

A live video observatory reveals temporal processes at a shelf-depth whale-fall

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Abstract: There have been very few studies of temporal processes at chemosynthetic ecosystems, even at relatively more accessible shallow water sites. Here we report the development and deployment of a simple cabled video observatory at \approx 30 m water depth in Gullmarsfjorden, Sweden. The camera provides a live video feed to the internet of faunal activity at the experiments, which to date have included 5 separate whale-fall deployments. Our data suggest that the time to decomposition of small cetacean carcasses at shelf-depth settings is considerably slower than at deep-sea sites. We have also provided a new methodology for the deployment of low-cost live video observatories at up to 30 m water depth, which can be used both for research and outreach activities.

Keywords: Skeletonization • Taphonomy • Porpoise • Carcass • Scavengers • Bacterial mat • Corps

Introduction

The study of temporal processes at chemosynthetic ecosystems is severely hampered by a lack of sampling resolution. In the majority of studies, inferences have to be made from sampling that is rarely less than several months apart, and often several years. Observations made during submersible or ROV operations, and from repeat visits, suggest that chemosynthetic ecosystems such as hydrothermal vents are highly dynamic at a range of temporal scales (e.g. Sarrazin et al., 1997; Shank et al., 1998). A crucial tool to better understanding temporal change is the development of cabled observatory systems at these ephemeral habitats. Several large deep-water projects are currently being constructed (e.g. Neptune Canada, 2009) and new methods to use video data are explored (e.g. Aguzzi et al., 2009). Here we show that small-scale inshore observatories installed at diver-accessible depths can also teach us much about the development of chemosynthetic ecosystems as well as illustrate the power of continuous observational marine data for both science and outreach.

When whales die, they sink to the seafloor and become food for scavenging animals (Smith & Baco, 2003). Microbial decomposition can also lead to the formation of a chemosynthetic ecosystem at these sites with similarities to both hydrothermal vents and seeps (Smith et al., 1989). At shelf-depth whale-falls, rather little is known about the feeding behavior of the scavenging communities, the development of the chemosynthetic bacterial mats, and the influence of external drivers such as tides, currents and photoperiod. Studies at shallow-water hydrothermal vents (Dando et al., 1995) and seeps (Sahling et al., 2003) suggest that whilst there are few (or no) specialist macrofaunal animals at these sites, sulphide-oxidising bacterial mats are abundant. The aims of our pilot project is to test the hypotheses that 1) shelf-depth whale-falls are consumed by a typical shallow-water scavenging fauna over a period of several weeks and 2) bacterial mats form over the carcass and remain until the bones are consumed or dispersed by currents. These observational data are also useful in understanding the taphonomic processes that occur at shelf-depths, which should assist paleontological studies of

whale-falls (e.g. Dominici et al., 2009), and macro-evolutionary studies of whales themselves (Gatesy & O'Leary, 2001).

Materials and methods

Observatory site and design

The Kristineberg cabled video observatory is located on the west coast of Sweden at a site centered on 58°15.31'N-11°26.95'E which is approximately 1 km from the Sven Lovén Centre for Marine Sciences (Kristineberg), a marine laboratory operated by the University of Gothenburg (Figure 1). The experiments have been run in depths from 6-30m at this site. The observatory in its current form consists of a stainless steel tubular frame with basal dimensions of approximately 1 x 1 m. Attached to the frame looking down vertically is a SubSea anodized aluminum camera housing (1000 m rated) containing an Axis 211 network camera connected to the shore using 100m of ethernet cable (S-F/UTP 4P CAT6 LSZH+PE). The ethernet cable is threaded into the housing using a SubConn wet connector. Power for the camera is provided down the ethernet cable using PoE (power over ethernet). A separate cable with 30 volts provides power to a ROS LED SmartLIGHT II attached to the side of the frame pointing obliquely at the experiment and providing continuous light for real time video as well as time laps recordings. The two cables running from the observatory are threaded into a protective plastic hose, which runs over the seafloor approximately 100m to an island where they are connected into the Kristineberg Observatory Node (KON) which constitutes an insulated and heated wooden hut which is operational in all weathers. The KON is connected with 400 V AC power and 24-fibre optic cable which is run underwater to the main laboratory and fed into the local network.

The video stream from the Axis 211 is sent to a server and encoded into a windows media stream and mirrored at a streaming server at the University of Gothenburg for public access and education/outreach projects (<http://uw-observatory.loven.gu.se>). Authenticated client access can

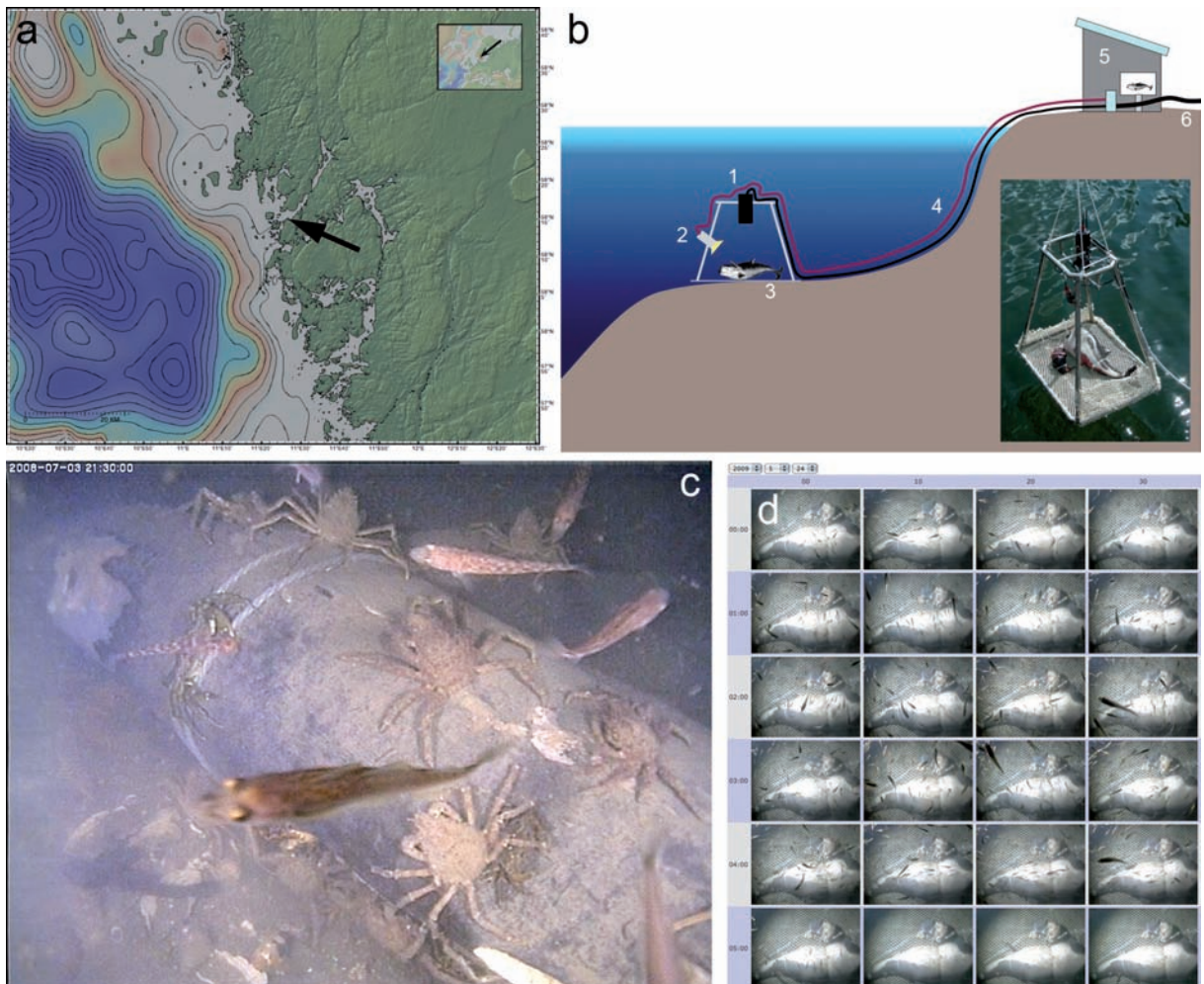


Figure 1. (a) map with arrow indicating observatory location on the Swedish west coast (Skagerrak), (b) outline of observatory: 1 - Axis 211 IP camera, 2 - LED light, 3 - carcass, 4 - power and PoE cable, 5 - Kristineberg Observatory Node (KON, server and power), 6 - fibre cable to shore, (c) one of the first frames from experiment #1 showing feeding on the skin by *Hyas araneus*, (d) the website (accessible by scientists) for archiving stills and footage, organised by time/date.

Figure 1. (a) carte indiquant la position de l'observatoire sur la côte suédoise (Skagerrak), (b) schéma de l'observatoire : 1 - Caméra vidéo, 2 - éclairage (Led), 3 - carcasse, 4 - alimentation, 5 - relais de l'observatoire, 6 - fibre optique, (c) une des premières images de l'expérimentation 1 montrant *Hyas araneus* se nourrissant sur la peau, (d) le site web (accessible aux scientifiques) d'archivage des données, gérées par heure et date.

Table 1. Whale-fall experiments at the Kristineberg Observatory located at 58°15.31'N-11°26.95'E.**Tableau 1.** Expérimentations sur des carcasses de baleines à l'observatoire de Kristineberg, localisé à 58°15.31'N-11°26.95'E.

Exp.	Carcass / bait	Depth	Camera system	Study period	Taphonomy	Notes
1	<i>P. phocoena</i> (intact, 30 kg)	30 m	Oblique	7/7/08 - 29/7/09 (23 d)	Mobile scavengers remove ~90% skin and ~10% flesh after 23d	Camera flooded after 23 d
2	<i>P. phocoena</i> (intact, 30 kg)	30 m	Oblique	5/11/08 - 12/12/08 (38 d)	Mobile scavengers remove ~90% skin and ~30-60% flesh after 38 d	Camera flooded after 38 d
3	<i>P. phocoena</i> (intact, 30 kg)	30 m	Oblique	5/2/09 - 22/3/09 (46 d)	Mobile scavengers remove ~40% skin and ~20-40% flesh after 46d.	Barnacle fouling after 24 d Camera flooded after 46 d
4	<i>P. phocoena</i> (intact, 20 kg)	23 m	Vertical, IP camera	19/5/09 - 11/8/09 (85 d)	Mobile scavengers remove 100% skin and 100% flesh after 85d	Fouling cleaned by SCUBA once per month
5	<i>B. acutorostrata</i> (fin bones)	6 m	Vertical, IP camera	3/9/09 - ongoing	Bones intact after 90d; bacterial mat present	Fouling cleaned by SCUBA once per month



also be made directly to the camera by scientists to adjust settings as well as view a higher-bandwidth MJPEG stream. An additional server records a still image every 10 minutes onto an archive. This archive is accessible by scientists wishing to collect data at any time. The current observatory design is as described above, earlier versions of the observatory differed slightly in the model of the camera, housing and position of the camera (oblique rather than vertical view) (Table 1).

Experiments

Including the experiment ongoing at the time of writing there have been 5 whale-fall experiments at the observatory (Table 1). The first experiment (#1) was put down after installation of the observatory in July 2008 and consisted of a \approx 30kg harbour porpoise (*Phocoena phocoena*). Experiments #2-3 were exactly the same as the first, experiment 4 was a smaller porpoise (20 kg) and experiment 5 consisted of the fin bone of a minke whale (*Balaenoptera acutorostrata*). All experimental material was collected from dead cetacean strandings. Experiments #4 and #5 were studied using a camera mounted vertically rather than obliquely. The first 3 experiments were terminated after failure of the camera at 23 days, 38 days and 46 days respectively. Experiment #4 lasted 85 days after which the carcass was completely gone. Experiment #5 is ongoing and this camera system (Axis 211 inside a SubSea housing) has provided over 12 months of continuous data without failure.

Data collection and analysis

During the experiments, live observations of the video stream could be made by any of the scientists connected to the website from anywhere in the world, including using portable devices that can play MJPEG (e.g. Apple iPhone). Species observed on the carcass actively feeding or associated with the remains were identified to the lowest taxonomic level (Figure 2) both from live video and time laps video capture. The first attempt at analysis consisted of collating images over a 24 hr period (1 image every 4 hours) from the archive every 3 days, to examine both daily and weekly-scale events. This was used on all experiments to provide preliminary observational data on changes at the whale-falls. Secondly, for experiment 4 (the longest-lasting) a time-lapse movie was made using 1679 images from the archive, each image being 1 hr apart. This created a movie 1.08 mins long played at a speed of 25fps (www.youtube.com/theuwoobservatory). Finally, as an exemplar for a future, larger study we analysed in detail the images from experiment #4 every 4 hours over an 85 day period (337 images) recording the number of mobile scavengers, quantity of bacterial mat (1-5 scores) and %

cover of skin, flesh and bone. Significant events were recorded in an event log.

Results

Technical issues

Corrosion of the camera housing (ROS CE-X36), pan and tilt (ROS PT-10-FB) and control box caused a failure of the observatory in experiments #1, #2 and #3 after 23 days, 38 days and 46 days respectively. The corrosion problem was cured by experiments #4 and #5 which used a more robust housing and sacrificial anodes on the steel frame. The second major problem was fouling, in particular barnacles on experiment 3 during spring. These were first observed as cyprid larvae attaching to the lens, then metamorphosing into adults over a period of \sim 20 days in March 2009. Regular cleaning of the lens (once per month) by divers has prevented any serious fouling problem in experiments #4 and #5.

Mobile scavenger community

The dominant mobile scavengers found feeding on the carcasses at 23m and 30m depth (exp1-4) were spider crabs *Hyas araneus* (Linnaeus, 1758), edible crabs *Cancer pagurus* (Linnaeus, 1758), hermit crab *Pagurus bernhardus* Linnaeus, 1758, seastars *Marthasterias glacialis* Linnaeus, 1758 and *Asterias rubens* Linnaeus, 1758. Associated with but not obviously feeding on the carcasses were the scallop *Pecten maximus* Linnaeus, 1758 and fish species including Atlantic cod *Gadus morhua* Linnaeus, 1758, horse mackerel *Trachurus trachurus* Linnaeus, 1758, goldsinny *Ctenolabrus rupestris* Linnaeus, 1758, and sea scorpion *Myoxocephalus scorpius* Linnaeus, 1758. Harbour seals, *Phoca vitulina* Linnaeus, 1758 were observed on several occasions exploring the observatory, camera and experiment area (but not feeding). At 6m depth the scavenging community of was dominated by *A. rubens*, *P. bernhardus*, whelk *Nassarius reticulatus* (Linnaeus, 1758), seastar *Henricia sanguinolenta* (O.F Müller, 1776) and shore-crab *Carcinus maenas* Linnaeus, 1758. Fish observed at this shallower experiment include eelpout *Zoarces viviparus* (Linnaeus, 1758), wrasse *Labrus mixtus* Linnaeus, 1758, pipefish *Syngnathus acus* Linnaeus, 1758 and flounder *Platichthys flesus* (Linnaeus, 1758). In total, 18 species were identified associated with the whale-falls from the video observatory.

Temporal trends

Decomposition of the carcass was studied in detail for experiment #4 over a \sim 3 month period (Table 1 & Fig. 2).

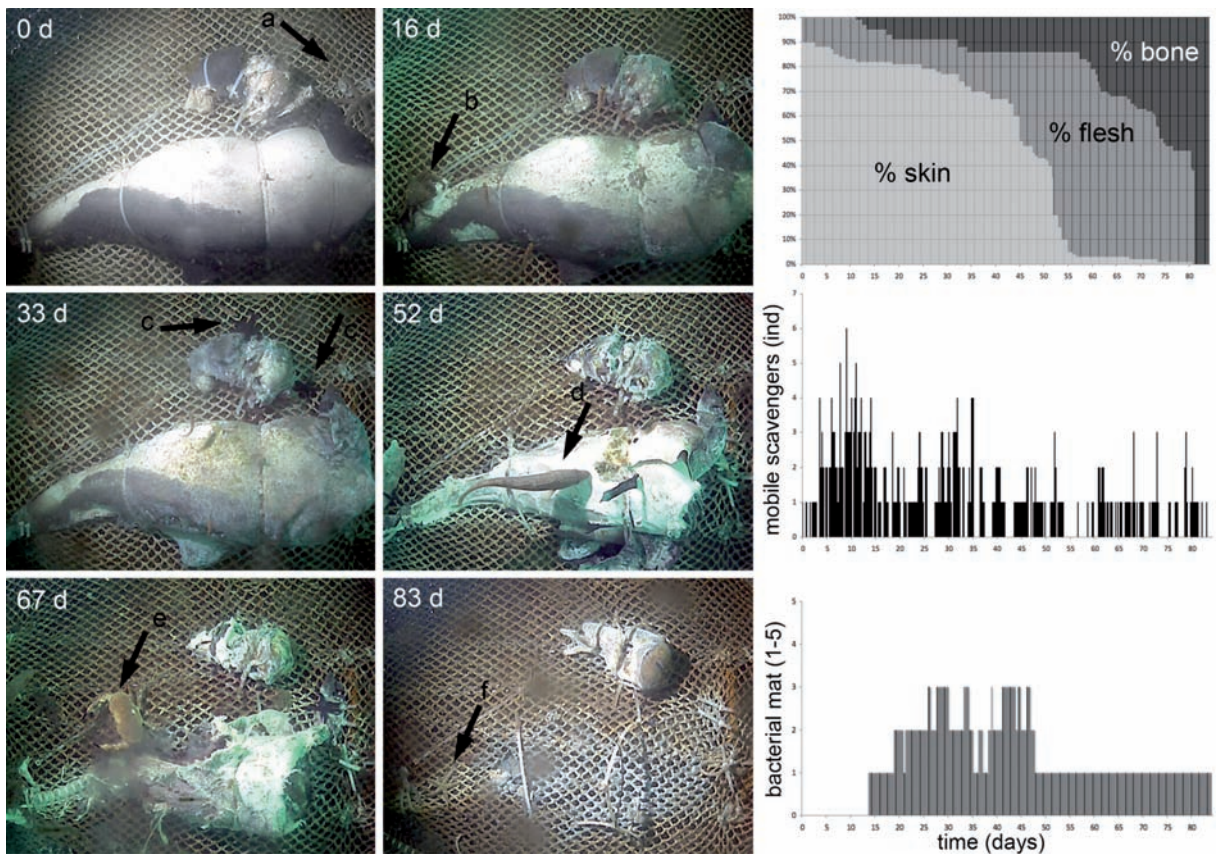


Figure 2. Temporal processes at a 30 m whale-fall at the Kristineberg Observatory. Video frames show the state of the carcass after 0, 16, 33, 52, 67, and 83 days, arrows highlighting observed feeding events by scavengers. Graphs from top, percentage of bone/flesh/skin remaining on the carcass over the 85 day period, abundance of mobile scavengers in the video frame, quantity (1-5 score) of bacterial mat.

Figure 2. Evolution temporelle sur une carcasse de baleine par 30 m de fond à l'observatoire de Kristineberg. Les images vidéo montrent l'état de la carcasse après 0, 16, 33, 52, 67 et 83 jours, les flèches montrent les épisodes de nutrition par des charognards. Schémas de haut en bas, pourcentage d'os, de chair et de peau restant sur la carcasse après 85 jours, abondance des charognards sur la vidéo, quantité (échelle arbitraire de 1 à 5) du biofilm bactérien.

During month 1, the skin was slowly removed by the steady action of a small number of mobile scavengers, with bacterial mat recorded forming on the skin surface after about 12 days. During month 2, the rate of skin removal, flesh exposure and bone exposure increased rapidly, with almost all the skin removed at the beginning of month 3. In the final month, the flesh was eaten and the bones exposed, separated and dispersed by currents as the carcass broke up. Bacterial mat was mainly recorded on the surface of the skin, and in experiment #5 we noted it forming on bones after a few days exposure. Preliminary data from experiments 1-3 is consistent with this pattern although these experiments did not last long enough for the flesh to be removed. A nocturnal cycle in fish abundance was clearly detected around all experiments, although the fish were not in general observed feeding but presumed to be attracted by the light, with some exceptions (e.g. Fig. 2). At

experiment #2, the carcass was observed to float (held in place approx 50cm above the seafloor by the line to the ballast) for approximately 2 days after implantation, before sinking back to the seafloor, still largely intact.

Discussion

In general, the carcasses at all deployed experiments were consumed by generalist mobile scavengers already well-known from the study areas. There was a notable absence of scavengers (lysianassid amphipods, hagfish *Myxine glutinosa* Linnaeus, 1758 and unidentified sharks) that have been recorded at deeper-water experiments (125 m) in nearby Kosterfjord, Sweden (Glover et al., 2005; Dahlgren et al., 2006). The fish present at the carcasses was not observed eating to any extent that could significantly contribute to the decomposition. The planctivore fish

species frequently observed was not included in the species list. Previous studies of porpoise decomposition at Atlantic abyssal (Jones et al., 1998) and bathyal (Kemp et al., 2006) depths also show strikingly different scavenging communities, with a much more dominant scavenging role being undertaken by fish (e.g. grenadier *Coryphaenoides armatus* Hector, 1875) compared to dominance by crustaceans (e.g. spider crabs *Hyas araneus*) at our shallow sub-littoral sites.

In addition to the differences in species composition, our data suggest a significantly slower rate of decomposition (in terms of time taken to skeletonize) in shallow shelf environments compared to deep-water. At bathyal and abyssal Atlantic depths, carcasses were skeletonized within 5-10 days (Jones et al., 1998; Kemp et al., 2006) compared to almost 2 months at our observatory sites. Our data suggest that the slow removal of the skin by scavengers and development of possibly toxic bacterial mat prevents rapid consumption of the flesh in this initial period, lasting about 1 month. These data are supported by previous observations of an intact, bacterial-mat coated, pilot whale carcass at 30m depth in Kosterfjord (Dahlgren et al., 2006), but more research is needed to further understand the processes behind the slow removal of cetacean skin at shallow depths. Once the skin has been removed and the flesh exposed, removal rates of the carcass increase dramatically over the second month and for that period are closer to those recorded in the deep sea (Figure 2). Final skeletonization and dispersal of the bones took over 3 months, with apparently limited opportunity for colonization by bone-eating worms (*Osedax mucofloris*) as the remaining bones were small and rapidly dispersed by currents, as previously hypothesized (Glover et al., 2008).

Other studies of shallow-water carcass scavenging are surprisingly rare, but include forensic studies of pig remains in Canada (Anderson & Hobischak, 2004) and a study with fish-bait in Antarctica (Smale et al., 2007). The pig experiments showed similarly quite slow rates of flesh consumption, while the Antarctic study showed large aggregations of nemertean worms (*Parbolasia corrugatus* McIntosh, 1876) or lysianassid amphipods with few other scavengers present. At the pig experiment, it was reported that the carcasses were buoyant for up to 28 hours after being deposited on the seafloor, after which they became negative again and decomposition accelerated (Anderson & Hobischak, 2004). We observed a similar pattern at experiment #2, where the carcass was buoyant for approximately 2 days, before sinking again, still intact. This is not unexpected since previous studies suggest that marine mammal carcasses initially float under certain oceanographic conditions, and depending on the nutritional status of the animal when it died (Schäfer, 1972). However, our limited data suggest that intact negatively-buoyant

carcasses are likely to be present on the seafloor at 30m shelf depths.

In terms of a chemosynthetic community, the only observations were of a thin, flocculent and fragile layer of bacterial mat forming on the skin after about 10 days, and on exposed bones after 2-3 days, as already reported for a 30m depth pilot whale in Sweden (Dahlgren et al., 2006). Some data collected from experiment #5 suggest that the bacterial mat return at a later stage covering these bones. This has also been documented at carcasses from large-bodied whale species in the deep sea (Smith & Baco, 2003) as well as at a 125m carcass in Swedish waters (Glover et al., 2005). It remains to be seen if these very shallow bacterial mats are home to new species of mat-eating worms, as has been recorded at deeper whale-falls (Wiklund et al., 2009).

Our study has provided the first detailed time-series for whale-fall succession in a shelf-depth setting. Our data suggests much slower (months rather than days) rates of scavenging and decomposition in shallow-waters compared to bathyal and abyssal depths. As at shallow vents and seeps, there is apparently an absence of specialist whale-fall species at depths of 30m or less, although a single occurrence of *Osedax mucofloris* has been recorded at 30m in Kosterfjord (Dahlgren et al., 2006). We have also provided a new technological method to study experiments in real-time in the marine environment, helping to overcome the substantial pedagogic challenge of understanding processes in the sea.

Acknowledgements

We are grateful to Sparbanksstiftelsen Väst for assistance in funding this project. We thank the crew at R/V Arne Tiselius and R/V Oscar von Sydow at the Sven Lovén Centre for Marine Sciences, Kristineberg for assistance during deployment of cables and camera systems. We are also grateful to Jens Bjelvenmark, Pia Norling and Erik Selander for help during dive operations. NDH is funded by the Natural Environment Research Council, UK and TGD is funded by the Swedish Research Council.

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