m² (0.595 and 2.841m² in 2004) including a correction factor for scallops on the edge. In some cases a third camera was mounted horizontally 50mm above the base of the frame to provide a side view of the area. The larger quadrats were used for density estimates while the smaller quadrats were used in estimating recruitment. At each station four quadrat samples were carried out. The vessel stopped at each station and the pyramid was lowered to the sea floor. Footage was recorded and then the frame was raised and the vessels drifted approximately 50m to the next point and the frame was lowered again. This was repeated for each station. The time, depth, number or live and dead scallops, latitude and longitude were recorded at each of the stations. All scallops were counted, including those along the edge of the quadrat image that were only partially visible. Mean densities and standard errors of scallops were calculated and the absolute number of scallops within a survey area was then calculated using the means. Distributions of scallops were then mapped for each year (Stokesbury et al, 2004; Stokesbury, 2012).

2.6.4 Scotland Pyramid Frame

A frame based on Dr Stokesbury's design was used in 2009 and 2010 in Scotland, as part of a study to develop photographic survey techniques for scallops in inshore waters and to obtain baseline abundance data for the Lamlash Bay No Take Zone (NTZ). A pyramid frame was used, fitted with a digital still camera which took quadrat images of 1.85m² of the seabed. A side elevated video camera was fitted to help identify any recessed scallops for which there was uncertainty. Three study areas were used and in each of these study areas there were 100 stations positioned randomly using ArcGIS, and four drops were made at each of these stations. Time depth, latitude and longitude were recorded at each drop. In total, 1944 quadrate images were used. All images were analysed post-survey, with the number of scallops present in each quadrat and the substrate type being recorded. Mean densities of scallops were calculated from the results (Boulcott et al, 2012).

3 Research

3.1 Research Rationale

There are two main reasons for testing new methods for scallop stock assessments, the first being the low efficiency of the current dredge method and the second being the need for a less destructive method to be used in sensitive and closed areas, and possible enhancement areas.

Due to an increase in areas being closed to bottom towed gear, such as scallop dredging, there is the possibility of scallopers being displaced from the main scalloping grounds putting pressure on other areas and the industry. Part of the Devon and Severn IFCAs mission statement is to maintain a viable industry, and therefore it is important to undertake efficient research with appropriate survey methods and to investigate future management such as enhancement and monitor these management programmes.

3.2 Research Aim

The aim of this study is to assess the suitability of using a pyramid frame with video cameras, based on Dr Stokesbury's design to estimate King Scallop (*Pecten maximus*) densities in the inshore waters of the Devon and Severn district, United Kingdom. This will be investigated by comparing different methods including the pyramid frame, dive surveys and a towed camera system.

3.3 Research Questions

1. How successful would a pyramid frame camera system, based on Dr Stokesbury's SMAST method, be in estimating *Pecten maximus* densities in the inshore waters of the Devon and Severn IFCA district?
2. How successful would the pyramid frame be in identifying all range of sizes of *Pecten maximus*?
3. Which, if any, of the three survey methods being tested is best suited to the inshore waters of the United Kingdom for investigating Pecten maximus densities in order

to make decisions of future management plans such as enhancement, and the monitoring of such management methods?

4 Methodology

4.1 Survey Design

The survey took place in three locations in the south of the county of Devon, United Kingdom. Two of the locations were in the Torbay area, one at The Ridge and one just off Breakwater Beach. The third location was in the Start Bay area between Hallsands and Beesands (figure 13). The pyramid frame and the divers were deployed at each site 12 times (figure 14, 15 & 16). Transects were then carried out with the flying array in the same locations (figure 17 & 18). These locations fall within the Devon and Severn IFCA district. The three survey locations were selected based on knowledge of the presence of king scallops obtained from the dive boat skipper who was chartered to carry out the survey.

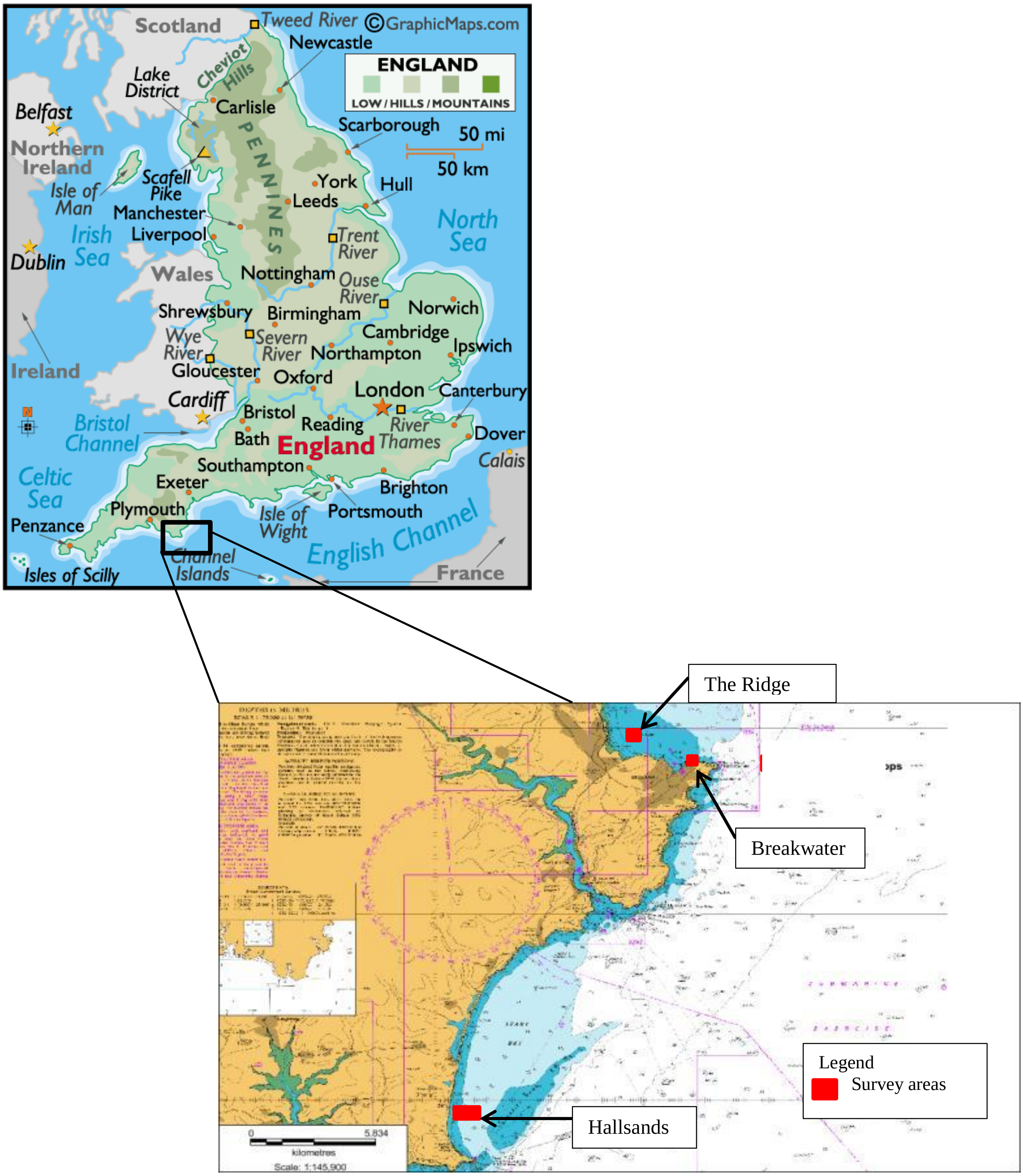

Figure 13 Survey locations in South Devon, UK

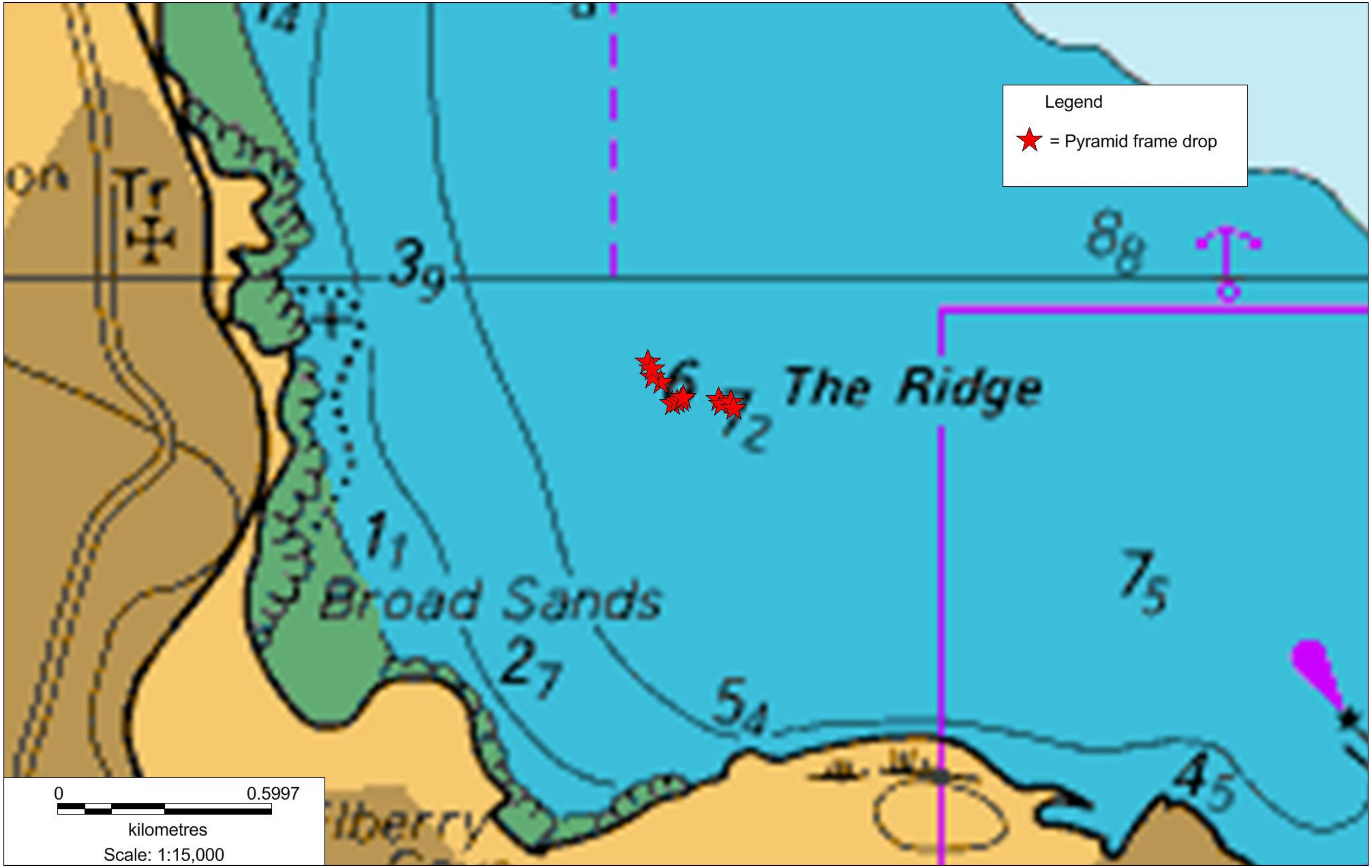

Figure 14. Pyramid frame drops at The Ridge, Torbay.

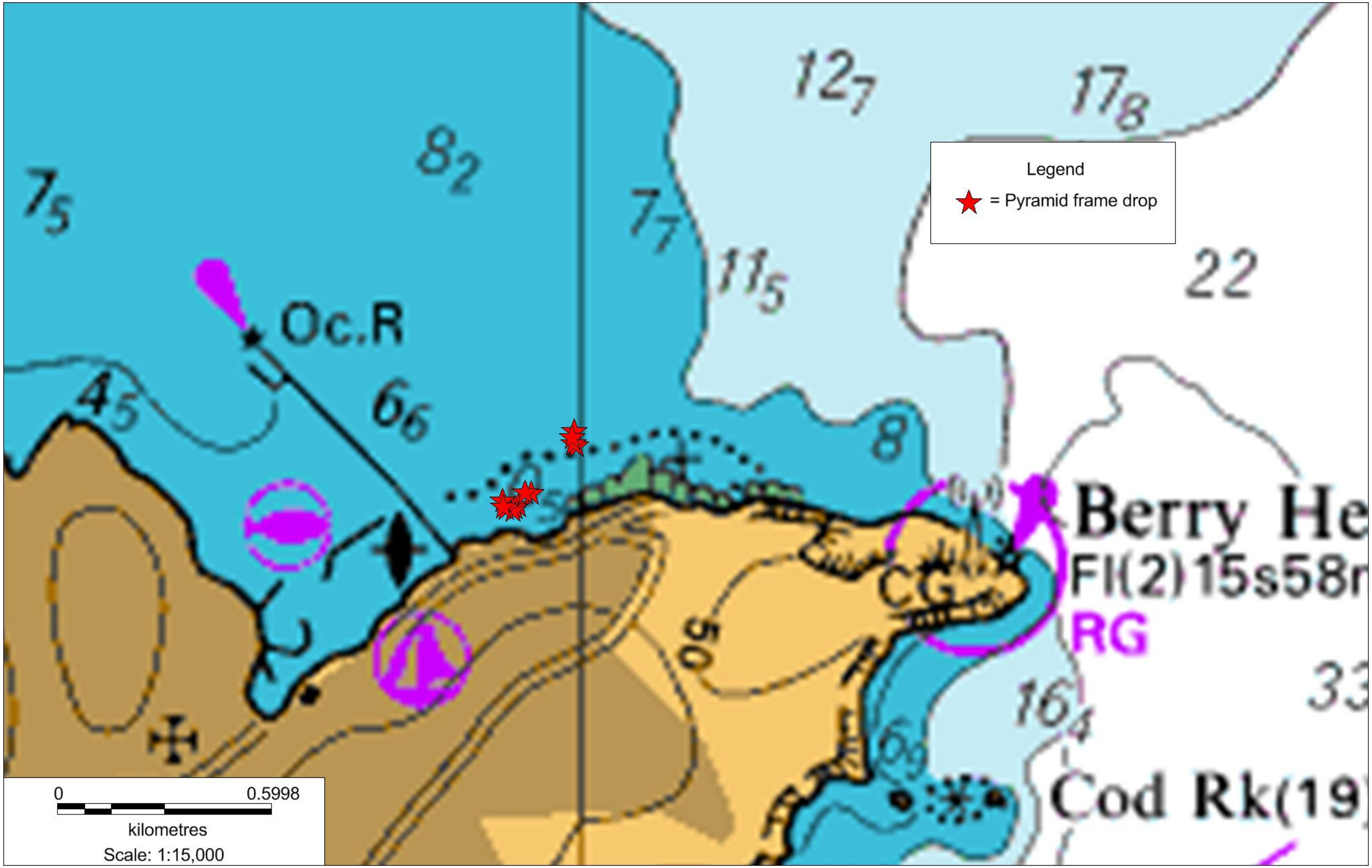

Figure 15. Pyramid frame drops at Breakwater, Torba.y.

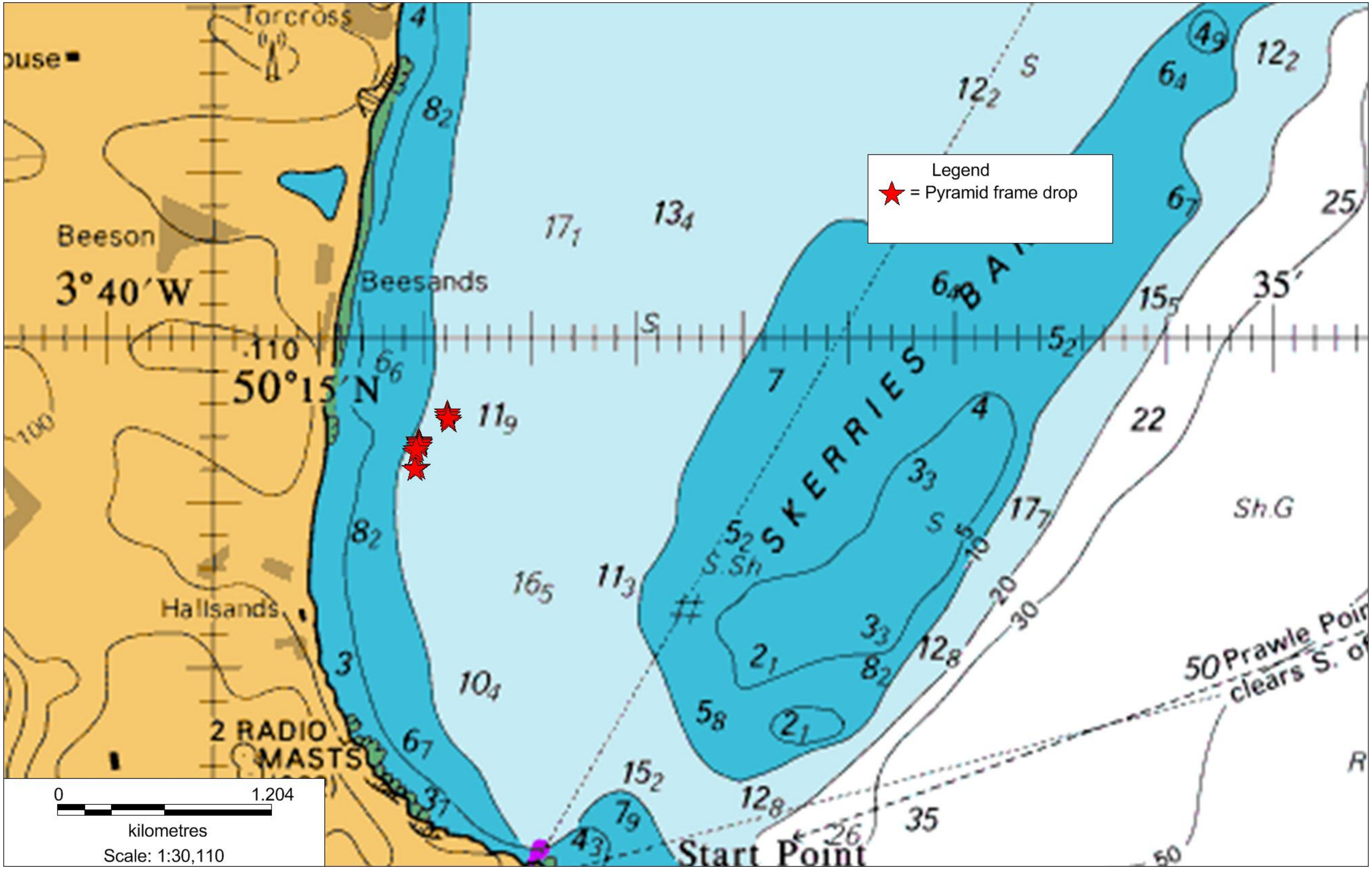

Figure 16. Pyramid frame drops at Hallsands, Start Bay.

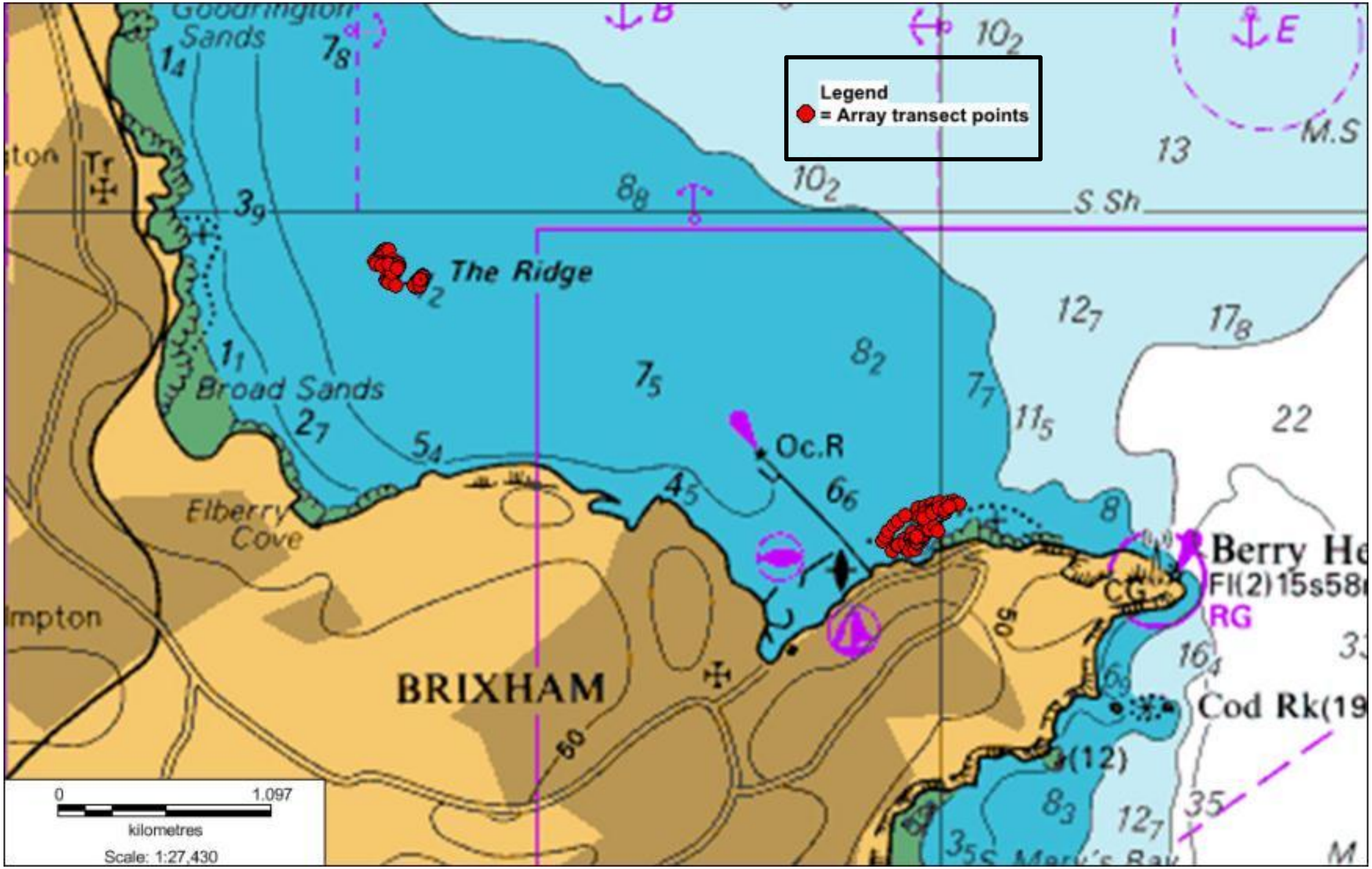

Figure 17. Flying array transects Torbay.

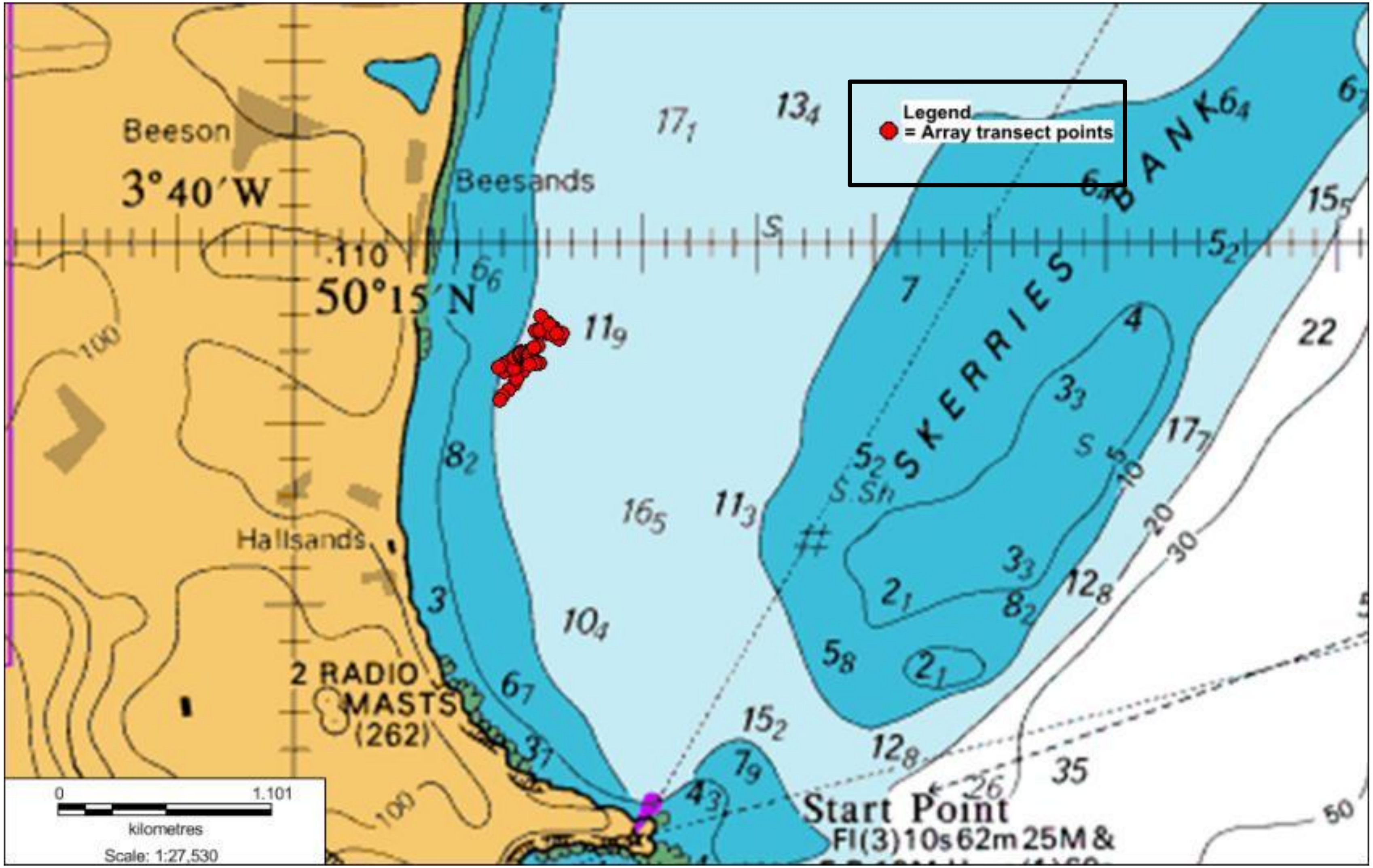

Figure 18. Flying Array transects Start Bay.

4.2 Pyramid Frame

The pyramid frame was adapted and scaled down from Dr Stokesbury's design. The reason for scaling down the frame was firstly due to the size of the vessels available to the Devon and Severn IFCA. These are considerable smaller than that used by Stokesbury and a frame of the same size could not be deployed from the survey vessels. Secondly the area surveyed is considerable smaller in the UK than in the US.

The frame was constructed using iron. The base of the frame makes a 1m² quadrat, this is for a large sample area. There is a 0.1m² quadrat to give a smaller sample area. Four cameras in total were mounted on the frame. A Bowtech Products SURVEYOR-SD underwater colour zoom camera was mounted 107cm from the bottom of the frame to cover the whole m² area. Two Bowtech Products DIVECAM-650C-AL miniature high resolution underwater colour CCD cameras were mounted on the frame, one at 32cm to film the smaller quadrat, and one mounted to take an oblique view across the seabed. A GoPro Hero 3 was mounted to the frame to take stills on a time lapse. Four lights were mounted to the frame, two Bowtech Products LED-K-SERIES lights for the SURVEYOR-SD and two Bowtech Products LED-K-SERIES lights, one for each of the divecams (figure 19 & 20). All cameras, apart from the GoPro, and all the lights were contacted to monitor systems on the boat via umbilical cables. The monitors were set up in the wheel house of the vessel (figure 21) for real time viewing as well as recording for reviewing the footage later.

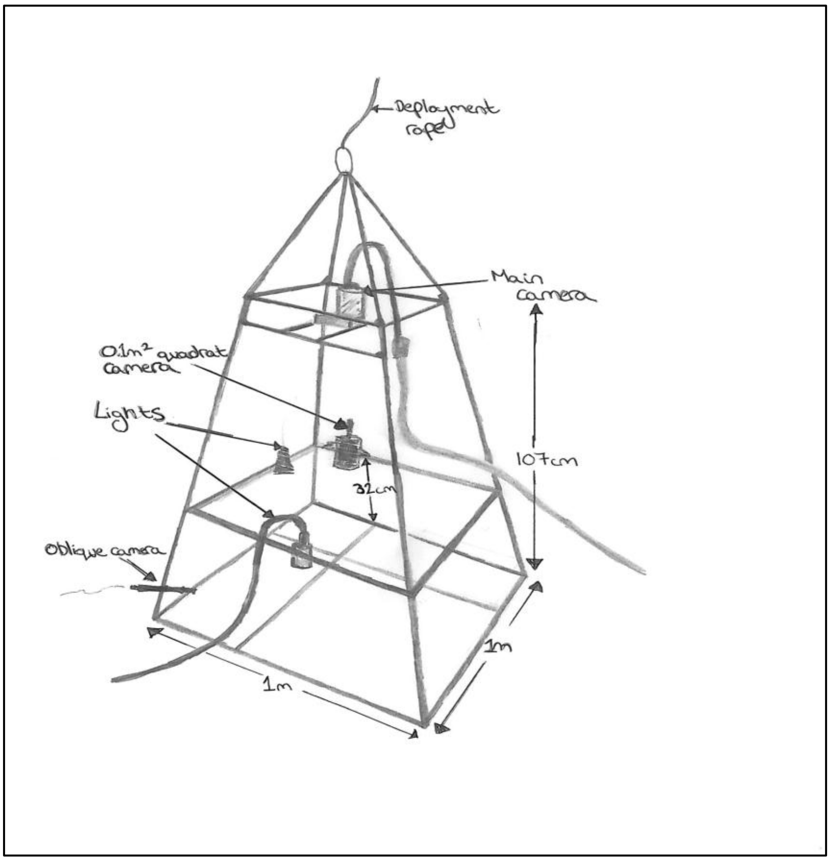

Figure 19. Pyramid Frame (Townsend, 2014).

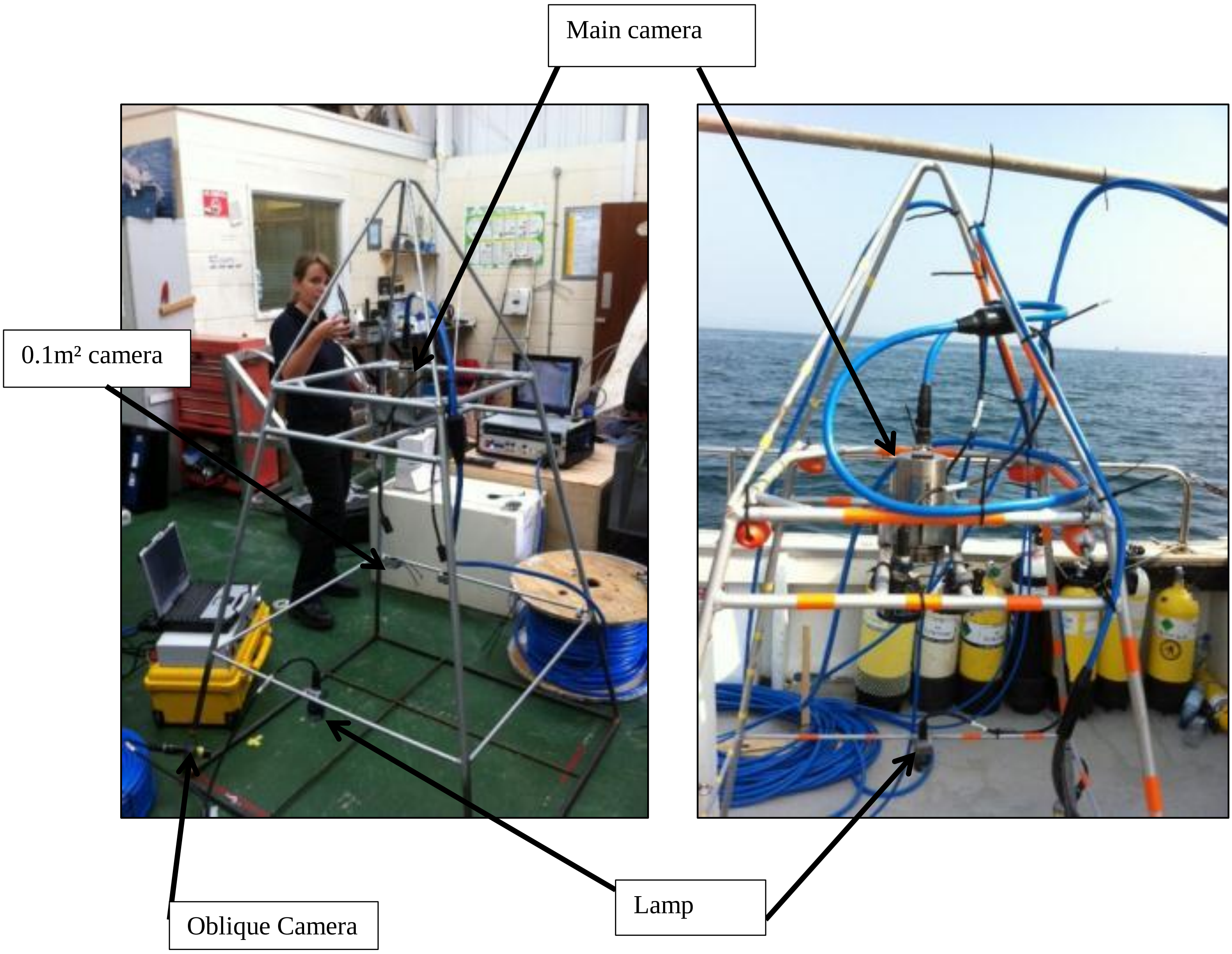

Figure 20. Pyramid frame set up.

Figure 21. Monitor system in the wheelhouse of the survey vessel.

4.2.1 Diver and Frame Deployment Method

A dive vessel was chartered for the survey along with four professional divers and the dive vessel skipper. A trial day was carried out to see how the divers and the frame would interact together. This was done in a sheltered location where it was unknown if there would be scallops as the main aim was to ensure operations ran smoothly, and the interaction between the divers and frame was safe and operational for the survey. The divers were happy overall with the frame but wanted it to be more visible to them underwater for safety reasons. A number of changes were made to the setup of the frame and deployment routine from the trial results ready for the survey to be carried out. This included making the frame more visible to the divers and an easier deployment system for the umbilical cables.

Once the site location was reached, two divers were deployed to find a suitable area with scallops present for the frame to be deployed. This was done by the divers sweeping the area for 30 to 40 minutes, or less if they found an area with scallops before this allotted time was used up. It was necessary for the divers to find an area with scallops so that the suitability of the frame could be assessed. Once the divers had located a suitable site they deployed a marker buoy to identify the location for the first of the four replicate drops. When the divers were safely aboard the vessel the frame was lowered for the first drop. This was done by hand, lifting the frame up and over the side of the vessels and then slowly lowering the frame by a rope attached to the top of the frame. The umbilical cables were let out along with the frame without putting any strain on them. Once the frame reached the seabed, footage was recorded and the live feed was viewed, any scallops within the quadrat were recorded on a survey form. Two divers were then deployed to locate the frame. Once it was located the divers placed a diving weight in each corner of the frame to use as a reference for their survey quadrat. When the weights had been placed the divers signalled to the camera with a dive board and an ok hand signal that they were ready for the frame to be moved. The frame was then hauled a couple of metres from the seabed, this was assessed using the live camera feed to indicate that the frame was a safe distance from the divers. Once the frame was safely out of the way the divers looked over the area of the quadrat both on the surface of the sediment and just under the sediment to collect any scallops within the quadrat. Any that were found were placed in a numbered bag which corresponded with the number of the drop. The divers then returned to the frame and signalled with an ok hand sign that they were back with the frame. The anchor of the vessel was then payed out 10 metres for the next replicate drop using the natural drift of the currents and wind. Once the vessel had drifted the 10 metres the frame was lowered again for the second drop. Again the live feed was viewed and any scallops identified were recorded. The divers then repeated the process of placing weights, signalling, and collecting scallops in the quadrat. The divers then returned to the surface with any scallops. Scallops that were found by the divers were then measured and recorded and returned to the sea, as the survey was done during the closed season for scalloping. This was repeated with two new divers for the next two replicate drops within that site. The whole process was repeated at three sites on each of the three locations making a total of thirty-six drops.

The divers worked using safe diving procedures and safe diving times, with a safety diver being present and ready to be deployed at all times as required by the HSE Diving Health and Safety Strategy to 2010.

All footage was transferred to a hard drive and DVD to be viewed again in the office for further analysis.

4.2.2 Method for Analysis of Pyramid Frame and Dive Survey

The footage was watched in real time to observe any scallops. The footage was then reviewed in the office to confirm any scallop sightings and to look for any that may have been missed while viewing in real time.

The divers collected the scallops into numbered bags and brought them to the surface to be recorded and measured.

4.3 Flying Array

The "flying array" is a camera system mounted on a sledge which maintains itself just above the seabed in order to prevent damage to the benthic substrate (Sheehan et al, 2010). To maintain the correct buoyancy of the sledge while towing two pressure resistant plastic tubes are mounted on the top of either side of the sledge to make it slightly positively buoyant. A short chain is attached to the back of the sledge which keeps it just off the seabed; the chain is the only part of the system which has contact with the seabed. As the bathymetry changes, more, or less of the chain makes contact with the seabed which forces the sledge to adjust its height until equilibrium is once again achieved (Sheehan et al, 2010).

Mounted on the flying array is a Bowtech SURVEYOR-HD High Definition Underwater Colour Zoom Video Camera with three LED lights, one attached either side of the camera and one on top of the camera. There are two Z-Bolt green point dive lasers either side of the camera 50cm apart. The 50 cm is used as the transect width. The camera and lights were attached via an umbilical to a monitor and recording system in the wheel house of the vessel. The vessel used was the Drumbeat of Devon, a 22m patrol vessel.

The sledge was towed behind the vessel using a tow rope attached to the sledge via a bridle. The umbilical was attached loosely to the tow rope using electrical tape. To help with buoyancy and to stop the umbilical and rope from hanging down in front of the camera a small buff was attached where the bridle meets the rope (figure 22 & 23). The sledge was deployed from the vessel using the on-board crane. A small rope was attached between the sledge and wire on the winch of the crane to allow the sledge to be manoeuvred safely. The sledge was lifted up and over the side of the vessel with the crane and then lowered into the water. Once the water had taken the weight of the sledge the small rope was detached and a drop weight was attached in its place which counteracted the pitch of the vessel. The crane was then used to lower the sledge to the seabed and for controlling the sledge during filming.

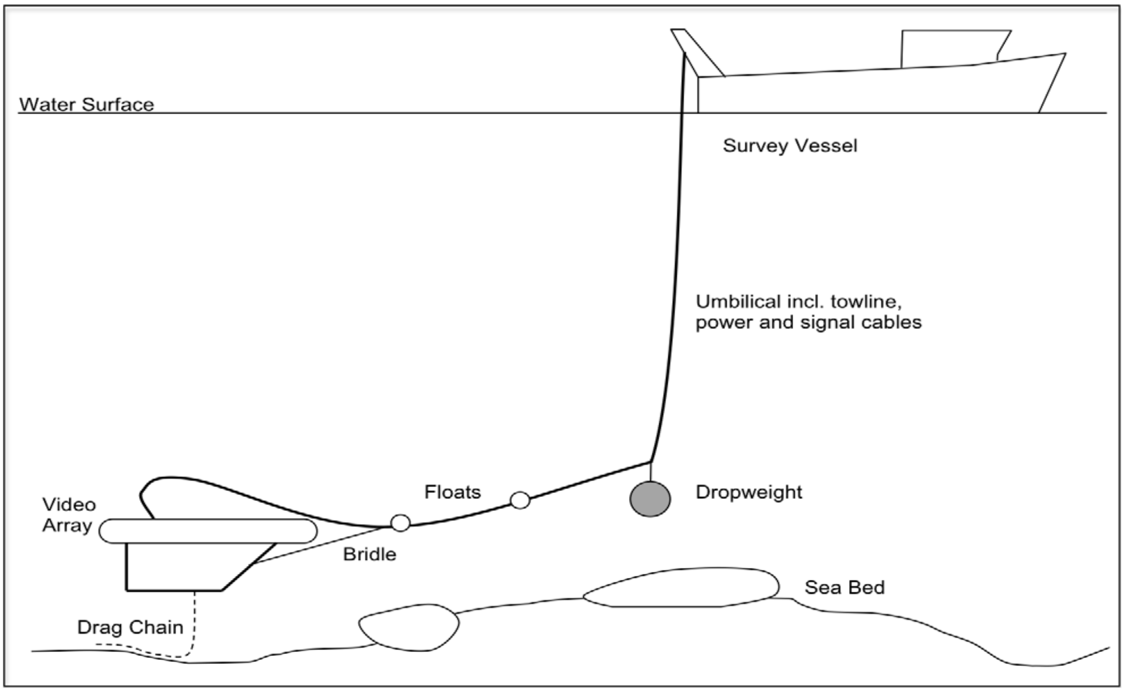

Figure 22. Schematic of array in use (Sheehan et al, 2010.)

Figure 23. Flying array in use (Sheehan et al, 2010).

Grids were made in MapInfo using the points where the pyramid frame had been dropped in the previous survey (figure 24). MapInfo is a geographical information system (GIS) used for mapping. These maps were then used for planning the transect surveys for the flying array. Three drift transects were then carried out on each of the three sites in the three locations to give coverage of the areas of the pyramid frame drops. The frame was deployed using the above method and the vessel was allowed to drift with tide and wind for 10 minutes with an average speed of 0.4knots to complete one transect. Footage was recorded from the time the sledge reached the seabed to the end of the transect. For each transect the speed in knots, the start and end times, the start and end coordinates and the coordinates every two minutes were recorded. The footage was watched in real time to make any adjustments needed to the depth of the sledge using the crane, as well as recording any scallops viewed in real time. Once a 10 minute transect was complete the recording was stopped, the sledge was brought up to the surface using the crane and securely fastened to the side of the vessels while the vessel repositioned for the next transect. The same method was repeated for a total of 27 transects. All the footage was transferred from the monitor system to the hard drive for later analysis in the office.

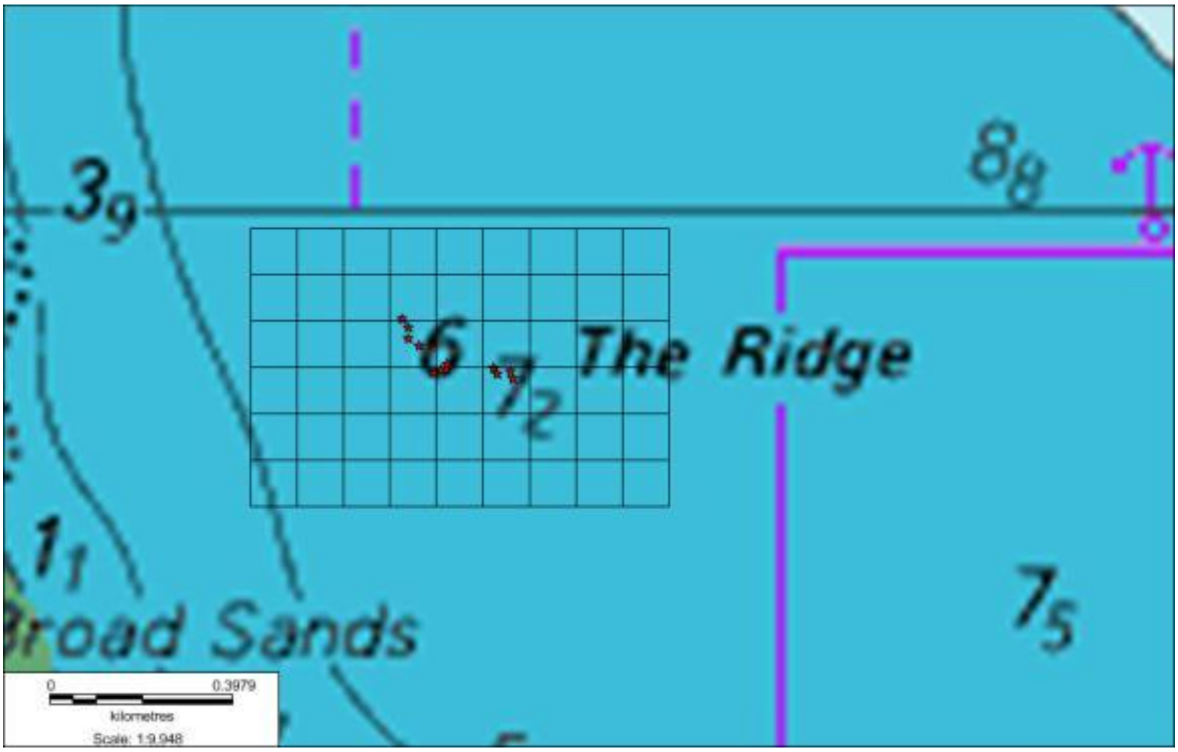

Figure 24. Example of grid made in MapInfo.

4.3.1 Analysis of Flying Array Footage

The footage was recorded onto a hard drive and brought back to the office for further analysis. Each individual piece of transect footage was watched back three times at half speed. This took around double the time it took to carry out the survey. If there was uncertainty at the time of viewing of the presence of a scallop the footage was paused and replayed over that segment of footage a number of times. The times of all confirmed scallops were recorded, as were uncertainties. The footage was then re-watched at these recorded times by a member of the Environment Team at Devon and Severn IFCA to confirm or dismiss the presence of king scallops. All confirmed king scallops were recorded and estimates of densities of scallops were calculated in order to compare the survey methods.

4.4 Analysis for Results

The estimated densities of scallops for each method were calculated in order to compare the methods. The densities were calculated by dividing the number of scallops by the area covered by each method. Along with the densities of scallops the time taken to survey for each method and the area covered were calculated.

In order to make comparisons of densities from each method SPSS statistical package was used. A Kruskal-Wallis test was carried out as an alternative to a one-way ANOVA due to the data being non-parametric. The data was non-parametric due to the small size of the sample. A one-way ANOVA or in this case a Kruskal-Wallis test is used for testing a null hypothesis that sets of data have the same mean, as with this study (Dytham, 2011).

5 Results

The pyramid frame produced a quadrat area of 0.75m², and with this a total area of 27m² was surveyed with video and the divers over a total of 36 drops. Within the 27m² one scallop (figure 25) was observed within the quadrat using the camera and nine were collected by the divers within the quadrat, resulting in the average densities of scallops seen in table 1.

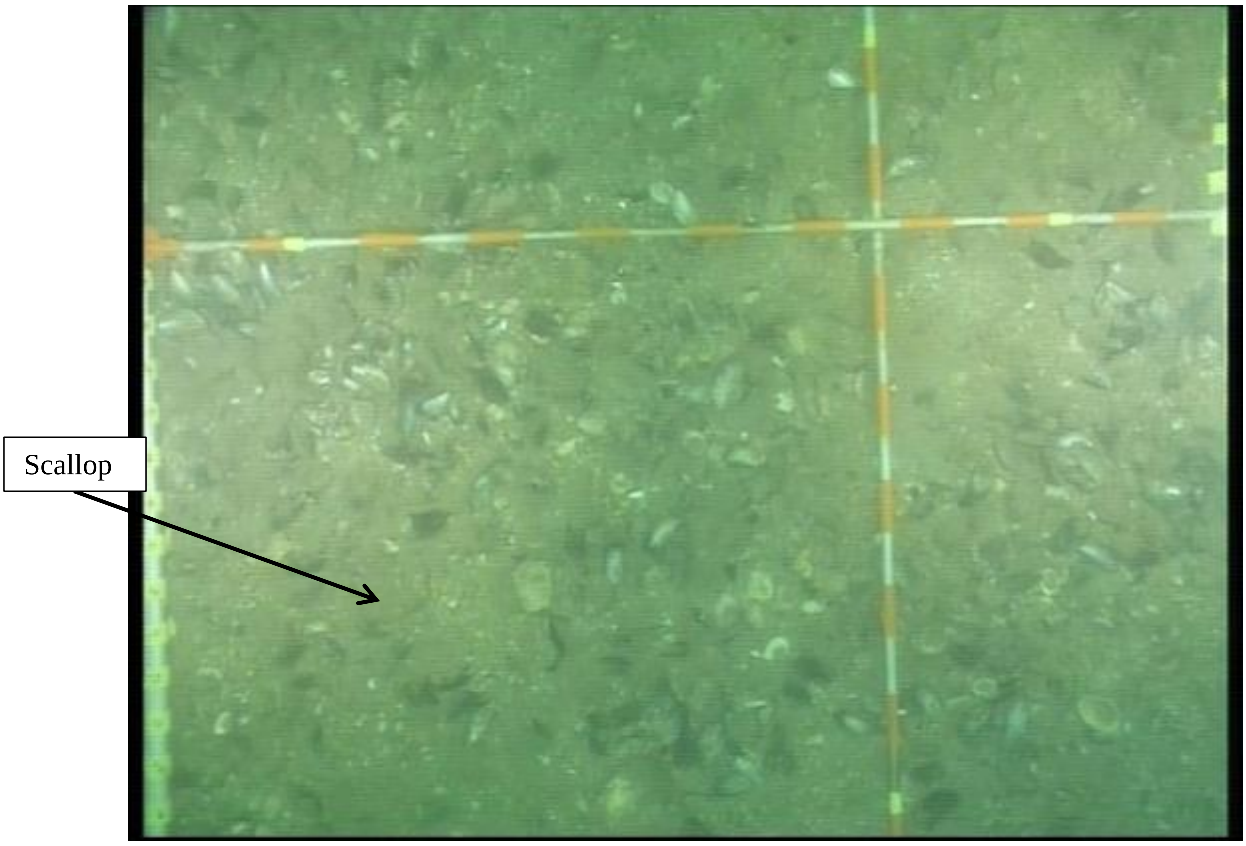

Figure 25. Hallsands site with pyramid frame and scallop.

Table 1. Scallop Densities for Locations and Methods.

Site	Scallops by Frame	Scallops by Divers	Area m²	Density Frame	Density Divers
Hallsands	1	5	9	0.11	0.56
Breakwater	0	4	9	0.00	0.44
The Ridge	0	0	9	0.00	0.00
Totals	**1**	**9**	**27**	**0.04**	**0.33**

The scallops collected by the divers were a range of sizes as seen in figure 26. Although nine scallops were collected by the divers only eight were measured due to a spat being misplaced. The one scallop viewed on the footage was 118mm, the size is known due to the divers collecting this scallop. The divers saw a number of scallops outside of the area of the quadrat nearby to the frame.

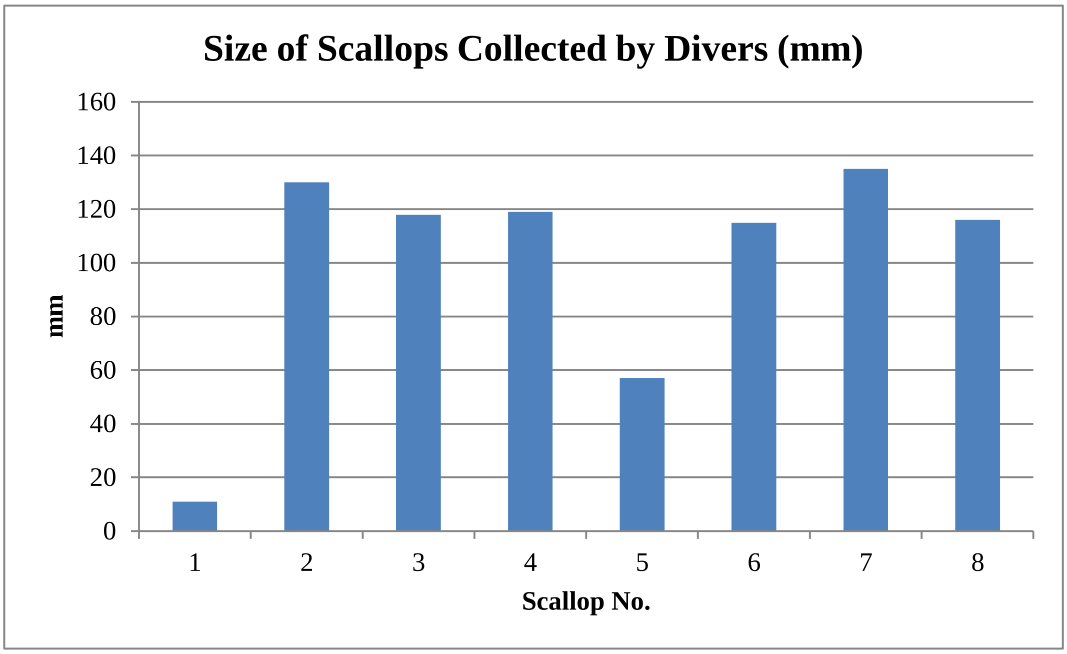

Figure 26. Size of scallops collected by divers.

Due to the lack of software currently available to the Devon and Severn IFCA the size of the scallops viewed with the flying array were not measured. An area of 1642.02m² was filmed using the flying array with a total of 44 scallops being observed; the total survey time for the array was 41 hours. The total time spent on surveying with the pyramid frame and divers was 89.25 hours (figure 27). For all the methods this time calculated from the start of survey day to end of survey day. Hours spent surveying versus area covered can be seen in table 2.

Table 2. Survey Time, Scallops Seen and Area Covered.

Methods	Hours	Scallops no.	Area Covered m²
Drop Frame and Divers	89.25	10	27
Flying Array	41	44	1642.02

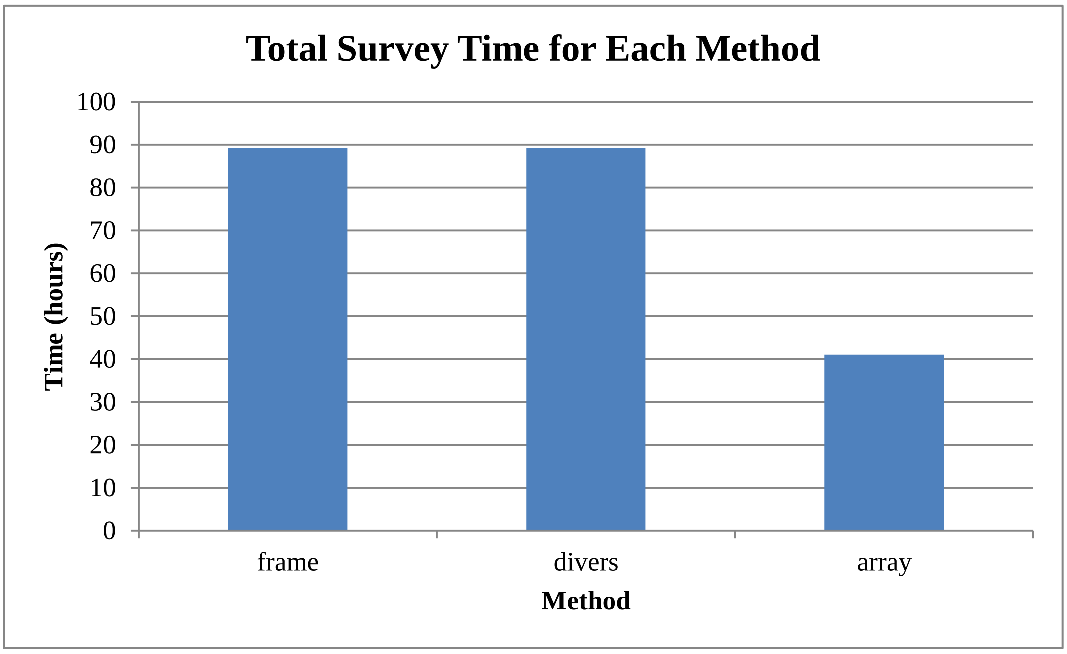

Figure 27. Graphical view of survey time for each method.

The total average density for the pyramid frame was 0.04m², for the divers it was 0.33m² and for the array 0.03m² (figure 28).

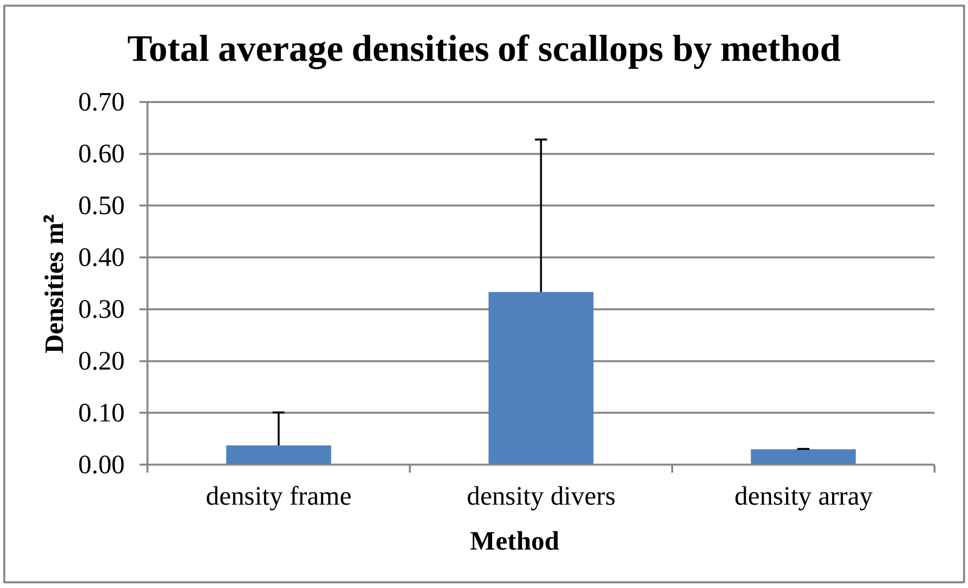

Figure 28. Total average densities of scallops for each method.

From the total area covered by each method, and the number of scallops counted at each site the average densities per m^2 of scallops was calculated for each method and site (figure 29)

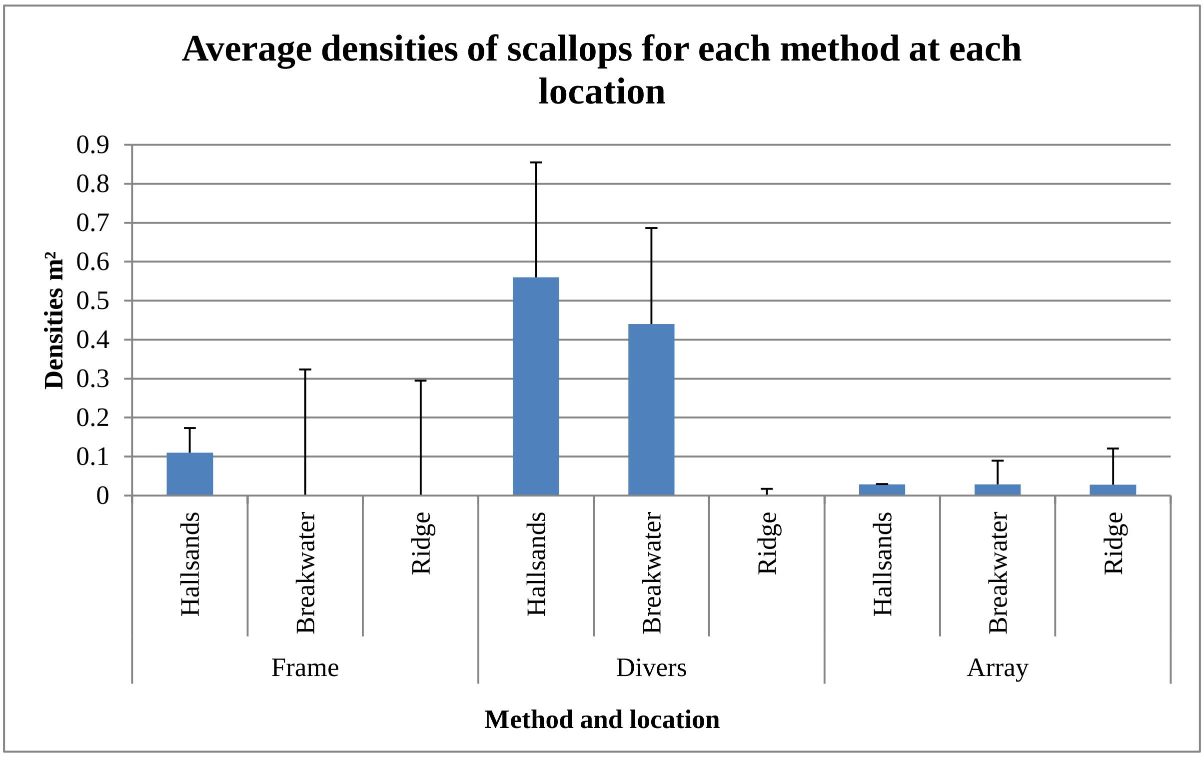

Figure 29. Average densities of scallops by site and method.

The densities of scallops calculated for both the pyramid frame and divers varied greatly between each site, whereas the densities with the flying array were similar for each site with two sites having a density of $0.029m^2$ and one site being 0.028 m^2 (table 3).

Table 3. Scallop Densities.

Site	Density Frame m^2	Density Divers m^2	Density Array m^2
Hallsands	0.111	0.556	0.029
Breakwater	0.000	0.444	0.029
Ridge	0.000	0.000	0.028
Mean Totals	**0.037**	**0.333**	**0.0287**
Std Dev	0.06415003	0.293972368	0.00057735

Visibility differed from site to site during the survey but was generally between 0.5m to 4m with the average being 2m. This made viewing difficult with the main camera on the pyramid frame (figure 30). The oblique camera fitted to the pyramid frame had a clearer picture but did not cover the whole area of the quadrat (figure 31).

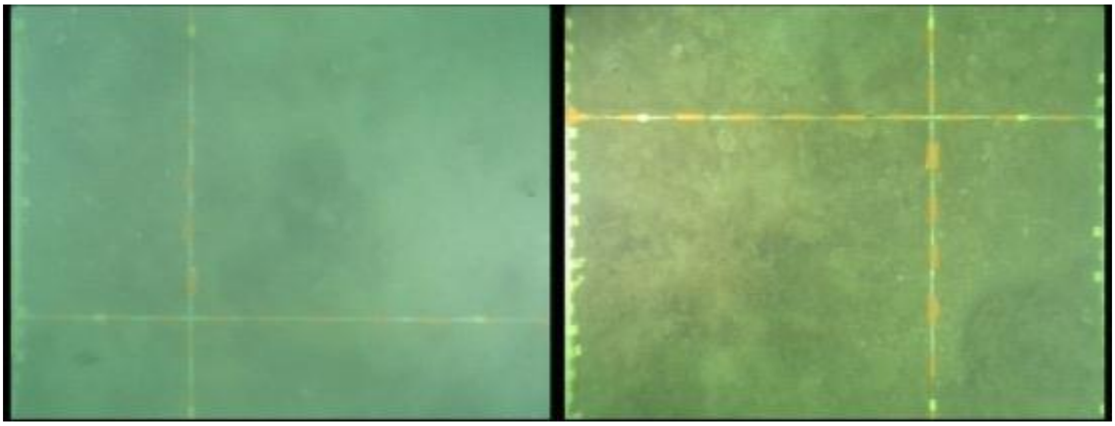

Figure 30. Breakwater and The Ridge with pyramid frame.

Figure 31. Hallsands and Breakwater with oblique camera on pyramid frame.

With clear visibility, observing scallops was more successful with the flying array (figure 32 &33). The stirring of sediment from bad weather conditions had a negative impact on some of the footage from the array (figure 34).

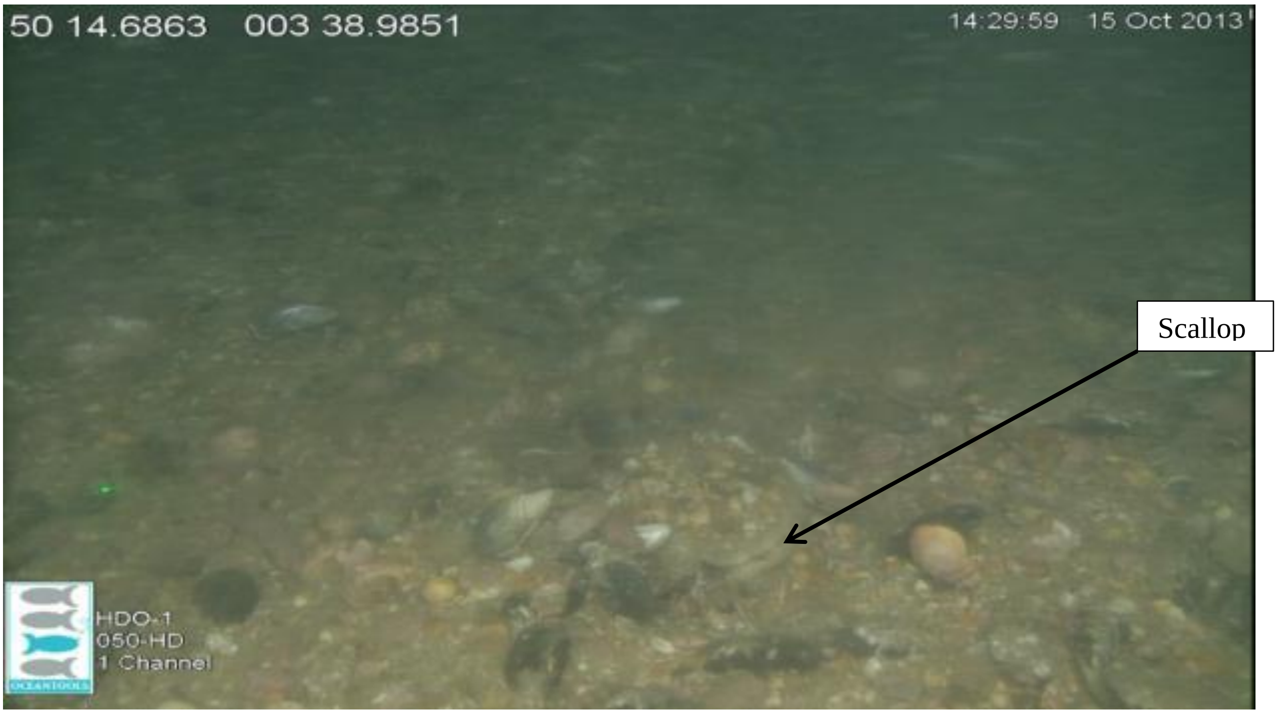

Figure 32. Scallop on flying array footage.

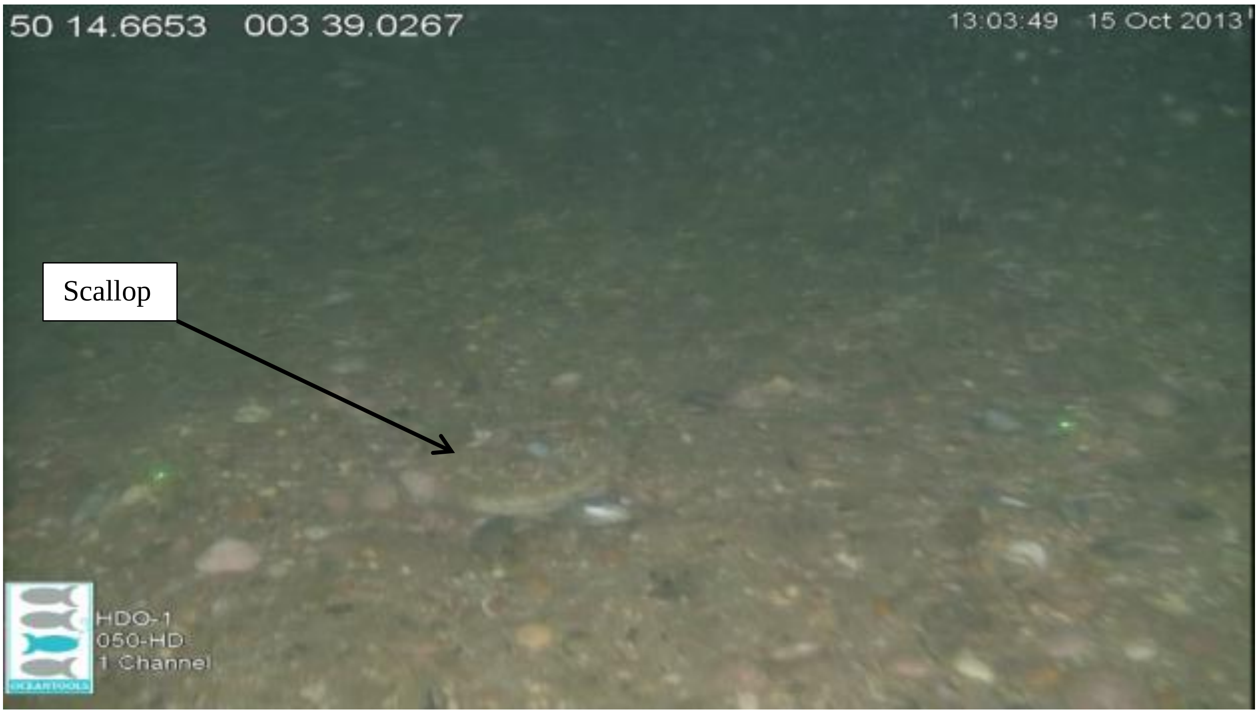

Figure 33. Scallop on flying array footage.

Figure 34. Poor visibility whilst using the flying array.

A Kruskal-Wallis test was carried out with a null hypothesis of:

"There will be no difference in the scallop densities recorded by the following three survey methods; pyramid frame, divers and flying array."

Kruskal-Wallis Test

Ranks

	survey method	N	Mean Rank
Scallop densities	Frame	3	3.33
	Divers	3	5.67
	Array	2	4.50
	Total	8	

Test Statistics[a,b]

	Scallop densities
Chi-Square	1.447
df	2
Asymp. Sig.	.485

a. Kruskal Wallis Test

b. Grouping Variable: survey method

A Kruskal-Wallis test was conducted to determine whether the scallop densities recorded during the surveys varied as a function of which survey method was carried out; the pyramid frame, divers, or the flying array. Results of the analysis indicated that scallop densities was not related to the survey method carried out (P = 0.485) therefore the null hypothesis cannot be rejected by the statistical test.

6 Discussion

This study was undertaken to assess different methods for scallop stock assessments, to determine which would be most applicable and appropriate for use within inshore water around England. The statistical analysis of the scallop densities proved to be inconclusive as to which of the three methods tested would be most suitable for scallop stock assessments in the Devon and Severn IFCA district. This could be due to the lack of data that was collected during the surveys. Although the results statistical analysis were not statistical significant, some conclusions of the suitability of the different methods can be made by taking into account all factors from the methods used and comparing past studies.

The results do show that although there were few scallops seen during the study, there were a number of scallops that weren't identified from the footage from the pyramid frame cameras, but were seen and collected by the divers. A total of nine scallops were counted by the divers within the quadrat but only one was observed on the footage. This demonstrates there was difficulty in locating the scallops using the camera when viewing the live feed footage and when reviewing the footage after the survey. A number of factors could have inhibited the ability to view the scallops with the pyramid frame camera. Firstly the visibility was poor in the survey areas; the divers reported visibility to range from as little as 0.5m to a maximum of 4m with the average being 2m during the course of the study. The camera was placed at 107cm from the bottom of the frame, which sits on the seabed; this meant that any visibility less than 107cm had an impact on the survey. Much of the visibility above 107cm was also extremely poor making viewing difficult. The divers were able to get closer to the seabed and use their hands to search through the sediment for scallops meaning the visibility had little effect on the number of scallops they could collect. The sediment type at both the Breakwater site and The Ridge was fine mud. If the pyramid frame was disturbed once deployed the sediment stirred up, which made the visibility worsen considerably. Visibility was an issue for the flying array as well as the pyramid frame. A number of attempts were carried out in order to obtain sufficient visibility at The Ridge. This poor visibility was due to a number of days of strong winds causing the sediment to stir up. Rosenkranz et al (2004) in Alaska, had visibility problems on a number of their video tows due to sediment being stirred up from equipment making contact with the seabed, naturally occurring sediment suspension, and from sinking phytoplankton. The success of video and still photography survey methods is dependent on the sea conditions and sedimentation therefore survey dates need to be flexible to allow for poor conditions. This flexibility was not possible for this survey due to time restraints.

The behaviour of the king scallop is another factor which could have had an influence on the number of scallops seen with the pyramid frame camera. The king scallop differs in behaviour to many scallops, including those surveyed by Dr Stokesbury, in that they recess into the seabed in order to avoid predation. Sediment can settle back down onto the scallop after it has recessed making them difficult to see from above (Brand, 2006a). An oblique camera was fitted to the frame in order to view scallops that could not been seen from above, however this camera did not cover the whole area of the quadrat. Boulcott et al (2012) concluded that although a pyramid frame system is not suitable for determining absolute abundance of king scallops because of the difficulties viewing the recessed scallops, that the method did allow successful collection of baseline data for the long-term study of abundance in Lamlash Bay No Take Zone and the method would be used in the future.

There was consideration of having an electric pulse from the frame which would cause a flight reaction in the scallops in order to view them. This was discounted after research into the method showed this had been attempted and had failed before (Defra, 2012). Defra contracted Cefas to carry out research into using an electric frame and found that although scallops reacted to the electric pulse in laboratory testing, no scallops reacted in any way to the electric pulse in the field tests (Defra, 2012).

The angle of the flying array camera seemed to make viewing the scallops easier compared to the pyramid frame. This is due to more of the scallop being visible from an oblique angle than from above.

The recess behaviour of the king scallop is more likely to be an issue when viewing the scallops with the pyramid frame than the density of the scallops. Densities of scallops in the US waters, where Dr Stokesbury's surveys are carried out, are similar to those in the UK, with the Mid-Atlantic densities ranging from $0.04m^2$-$0.79m^2$ and on Georges Bank $0.09m^2$-$0.26m^2$ (Stokesbury, 2012). However unlike the king scallop the sea scallops rest on top of the seabed making them easier to spot. Boulcott et al (2012) concluded that the recess behaviour of king scallops in Scottish waters could have an impact when using a drop down frame for determining absolute abundance reliably compared to dive surveys.

They also concluded that the technique is unable to provide reliable size estimates of individuals or identify smaller scallop spat. Their results were however comparable to dive survey results carried out in the same area in terms of density estimates. Lambert et al (2012), found the king scallop more difficult to sample than queen scallops in the Cardigan Bay SAC when using towed camera systems due to the recessed position of the scallop. They found that the sediment type plays a role in the detection of king scallops, with them being easier to spot on sandy grounds rather than rocky substrates with associated epifauna.

The densities of scallops vary with each method however they all fall within the average densities of king scallops in the UK. There were large variations between the densities of scallops at the different sites when using the pyramid frame camera and the divers; however with the flying array the densities were consistent across the sites and sediment types.

With only one scallop being seen on the cameras with the pyramid frame conclusions cannot be made as to the suitability of using the frame to identify all size ranges of king scallops. However the divers could identify different sizes of scallops during their survey. Being able to identify the size of the scallops is necessary if the aim of a study is to assess size distribution in the population and the health of recruitment into a scallop population, which is important when considering management plans. Currently the Devon and Severn IFCA do not have the software for measuring scallops with the flying array footage; however this would be possible with the correct software.

The total area covered by the pyramid frame was 27m^2 which took a total of 89.25 hours to survey; however this time included diving time. The divers had to have a number of safety breaks throughout the survey day and it took them time to reach the frame and return to the vessel. Without the use of divers the time would likely be lowered significantly; however this would still be a large amount of time resources for the area covered. The flying array covered a significantly greater area of 1642.02m^2 in a shorter time of 41 hours. Rosenkranz (2004) concluded after a pilot survey in Alaskan waters with a drop down frame, similar to the one used in this study, that a different sampling device was needed to cover more area to obtain meaningful density estimates. In a one week pilot study they covered an area of 400m^2 with a drop down frame and produced zero scallops in 90% of the drops. An area of

40,000m² was covered with a towed camera sled system in a two week period on the same scallop bed as part of a trial of the sled. During the full survey an area of 124,000m² was covered and over 12,000 scallops were counted. In contrast Stokesbury et al (2004) found the drop down frame method to be fast, accurate and precise, covering an area of 54,793km² in the 2003 survey of sea scallops.

There was only a small number of king scallops seen during this survey, both during the survey itself and when the divers were trying to find the most suitable locations for the survey. During the search dives at Thatchers Rock, a well-known scallop bed, the divers did not observe any king scallops. The scallop fishery opened after the survey was completed, the season runs from the 1st of October until the end of June in this part of the district; however it was reported that the best fishing of the season was over in two days (Robbins, pers. Comm, 2014). This is an indicator that there was a possible decrease in king scallop stocks this year, this may have had an impact on the results of the study.

From the results of this study it would appear that the pyramid frame is not the most suitable method for surveying king scallops in the inshore waters of Devon. This is due to a number of factors including the behaviour of the scallops and the limited area the frame was able to cover compared to the flying array. Although Dr Stokesbury has had success with this method, the behaviour of the sea scallops differ from that of king scallops, and the frame used was on a larger scale. This larger frame along with the resources available to Dr Stokesbury's team enables them to cover a much greater area than was possible in this study. Boulcott et al (2012) had some success with a pyramid frame for surveying king scallops in UK waters, but again their frame was on a larger scale than what was available for this study. They did however conclude there are many limitations to using this method.

The flying array was a more successful method for surveying king scallops during this study. A greater area could be covered in less time and the scallops were easier to observe on the footage. This is supported by a number of studies which have used towed camera systems since the 1970's. Franklin et al (1980b) carried out surveys off the coast of Devon and Cornwall, UK, using underwater video and stills on a towed sled between 1976 and 1978. They concluded that this method was extremely useful for surveying pectinid populations and that the system is more accurate than traditional survey methods such as dredging. However they did encounter some problems with the analysis especially with the quality of the images which made identification difficult and demanding. Video and analysis technology has moved on considerably since Franklin's surveys in the 1970s and some of the problems they faced have been overcome. Giguere and Brulotte (1994) found when comparing video and dredge sampling techniques for sea scallops in the Gulf of Saint Lawrence, that video surveying was the best method for both shell height frequency distribution and density estimates. They did find a number of limitations for the use of video, the main limitation being the amount of time needed to review the footage. They also found the need for good atmospheric and environmental conditions in order for the survey to be a success, which was backed up during this study. Rosenkranz et al (2004) concluded after their first attempt of using a video sled system that it is a viable method for assessing Alaska's scallop stocks, and they are planning on developing this technology to conduct video surveys of the three main scallop fishing areas in Alaska on an annual rotating basis. A number of studies support that towed camera systems are more efficient, and are more appropriate for the use in sensitive areas than dredge surveys, and can survey larger areas and at deeper depths than dive surveys (Pickett & Franklin, 1975; Franklin et al 1980; Mason et al, 1982; Giguere & Brulotte, 1994; Hall-Spencer et al, 1999; Rosenkranz & Byersdorfer, 2004; Brand, 2006b).

Dive surveys have been a popular method for surveying scallops and are reported to be the most efficient (Mason et al, 1982; Katsanevakis, 2005; Williams, 2009). However there are a number of limitations including divers only being able to cover a small area on each dive, depth restrictions to divers, and the large costs associated with dive surveys. Therefore divers are not suitable for large scale surveys in deeper waters, but are appropriate for smaller scale surveys in shallow waters such as closed areas and enhancement areas.

6.1 Study Limitations

A number of difficulties were observed during the course of this study including; site selection, frame design, weather conditions and time limitations.

Site selections were made based on the knowledge of scallops being present in the previous seasons. Of the original three sites only two could be used due to a lack of scallops being present. Thatchers Rock had to be abandoned as a site due to the divers finding no scallops in the three search dives they carried out. Owing to the time and funding restrictions of the survey, the lack of scallops at this site meant that all the other sites had to be used regardless of the number of scallops observed by the divers on the search dives. In order to find a new site without using up the diver's time a small camera was deployed from a RIB at a number of locations. However this attempt was unsuccessful and the sites had to be chosen from the prior knowledge of both divers and fishermen.

A number of design flaws were found with the frame itself, some of which could be rectified and the others had to be taken into consideration when analysing the results. The small camera which filmed the $0.1m^2$ quadrat moved and the full quadrat could not be seen after two drops. This was thought to be due to the divers knocking into it. The camera had to be adjusted and more tightly secured in place. Technical difficulties were then experienced with this camera and therefore it was replaced by a camera which had a larger circumference, and this did not fit into the mount on the frame. This caused more problems of camera movement whilst on the seabed. At The Ridge there were some areas which were made up of boulders and rocks. This meant there was a potential for the oblique camera, which was mounted low down on the frame, to get damaged. In order to be able to survey at this site adjustments had to be made to the frame. Two wooden poles were attached to form a cross on the bottom corner below the camera to give the camera some protection from rocks or boulders.

The sediment type caused problems for the divers as well as the deployment of the frame. The sediment at the Breakwater site was gravel and fine mud. There were two unsuccessful drops at this site due to sediment stirring up when the divers came into contact with the frame. This caused the divers to lose sight of the frame, their weight bag, and each other meaning they had to abandon the dive and return to the surface for safety reasons. The divers then minimised any contact they had with the frame in order to stop this from happening again.

The main flaw to the design of the frame was the placement of the main camera. When designing the frame, calculations were made to determine the height and position each camera had to be in order to film the correct area. During these calculations the effect of light travelling through water was not taken into account. As light travels from air to denser water the light rays are refracted resulting in a magnification of underwater objects by roughly one-third as compared to viewing them in air (Mc-Graw-Hill, 2005). As this process was not taken into account when mounting the camera, the full $1m^2$ quadrat was not visible during the drops. Due to time constraints the frame could not be returned to the marine engineer to make adjustments to the placement of the mount, therefore the new area had to be calculated. This was done by attaching coloured measurement markers along the bottom bars of the frame and once the frame was deployed using the footage to work out the new area.

6.2 Recommendations for the Pyramid Frame

This study was designed to develop survey methods and protocols to inform on future management of scallop stocks in the inshore waters of Devon. Although the pyramid frame may not be suitable for king scallop stock assessments the method is not completely redundant and could be used for other marine surveying. Examples of surveys the frame may be used for is seabed and sediment mapping and possibly for biogenic reefs such as mussel beds. From 1999-2009 Dr Stokesbury's frame, on which this method was based, was successfully used to carry out sediment mapping of an area of $36,669km^2$ of George's Bank, USA. The spatial structure of sediment coarseness, dominance, heterogeneity and maximum size characteristics were mapped. This method was used as an alternative to grab sampling or acoustic sampling (Harris & Stokesbury, 2010). The Devon and Severn Inshore Fisheries and Conservation Authority has used the frame since the scallop survey to undertake benthic habitat identification in an area where the traditional flying array system could not be used due to the possibility of snagging the equipment on wrecks in the area. Being able to lower the frame down instead of towing it along meant any obstacles could be seen before contact and the frame could be brought up quickly and not towed into structures. Being able to carry out this habitat identification is currently of particular importance due to Defra's revised approach to the management of commercial fisheries in European Marine Sites. As part of the new mobile fishing permit byelaw put in place by the Devon and Severn IFCA, research is being carried out to verify that the current habitat maps are correct in order to allow access to fishing in areas within the EMS without causing damage to the designated features.

In order to measure scallops or other benthic species with the pyramid frame, scale bars could be added to the frame. When analysing the footage the feature of interest can be compared to the scale bars by eye or with the use of on screen computer callipers.

The frame system could be piloted for the use of verifying the presence or absence of biogenic reefs such as *Mytilus edulis* (blue mussel) beds instead of traditional grab methods, which can be destructive, when groundtruthing side scan sonar or other acoustic systems data. This possibility has been discussed at a national *Mytilis edulis* workshop organised by the Centre for Environment, Fisheries and Aquaculture Science (Cefas) and Defra on developing Marine Strategy Framework Directive indicators for good environmental status of biogenic reef, in particular blue mussel beds.

6.3 Recommendations for Scallop Video Surveys

When carrying out any form of underwater video or photographic surveying visibility will be a factor that needs to be taken into consideration and there needs to be flexibility in survey dates if, for example there have been storm conditions or there is a plankton bloom. This was clear during this study with both of the camera methods. In high-turbidity waters with poor visibility such as at The Ridge, freshwater lens camera systems can be used. A large lens of distilled water is placed in front of the camera which cuts down the path length that light must travel through the turbid water. Freshwater lenses can eliminate approximately three-fifths of suspended particulate matter between the camera and the seabed improving the clarity of the image (Spink & Read, 2013).

When using the flying array system in the future, it would be recommended that software is used to enable the analysis of the size ranges of the scallops in order to establish the structure of the population and recruitment into the fishery. There are different software packages which can do this through different methods. Rosenkranz et al (2004) used software which measured the scallop diameter in pixels and then converted the pixels into millimetres, whereas Giguere & Brulotte (1994) used morphometry software.

6.4 Future Use for Management

The most appropriate method for king scallop stock assessments has been identified as the flying array. It is recommended that this method be used to carry out a baseline survey of the main scallop fishery beds in the Devon and Severn IFCA district. This would establish the current status of the scallop stocks in order to make sustainable management decisions.

A recommendation would be that further stock assessments are undertaken on an annual basis. Before undertaking any stock assessment the alterations suggested in section 6.3 should be made to the equipment to ensure that the surveys are efficient and effective. In order to get a better understanding of the health of the stock it is important to identify the size structure of the population using a software package, as used in other studies, to measure a random sample of individual scallops. An indication of a healthy scallop population would be a large cohort of young individuals. If this is not the case once the baseline data has been examined it would be suggested to consider using enhancement alongside closed rotational beds as a management method in order to maintain a stable fishery. If enhancement and closed areas are established it is important to monitor the effective of these measures. If the areas are small and shallow then dive surveys can be carried out annually to assess the stocks. In larger, deeper areas the flying array should be used.

7 Conclusion

Stock assessments are an important aspect of fisheries management. The traditional method of using dredges for king scallop stock assessments has a low level of efficiency and is unsuitable for use in sensitive areas due to its destructive nature. For these reasons different methods are needed that are more efficient and non-destructive such as video surveying and diving.

This study demonstrates that the pyramid frame is currently not the most suitable method for carrying out stock assessments of king scallops in the inshore waters of Devon. The flying array was a more successful method both in terms of observing the scallops, and the area that could be covered with minimum time resources. This method would be recommended for large scale surveys. At the time of the study, due to software being unavailable to the Authority it was not possible to identify the size ranges of the scallops using the flying array. However a future recommendation would be to invest in such software to allow more accurate assessment of scallop populations. It would also be recommended to use a freshwater lens in order to increase the clarity of the images. From the literature review it would appear dive surveys are more appropriate when conducting small scale stock assessments in shallow waters.

Although the pyramid frame was not suitable for surveying king scallop stocks, the method is not completely redundant and can be used for other research including the mapping of uneven seabed or when surveying near wrecks, and the mapping of biogenic reefs in combination with other methods such as side scan sonar.

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Annex 1 Array Data

Site	transect	clip no.	speed	Latitude	longitude	Time	Distance (m)	Scallops	Area covered m²	Density per m²
Breakwater	1.1	34	0.5	50 24.086	003 30.256	11:12:42				
				50 24.100	003 30.245	11:14:21				
				50 24.114	003 30.228	11:16:20				
				50 24.129	003 30.208	11:18:33				
				50 24.143.	003 30.188	11:20:27				
				50 24.157	003 30.159	11:22:42	154.33	4	77.165	0.052
Breakwater	1.2	35	0.4	50 24.059	003 30.136	11:30:48				
				50 24.065	003 30.114	11:32:44				
				50 24.081	003 30.100	11:34:40				
				50 24.092	003 30.082	11:37:20				
				50 24.115	003 30.053	11:40:48	123.46	2	61.73	0.032
Breakwater	1.3	36	0.4	50 24.065	003 30.152	11:48:43				
				50 24.072	003 30.143	11:50				
				50 24.087	003 30.128	11:52:58				
				50 24.095	003 30.105	11:55:04				
				50 24.106	003 30.081	11:57:02				
				50 24.121	003 30.063	11:58:43	123.46	3	61.73	0.049
Breakwater	1.4	37	0.5	50 24.061	003 30.212	12:07:17				
				50 24.075	003 30.191	12:09:38				
				50 24.090	003 30.161	12:12:06				
				50 24.110	003 30.124	12:15:06				
				50 24.112	003 30.090	12:17:17	154.33	1	77.165	0.013
Breakwater	1.5	38	0.5	50 24.068	003 30.126	12:24:43				

				50 24.084	003 30.109	12:27:11				
				50 24.100	003 30.092	12:29:07				
				50 24.106	003 30.073	12:31:10				
				50 24.119	003 30.050	12:33:14				
				50 24.127	003 30.026	12:34:43	154.33	1	77.165	0.013
Breakwater	1.6	39	0.6	50 24.074	003 30.186	12:42:04				
				50 24.081	003 30.158	12:44:24				
				50 24.090	003 30.130	12:46:19				
				50 24.100	003 30.107	12:48:30				
				50 24.113	003 30.081	12:50:16				
				50 24.120	003 30.055	12:52:04	185.19	5	92.595	0.054
Breakwater	2.1	40	0.6	50 24.152	003 30 078	13:01:59				
				50 24.164	003 30.038	13:04:29				
				50 24.116	003 30.015	13:06:11				
				50 24.164	003 29.986	13:08:40				
				50 24.183	003 29.953	13:10:32				
				50 24.189	003 29.925	13:11:59	185.19	3	92.595	0.032
Breakwater	2.2	41	0.5	50 24.154	003 30.093	13:21:50				
				50 24.167	003 30.071	13:24:15				
				50 24.171	003 30.043	13:26:21				
				50 24.178	003 30.012	13:28:27				
				50 24.173	003 29.988	13:30:14				
				50 24.181	003 29.967	13:31:50	154.33	1	77.165	0.013
Breakwater	2.3	42	0.5	50 24.177	003 30.100	13:40:26				
				50 24.181	003 30.072	13:42:44				
				50 24.188	003 30.043	13:44:46				
				50 24.191	003 30.008	13:46:55				
				50 24.193	003 29.975	13:49:01				

				50 24.196	003 29.947	13:50:26	154.33	0	77.165	0.000
Ridge	1.1	54	0.3	50 24.890	003 32.387	11:26:31				
				50 24.888	003 32.403	11:28:37				
				50 24.882	003 32.414	11:30:50				
				50 24.874	003 32.426	11:33:04				
				50 24.865	003 32.437	11:35:12				
				50 24.859	003 32.446	11:36:31	92.59	1	46.295	0.022
Ridge	1.2	55	0.3	50 24.861	003 32.369	11:46:46				
				50 24.851	003 32.370	11:48:54				
				50 24.851	003 32.384	11:50:58				
				50 24.855	003 32.400	11:52:59				
				50 24.852	003 32.409	11:55:02				
				50 24.847	003 32.417	11:56:46	92.59	0	46.295	0.000
Ridge	1.3	56	0.1	50 24.870	003 32.414	12:07:12				
				50 24.861	003 32.420	12:09:40				
				50 24.856	003 32.425	12:11:21				
				50 24.856	003 32.432	12:13:38				
				50 24.851	003 32.436	12:15:46				
				50 24.849	003 32.442	12:17:31	30.86	0	15.43	0.000
Ridge	2.1	57	0.2	50 24.830	003 32.361	12:29:30				
				50 24.824	003 32.365	12:31:33				
				50 24.818	003 32.371	12:33:49				
				50 24.814	003 32.379	12:35:42				
				50 24.807	003 32.383	12:37:36				
				50 24.799	003 32.386	12:39:30	61.73	1	30.865	0.032
Ridge	2.2	58	0.1	50 24.851	003 32.341	12:49:14				
				50 24.843	003 32.343	12:51:29				
				50 24.840	003 32.348	12:53:29				

				50 24.831	003 32.355	12:56:00				
				50 24.827	003 32.360	12:57:28				
				50 24.826	003 32.365	12:59:14	30.86	3	15.43	0.194
Ridge	2.3	59	0.3	50 24.827	003 32.375	13:10:12				
				50 24.820	003 32.375	13:12:36				
				50 24.814	003 32.379	13:14:36				
				50 24.813	003 32.385	13:16:50				
				50 24.816	003 32.390	13:18:42				
				50 24.806	003 32.399	13:20:12	92.59	0	46.295	0.000
Ridge	3.1	60	0.3	50 24.818	003 32.240	13:29:33				
				50 24.808	003 32.244	13:31:51				
				50 24.799	003 32.248	13:33:46				
				50 24.792	003 32.253	13:35:52				
				50 24.792	003 32.262	13:37:58				
				50 24.786	003 32.269	13:39:33	92.59	0	46.295	0.000
Ridge	3.2	61	0.2	50 24.812	003 32.253	13:51:21				
				50 24.810	003 32.252	13:53:47				
				50 24.803	003 32.263	13:55:38				
				50 24.799	003 32.267	13:57:34				
				50 24.798	003 32.273	13:59:40				
				50 24.792	003 32.276	14:01:21	61.73	0	30.865	0.000
Ridge	3.3	62	0.1	50 24.814	003 32.240	14:14:50				
				50 24.809	003 32.243	14:17:15				
				50 24.807	003 32.247	14:18:58				
				50 24.806	003 32.251	14:21:04				
				50 24.802	003 32.254	14:23:00				
				50 24.793	003 32.354	14:24:50	30.86	0	15.43	0.000
Hallsands	1.1	63	0.7	50 14.6394	003 39.0225	12:39:12				

				50 14.6207	003 39.0423	12:41:36				
				50 14.6035	003 39.0600	12:43:20				
				50 14.5873	003 39.0840	12:45:30				
				50 14.5728	003 39.1055	12:47:38				
				50 14 5609	003 39.1215	12:49:12	216.06	3	108.03	0.028
Hallsands	1.2	64	0.6	50 14.6884	003 38.9877	13:00:00				
				50 14.6750	003 39.0105	13:02:18				
				50 14.6636	003 39.0330	13:04:17				
				50 14.6559	003 39.0561	13:06:28				
				50 14.6469	003 39.0769	13:08:17				
				50 14.6390	003 39.0975	13:10:00	185.19	5	92.595	0.054
Hallsands	2.1	65	0.5	50 14.6890	003 39.0278	13:18:45				
				50 14.6787	003 39.0535	13:21:37				
				50 14.6720	003 39.0684	13:23:06				
				50 14.6619	003 39.0910	13:25:25				
				50 14.6545	003 39.1077	13:27:06				
				50 14.6505	003 39.1222	13:28:45	154.33	1	77.165	0.013
Hallsands	1.3	66	0.4	50 14.6641	003 38.9467	13:38:40				
				50 14.6618	003 38.9675	13:41:02				
				50 14.6595	003 38.9877	13:42:58				
				50 14.6541	003 39.0379	13:46:58				
				50 14.6483	003 39.0578	13:48:40	123.46	1	61.73	0.016
Hallsands	2.2	67+68	0.4	50 14.7094	003 38.9534	13:56:16				
				50 14.7049	003 38.9697	13:58:30				
				50 14.7001	003 38.9848	14:00:28				
				50 14.6953	003 39.0004	14:02:30				
				50 14.6889	003 39.0105	14:04:35				
				50 14.6841	003 39.0316	14:07:23	123.46	2	61.73	0.032

				50 14.6811	003 39.0408	14:08:45				
				50 14.6792	003 39.0567	14:10:43				
Hallsands	2.3	69	0.2	50 14.6863	003 38.9830	14:29:27				
				50 14.6866	003 38.9910	14:31:46				
				50 14.6873	003 38.9965	14:33:47				
				50 14.6915	003 39.0115	14:35:46				
				50 14.6956	003 39.0268	14:37:57				
				50 14.6911	003 39.0330	14:39:36				
				50 14.6843	003 39.0311	14:41:39				
				50 14.6859	003 39.0303	14:42:22	74.07	4	37.035	0.108
Hallsands	3.1	70	0.5	50 14.7495	003 38.8685	14:57:55				
				50 14.7592	003 38.8860	15:00:09				
				50 14.7670	003 38.9014	15:02:13				
				50 14.7784	003 38.9176	15:04:16				
				50 14.7863	003 38.9346	15:06:22				
				50 14.7917	003 38.9429	15:08:12	154.33	1	77.165	0.013
Hallsands	3.2	71	0.5	50 14.7299	003 38.8609	15:16:40				
				50 14.7397	003 38.8921	15:18:54				
				50 14.7455	003 38.9151	15:20:45				
				50 14.7528	003 38.9393	15:22:54				
				50 14.7542	003 38.9516	15:24:51				
				50 14.7550	003 38.9669	15:26:52	154.33	1	77.165	0.013
Hallsands	3.3	72	0.4	50 14.7444	003 38.8509	15:35:44				
				50 14.7450	003 38.8757	15:38:26				
				50 14.7462	003 38.8965	15:40:04				
				50 14.7494	003 38.9191	15:42:04				
				50 14.7513	003 38.9454	15:44:10				
				50 14.7511	003 38.9617	15:45:50	123.46	1	61.73	0.016

			0.392593			**Total (m)**	**3284.04**	**44**	**1642.02**	**0.027**
									Average densities	
									Hallsands	0.029
									Breakwater	0.029
									The Ridge	0.028
									Total	**0.030**
									Area covered	
									Breakwater	694.475
									The Ridge	293.200
									Hallsands	654.345
									Total	**1642.020**
									Scallop	
									Breakwater	20
									The Ridge	5
									Hallsands	19
									Total	**44**

Annex 2 Pyramid Frame and Diver Data

Date	Location	Site No.	Replicate No.	Time	Latitude	Longitude	Depth	Visual Scallops (m^2)	Diver Scallops (m^2)	Scallop Size	Visual (10th m^2)	Diver (10th m^2)	Sediment
02/09/13	Hallsands	1	1	12:24	50°14.770	003°38.904	14.3m	0	0		0	0	shelly gravel
		1	2	12:53	50°14.762	003°38.903	14.6m	0	0		0	0	shelly gravel
		1	3	13:45	50°14.753	003°38.899	14.9m	0	0		0	0	shelly gravel
		1	4	13:55	50°14.746	003°38.897	14.9m	0	1	11mm	0	0	shelly gravel
03/09/13	Hallsands	2	1	12:20	50°14.687	003°39.037	12.9m	0	1	125mm	0	0	shelly gravel
		2	2	12:45	50°14.681	003°39.036	13.2m	0	0		0	0	shelly gravel
		2	3	13:21	50°14.678	003°39.035	13.6m	0	0		0	0	shelly gravel
		2	4	13:30	50°14.669	003°39.035	14.0m	0	0		0	0	shelly gravel
	Hallsands	3	1	15:08	50°14.603	003°39.046	15.5m	0	0		0	0	shelly gravel
		3	2	15:15	50°14.599	003°39.058	15.4m	0	1	130mm	0	0	shelly gravel
		3	3	16:05	50°14.651	003°39.055	15.6m	1	1	118m	0	0	shelly gravel
		3	4	16:14	50°14.660	003°39.050	15.6m	0	1	119m	0	0	shelly gravel
04/09/13	Breakwater Beach	1	1	11:38	50°24.077	003°30.146	5.5m	0	2	57mm, 115mm	0	0	very fine mud/deep

		1	2	12:33	50°24.073	003°30.153	5.3m	0	0		0	0	very find mud/deep
		1	3	12:51	50°24.069	003°30.159	5.2m	0	0		0	0	very find mud/deep
		1	4	13:01	50°24.072	003°30.174	5.5m	0	0		0	0	very find mud/deep
		2	1	14:31	50°24.095	003°30.115	7.3m	0	0		0	0	very find mud/deep
		2	2	14:54	50°24.096	003°30.129	7.7m	0	1	135mm	0	0	very find mud/deep
05/09/13	Breakwater Beach	2	3	10:19	50°24.084	003°30.183	7.0m	0	0		0	0	very find mud/deep
		2	4	10:40	50°24.074	003°30.181	6.5m	0	0		0	0	very find mud/deep
		3	1	12:59	50°24.167	003°30.009	8.5m	0	1	116mm	0	0	very find mud/deep
		3	2	13:30	50°24.170	003°30.016	8.4m	0	0		0	0	very find mud/deep
		3	3	13:58	50°24.179	003°30.018	8.9m	0	0		0	0	very find mud/deep
		3	4	14:17	50°24.189	003°30.014	9.6m	0	0		0	0	very find mud/deep
28/08/13	The Ridge	1	1	15:28	50°24.805	003°32.374	8.9m	0	0		0	0	fine mud/silt
		1	2	15:55	50°24.808	003°32.362	8.7m	0	0		0	0	fine mud/silt
		1	3	16:41	50°24.810	003°32.353	8.4m	0	0		0	0	fine mud/silt
		1	4	17:00	50°24.815	003°32.349	8.5m	0	0		0	0	fine mud/silt
11/09/13	The Ridge	2	1	13:12	50°24.811	003°32.265	10m	0	0		0	0	fine mud

		2	2	13:35	50°24.804	003°32.258	9.6m	0	0		0	0	fine mud
		2	3	14:10	50°24.807	003°32.235	9.2m	0	0		0	0	fine mud
		2	4	14:24	50°24.798	003°32.230	9.1m	0	0		0	0	fine mud
12/09/13	The Ridge	3	1	13:09	50°24.837	003°32.401	10.6m	0	0		0	0	rock/gravel/shells
		3	2	13:28	50°24.845	003°32.421	10.5m	0	0		0	0	fine mud
		3	3	14:08	50°24.868	003°32.432	9.8m	0	0		0	0	fine mud
		3	4	14:21	50°24.858	003°32.422	9.8m	0	0		0	0	fine mud
							Total	**1**	**9**		**0**	**0**	

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