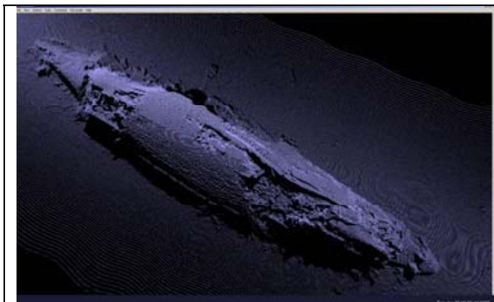
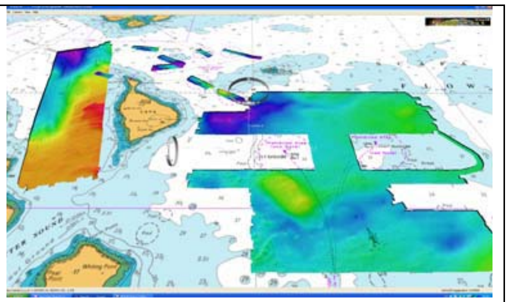
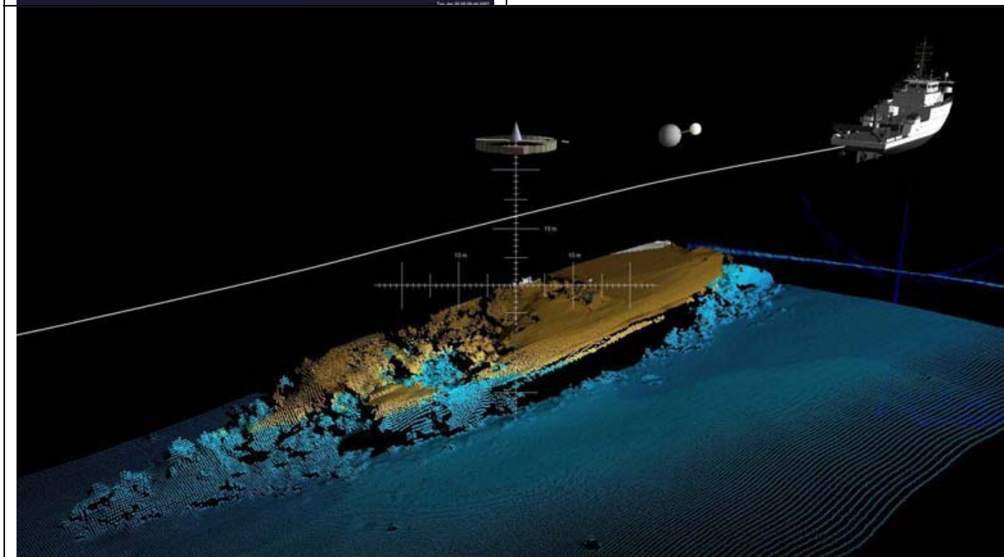
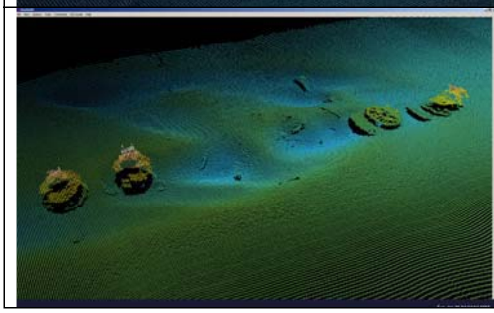
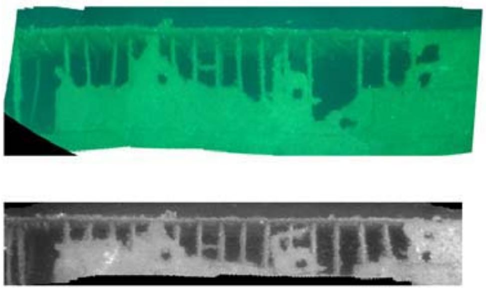
ScapaMAP2

Marine Heritage Monitoring with High-Resolution Survey Tools:

Scapa Flow 2001-2006

Final Report

Acknowledgements

The initial idea for the ScapaMAP project was conceived by Ian Oxley while working at Heriot-Watt University on his PhD thesis and came to fruition with the support of Gordon Barclay and Olly Owen of Historic Scotland. Ian was also responsible for the management of the project in its first year. The final outcome of the project, however, was the culmination of the support of many individuals and organisations during the programme.

The importance of The Scheduled wrecks of Scapa Flow as a recreational diving destination is undisputed and the need for monitoring continued site formation processes are well understood although the practicalities on this scale are daunting by conventional techniques. ScapaMAP2 was therefore funded by Historic Scotland to assess the current condition of the sites five years on using high-resolution survey tools.

Again the programme involved many participants. In particular, thanks are due to Gordon Barclay, Andrew Burke, Philip Robertson of Historic Scotland for their continued support. Dr Larry Meyers (Center for Coastal and Ocean Mapping, University of New Hampshire) for allowing his staff time to take part in the 2006 field season. In particular, to Dr Brian Calder (CCOM), Duncan Mallace and Paul Robertson (NetSurvey) and Rob Spillard (MCA) for their efforts during the 2006 fieldwork. Dr Calder was instrumental in the subsequent data analysis and much of the technical text. Dr Yuri Rhzanov (CCOM) for his technical and moral support in the mosaic work. Thanks are also due to the captain & crew of the Anglian Sovereign. During diving operations the assistance of Andy Cuthbertson and Kevin Grieve of the Orkney Dive Boat Operators Association is also gratefully acknowledged.

The assistance of the following organisations is also most gratefully acknowledged: Historic Scotland; Center for Coastal and Ocean Mapping, University of New Hampshire, Maritime Coastguard Agency, NetSurvey Ltd, RESON UK, Orkney Hyperbaric Trust, UK Hydrographic Office, Orkney Island Council Department of Harbours & Orkney Dive Boat Operators Association.

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SUMMARY

Our experience with ScapaMAP shows that remote survey provides a rapid alternative to more conventional marine archaeological investigations, and that recovery of targets is sufficient to allow effective repeat surveys to be carried out without extreme measures. The requirements for marine archaeological surveys are basically those for hydrographic survey, although we are frequently more interested in relative, rather than absolute, error, and therefore we need to pay more attention to factors such as offsets between components of the survey system, or horizontal positioning uncertainty, rather than things like water levels or other vertical correctors. Careful planning of survey lines is also required to ensure efficient and effective imaging of objects with large vertical extent.

Processing methods for marine archaeological data are driven primarily by the desire to maximize resolution, rather than preserving shoal points. This is especially difficult where small over-hanging features are observed with little reliable redundancy. Standard hydrographic tools are effective, however, when paired with a sufficiently observant, trained operator.

Visualization and display of objects with large vertical extent and complex morphology is problematic, and depends on the intended goal of the display. Scientific investigation and public outreach demand different approaches in data type, colour-coding and lighting among other factors. Our experiments indicate that point-cloud type displays are generally more effective than surface type displays because of the observer's ability to fill in the gaps between the points with an inferred surface, and that interactive displays, or at least animated versions of data, are more effective because they provide much better depth cues for the observer due to the effects of motion parallax, making it easier to interpret the 3D structure of the objects.

That said, the importance of diver observations to verify the remote sensing data and its subsequent visualisation cannot be over emphasised.

Future management plans should endeavour to include education through outreach programmes highlighting the need for the conservation of our submerged cultural heritage to augment the shortcomings of current legislation. Any continued site monitoring should also aim to include the diving community as part of this programme.

Glossary

Acronym

AAAMA	**A**rchaeological **A**reas and **A**ncient **M**omuments **A**ct 1972
ARCs	**A**dmiralty **R**aster **C**hart **s**ystem
AVI	**A**udio **V**ideo **I**nterleave
BST	**B**ritish **S**ummer **T**ime
CAD	**C**omputer-**A**ided **D**esign
CCOM	**C**enter for **C**oastal and **O**cean **M**apping
CRM	**C**ultural **R**esource **M**anagement
CTD	**C**onductivity, **T**emperature and **D**epth profiler
DAN	**D**ivers **A**lert **N**etwork
DGPS	**D**ifferential **G**lobal **P**ositioning **S**ystem
DSP	**D**igital **S**ignal **P**rocessing
DTM	**D**ynamic **T**errain **M**odel
DVD	**D**igital **V**ersatile **D**isc
EANx	**E**nriched **A**ir **N**itrox
ETV	**E**mergency **T**owing **V**essel
GeoZui4D	**Geo**referenced **Z**ooming **u**ser **i**nterface **4D**
GIS	**G**eographic **I**nformation **S**ystem
GPS	**G**lobal **P**ositioning **S**ystem
HDCS	**H**ydrographic **D**ata **C**leaning **S**ystem
HIPS	**H**ydrographic **I**nformation **P**rocessing **S**ystem
ICZM	**I**ntegrated **C**oastal **Z**one **M**anagement
IMU	**I**nertial **M**otion **U**nit
JHC	**J**oint **H**ydrographic **C**enter
JPEG	**J**oint **P**hotographic **E**xperts **G**roup
MCA	**M**aritime & **C**oastguard **A**gency
MBES	**M**ulti-**B**eam **E**cho **S**ounder
NAS	**N**etwork **A**ttached **S**torage
NERC	**N**ational **E**nvironmental **R**esearch **C**ouncil
NetCDF	**Net**work **C**ommon **D**ata **F**orm
NDT	**N**on-**D**estructive **T**esting
NFSD	**N**ational **F**acility for **S**cientific **D**iving
NMRS	**N**ational **M**onuments **R**ecord for **S**cotland
ODBOA	**O**rkney **D**ive **B**oat **O**perators **A**ssociation
ODIG	**O**rkney **D**iving **I**nterest **G**roup
OHT	**O**rkney **H**yperbaric **T**rust
OIC	**O**rkney **I**slands **C**ouncil
PDE	**P**roject **D**ive **E**xploration
PDF	**P**ortable **D**ocument **F**ormat

PFM	**P**ure **F**ile **M**agic
PMRA	**P**rotection of **M**ilitary **R**emains **A**ct 1986
POS/MV	**P**osition and **O**rientation **S**ystem for **M**arine **V**essels
POSPAC	**P**osition and **O**rientation **S**ystem Post-processing **Pac**kage
PPK	**P**ost **P**rocessed **K**inematics [solution]
RAID	**R**edundant **A**rray of **I**ndependent **D**rives
ROV	**R**emotely **O**perated **V**ehicle
RTK	**R**eal **T**ime **K**enematic [solution]
SAC	**S**capaMAP **A**coustic **C**onsortium
SIPS	**S**idescan **I**nformation **P**rocessing **S**ystem
SMR	**S**ites and **M**onuments **R**ecord
SMS	**S**einer **M**ajestät **S**chiff (English: *His Majesty's Ship*)
SONAR	**SO**und **NA**vigation and **R**anging
SPM	**S**ingle **P**oint **M**ooring
SULA	**S**cientific **U**nderwater **L**ogistics **A**nd **Diving**
TIFF	**T**agged **I**mage **F**ile **F**ormat
TIN	**T**riangulated **I**rregular **N**etwork
TPU	**T**ransceiver **P**rocessing **U**nit
UKHO	**U**nited **K**ingdom **H**ydrographic **O**ffice
UNESCO	**U**nited **N**ations **E**ducational, **S**cientific and **C**ultural **O**rganization
WAAS	**W**ide **A**ngle **A**ugmentation **S**ervices
WGS72	World Geodetic System 1972
XTF	e**X**tended **T**riton **F**ormat

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1 Introduction

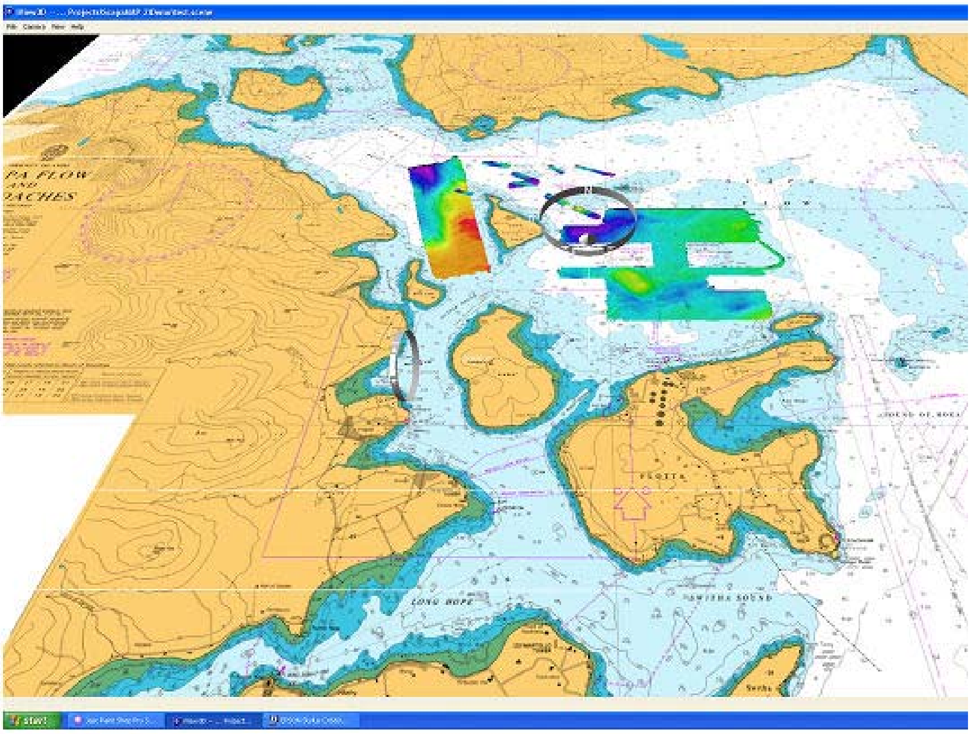
Since the initial survey work carried out in the ScapaMAP project, continued deterioration of the Scheduled wrecks has been noted by divers visiting the sites. In addition, the hope that scheduling the wrecks would have prevented further removal of artefacts from the sites has not materialised. Several reports have been made to the Northern Constabulary relating to divers removing artefacts from the scheduled sites. ScapaMAP II was therefore developed to fulfil the following aims:

- Resurvey the sites using high-resolution remote sensing techniques (a recommendation from the ScapaMAP project) to see if this could be used to determine both fine and gross changes in the wrecks structure.
- Conduct diver lead surveys to verify these changes
- Increase the public awareness for the need to conserve underwater heritage sites through diver participation and materials produced.

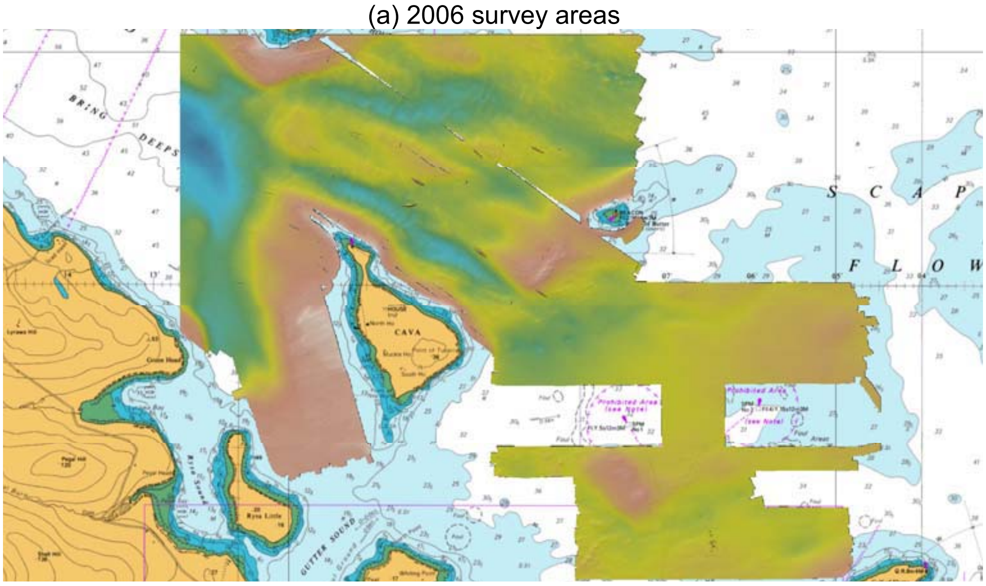
During the remote sensing survey it became apparent that little would be served by resurveying the seabed around the Scheduled sites. Anecdotal evidence suggested that following the scheduling of the wrecks attention had turned to the salvage sites by divers requiring a souvenir of there visit. Once the wrecks were resurveyed it was therefore decided to survey the salvage sites and should time remain the area to the south of that surveyed during the ScapaMAP programme. The extent of the 2006 survey (a) together with the combined area coverage (b), to date is shown in Figure 1.1.

This document presents the results of the investigation into methods for monitoring of marine heritage sites, using the remains of the Imperial German Navy (scuttled 1919) in Scapa Flow, Orkney as a case study. Using the baseline bathymetric survey in 2001, videography, and a repeat bathymetric and volumetric survey in 2006, it illustrates the requirements for such surveys over and above normal hydrographic protocols and outline strategies for effective imaging of large wrecks. Best practices for manipulation of such data (including processing and visualization) are outlined, and it draws the distinction between products for scientific investigation and those for outreach and education, which have very different requirements. It then describes the use of backscatter and volumetric acoustic data in the investigation of wrecks, focusing on the extra information to be gained from them that is not evident in the traditional bathymetric DTM models or sounding point-cloud representations of data. A comparison of the 2001 and 2006 data is also undertaken.

Finally, it considers the utility of high-resolution survey as part of an integrated site management policy, with particular reference to the economics of marine heritage monitoring and preservation.



(a) 2006 survey areas



(b) Merged 2001 and 2006 survey areas

Figure 1.1: 2006 survey areas included the Scheduled wrecks, SMS Bayern turrets, Gutter Sound and area to the north of Flotta (a); this was merged with the bathymetric data of the seabed around the Scheduled sites obtained in 2001 (b).

2 Scapa Flow 2001 – 2006

2.1 Diving Activity

Scapa Flow still remains an important global diving destination as evident by the number of dive boat operators businesses. Currently twelve dive boat charter businesses operate in Orkney with a number of other UK and foreign vessels visiting each year.

Determining the true level of diving activity is problematic. Although Scapa Flow is within the Orkney Islands Council Harbours area and a dive permit is required, use of the permits issued to determine actual number of divers has its drawbacks.

Generally operators apply for permits at the start of the season based on the bookings they have. Permits are then issued for a maximum of 12 divers per vessel. However not all groups comprise of 12 divers and in some cases groups may cancel their booking which is not subsequently filled although a permit has still been issued.

Table 2.1 gives the number of permits issued to commercial and recreational dive groups for the period 2001 – 2006. As can be seen there has been a slow rise in the number of permits issued over the period.

Table 2.1. *Dive permits issued by the Orkney Island Council Harbours Department 2001 –2006.*

	2001	2002	2003	2004	2005	2006
Commercial	1	4	3	8	3	4
Recreational	200	233	215	229	240	249

However, several dive operators show nil returns for several years, when they were known to be in operation. Once these are taken into consideration there would appear to be little change over this period.

Over the last few years some dive boat operators have returned the actual number of divers on their vessels each week to the Orkney Hyperbaric Trust (OHT) as part of their ongoing research work. Based on this it would appear that overall cancellation rates are low and that on average there are 10.5 divers/permit. In 2006 this would put the total number of divers on dive boats at around 2,500.

During the course of the 2001 – 06 seasons data was collected by OHT in collaboration with the Divers Alert Network (DAN) for their ***Project Dive Exploration.*** This study is examining diver's general diving patterns and state of health. Dive locations are reported as part of the study. Approximately 10 % of the total number of recreational divers, estimated to have visited Scapa Flow each year, participate in the study. Based on this information it is therefore possible to estimate the actual number of dives undertaken and the relative frequency with which the various dive sites are visited. On average divers conduct 10.9 dives per trip. This would put the total amount of dives carried out by recreational divers at around 27,250. The relative frequency with which the Scheduled sites and other German wreck sites are dived by PDE participating divers is shown in Table 2.2. It should be noted that this data was largely derived from divers onboard vessels that also conduct expeditions outside Scapa Flow. Consequently, as other vessels restrict their diving to within Scapa Flow this probably represent an underestimation of the true proportion of the dives being undertaken on the German wrecks.

Table 2.2. *Estimated frequency with which wrecks in Orkney Waters are dived. Data based on information collected during the Diving Alert Network (DAN)* ***Project Dive Exploration*** *2001 - 04.*

Dive Site	2001		2002		2003		2004	
	Dives	%	Dives	%	Dives	%	Dives	%
SMS Markgraf	91	4	99	4	84	3	81	3
SMS Kronprinz Wilhelm	217	9	270	10	228	9	247	10
SMS Konig	21	1	34	1	17	1	14	1
SMS Köln	193	8	253	10	220	9	260	11
SMS Karlsruhe	214	9	287	11	306	12	284	12
SMS Dresden	187	8	251	10	232	9	205	9
SMS Brummer	207	9	301	12	219	9	213	9
Total Scheduled	1130	46	1495	58	1306	53	1304	55
Salvage Grounds	67	3	57	2	104	4	80	3
Total	***2431***	***49***	***2594***	***60***	***2460***	***57***	***2391***	***58***

Based on the number of Dive Permits issued, information from dive boat operators, and participating PDE divers Table 2.3 gives an estimate of the total number of dives carried out on the Scheduled sites and other German wreck sites in 2006.

Table 2.3. *Estimated number of divers visiting each scheduled site. Calculations based on DAN* ***Project Dive Exploration****, dive boat operators and Orkney Harbours Department* ***Permits to Dive***

Dive Site	**Relative Frequency (% of Total Dives)**	**Estimated Number of Dives (2006)**
SMS Brummer	9.5	2589
SMS Dresden	8.8	2398
SMS Köln	9.4	2562
SMS Karlsruhe	11.0	2998
SMS Markgraf	3.6	981
SMS Konig	0.9	245
SMS Kronprinz Wilhelm	9.7	2643
Salvage Areas	3.1	845
	56.0	**15,260**

Table 2.4 gives a comparison of the number of visitors at Orkney's main visitor sites compared with the dives carried out on the German wreck sites.

In a recent survey conducted by Visit Orkney divers account for approximately 2% of the visitors to Orkney but account for around 8% of the tourism revenue.

Table 2.4. *Comparison of visitor numbers at various Orkney visitor sites 2006.*

Site	Visitor Numbers
Skara Brae	64529
Maeshowe	24708
German Wreck sites	**15260**
Broch of Gurness	11394
Bishop's Palace	9,093
Brough of Birsay	5872
Hackness Martello Tower	1887

2.2 Reported Deterioration

Divers continue to comment on structural changes to the wrecks from their previous dive trips. However there is no central repository to gather this information together either as written reports or photographic evidence.

The main items commented on are the continued deterioration of the light cruisers.

- SMS Köln - deck plating corrosion
- SMS Brummer - forward gun & deck collapse
- SMS Dresden - bow section collapse

2.3 Causes of Artefact Recovery or Damage

There have been a number of cases of artefact removal or damage to the wrecks since 2001. These are categorised by the nature of the activity.

2.3.1 Reports of illegal recoveries by divers

- Removal of Artefacts from SMS Brummer

In October 2001 a recreational diver on holiday in Scapa Flow reported that he had witnessed a group of divers removing artefacts from the wreck of the SMS Brummer to the Receiver of Wreck. This information was then passed to the Northern Constabulary who started an investigation. Initial investigations lead to a visiting vessel and divers. However no items were recovered and no persecution took place.

- Markgraf Reported Salvage attempt

On the 29 July 2005 a recreational diver reported seeing lifting bags attached to the auxiliary rudder steering mechanism during a dive on the SMS Markgraf. On the 2 August 2005 this was investigated. No evidence of lifting bags was found, however, ropes were attached to the mechanism in preparation for recovery (Figure 2.2).

Figure 2.1: Auxiliary steering mechanism in the SMS Markgraf with ropes and karabiners attached.

- Steering indicator recovery

A diver was stopped at Kirkwall airport on the 11 November 2004 with several brass items in his possession. These appeared to be a heading indicator and several speaking tube mouthpieces with name plates.

During questioning by the police the diver stated that the items had come from an area of debris at one of the salvage sites and not from one of the scheduled sites.

Following further investigation the diver reported the items to the Receiver of Wreck and donated them to the museum. No further action was taken.

This case highlights the problem of identifying the origin of recovered artefacts and having the wreck sites protected through scheduling with no protection offered to the salvage grounds.

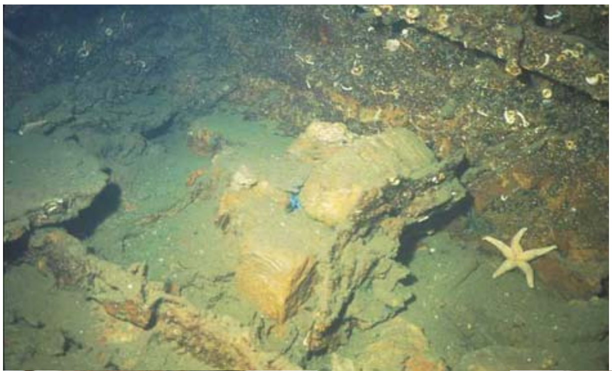
- *Karlsruhe valve recovery*

Following an incident where two divers recovered a valve from the wreck SMS Karlsruhe the divers themselves reported this to the police. During questioning the divers stated that they did not know that the wrecks were scheduled under the Archaeological Areas and Ancient Monuments Act. Under this act Section 2 (8) ignorance of the Act is an acceptable defence. No further action was taken.

2.3.2 <u>Legitimate recovery operations</u>

- *Postcard Recovery*

In September 2003 diver reported the discovery of postcards on the SMS Karlsruhe. In March 2004 a recovery operation, funded by Historic Scotland was undertaken and the recovered postcards shipped to AOC Archaeology for conservation. Following a lengthy process they are now stored in the Kirkwall Library Archive. Figure 2.1 (a), (b) & (c).



(a) Stacks of postcards *in situ* prior to removal once the sediment had been removed.

(b) postcard when recovered

(c) conserved postcard

Figure 2.2: Postcards recovered from the SMS Karlsruhe March 2004. (a) *in situ*, (b) as recovered & (c) post conservation.

2.3.3 Fishing activity

- Damage by fishing vessel

Fishing activity in Scapa Flow has centred around prawn (*Nephrops norwegicus*), lobster (*Homarus gammarus*), "clams" – Queen scallop (*Aquipectin opercularis*) & King scallop (*Pectin maximux*), "Buckie" – Common Whelk (*Buccinum undatum*) and a variety of crab species – Brown crab (*Cancer pagurus*), Velvet crab (*Necora puber*) & Green crabs (*Carcinus maenas*) fisheries. The main fishing gear used are either pots or trawls both of which are capable of causing damage to a greater or lesser degree if they become entangled.

Wreck sites often display higher species abundance and diversity compared to the surrounding seabed due to the additional habitat they provide. Consequently, fishermen may attempt to fish in close proximity to wreck site in order to obtain a high yield catch. In general the position of the wreck on the seabed are well known due to the economic significance of damaged or lost fishing gear, and therefore this tends to be a rare occurrence.

However, in 2003 a fishing vessel reported snagging its clam dredges on the Kronprinz Wilhelm. Heriot-Watt University were asked to investigate the damage. During dives on the wreck several lost dredges were found along with other forms of fishing gear were found (Figure 2.3 a(a) & (b)). It could not be determined if damage to sections of the site along the seabed were the result of fishing gear or natural deterioration.

(a) Queen scallop trawl.

(b) Buckie pot.

Figure 2.3: Fouled fishing gear on SMS Kronprinz Wilhelm.

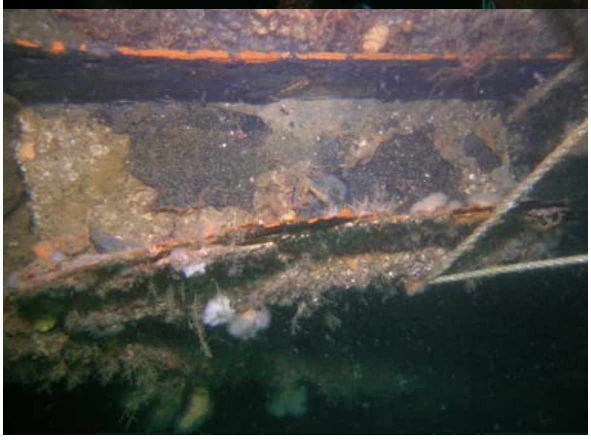
2.3.4 Accidental

- Inadvertent Damage

On a repeat visit to the SMS Brummer from the previous day the survey team noted that one of the two surface marker buoys on the shotline was missing. On reaching the wreck the divers noted that a large piece of metal to which the shotline had been attached had been pulled off the hull. This is shown in figures 2.4(a) and (b). What appears to have happened is that a passing vessel had fouled the shotline and as it was pulled taught it had simultaneously pulled the fastening off the hull and severed the line at the buoy.

Although, not a frequent occurrence from the number of disused shotlines on the wrecks this is not an isolated occurrence. During the survey, despite surveying at relatively low speeds and giving the shotlines a wide berth, the pressure wave generated by the Anglian Sovereign dragged several shotlines under the hull and severed them. However, not all such incidents result in damage to the wreck.

(a) damage to hull caused by shotline fastening being torn off.



(b) Fastening suspended by shotline after being torn off hull.

Figure 2.4: Inadvertent damage sometimes occurs when passing vessels foul the shotlines. On occasion prior to the shotline being severed the fastening may be torn off the hull (b) resulting in hull damage (a).

3 Work Undertake

3.1 Remote Sensing Survey

Following discussions between Historic Scotland, the Maritime Coastguard Agency's Receiver of Wreck and SULA Diving it was proposed that the ETV ANGLIAN SOVEREIGN (Figure 3.1) be used to conduct a remote sensing survey over the Scheduled sites in Scapa Flow. The ANGLIAN SOVEREIGN is used for hydrographic surveys in support of the UK Civilian Hydrographic Programme when not in use as a towing vessel, and is permanently equipped for this purpose.

Arrangements were finally put in place for this to proceed however this could only commence once the vessel had completed its own work programme. Consequently, the survey in Scapa Flow was schedules for the autumn of 2006.

Figure 3.1: The ETV ANGLIAN SOVEREIGN, with which the survey was conducted. The ship has a hull-mounted Reson 7125 MBES system (right) for hydrographic surveying when not being used as an emergency towing vessel, making it an ideal platform for surveys such as ScapaMAP II.

3.1.1 Hardware and Software Configuration

The survey was carried out aboard the ETV ANGLIAN SOVEREIGN, an Emergency Towing Vessel under contract to the Maritime and Coastguard Agency (MCA). The ANGLIAN SOVEREIGN is used for hydrographic surveys in support of the UK Civilian Hydrographic Programme when not in use as a towing vessel, and is permanently equipped for this purpose. The MCA contract survey services through NetSurvey Ltd., who provided support for the ScapaMAP II surveys. The hardware configuration of the systems described below is summarised in

Figure 3.2.

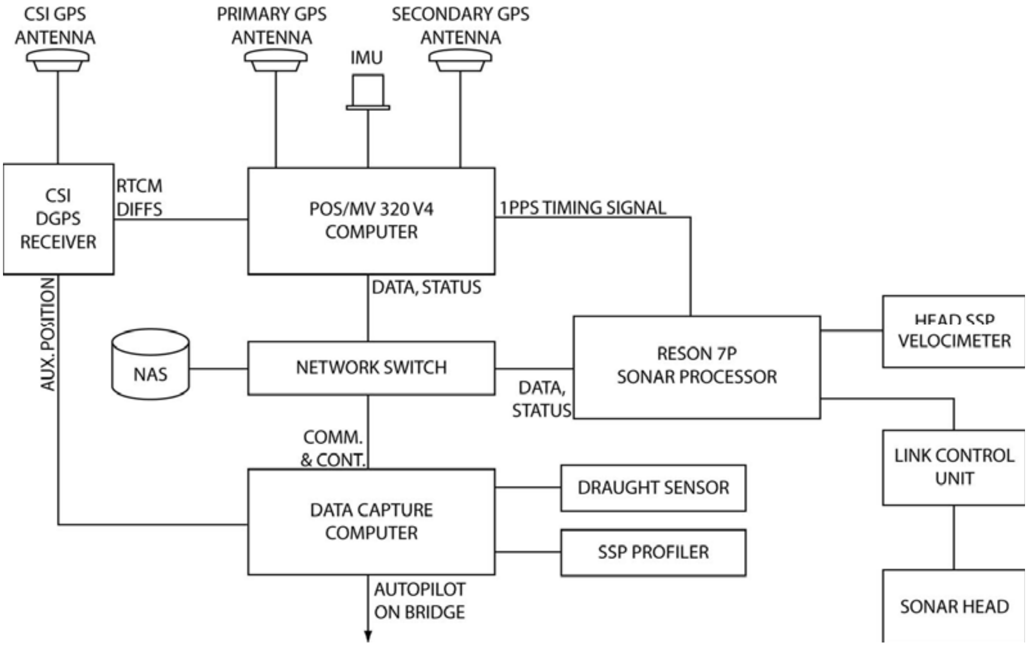


Figure 3.2: Hardware configuration of the survey suite of the ETV ANGLIAN SOVEREIGN. Note that the power supplies and some extraneous equipment (monitors, keyboards, etc.) have been omitted for clarity.

The ANGLIAN SOVEREIGN was equipped with a Reson 7125 Multibeam Echosounder (MBES) system (serial nos. 3904085 (Transmit), 4504219 (Receive), 46750 (Link Control Unit) and 46747 (Topside Processing Unit), firmware V3.1.0.2, distribution software V2.7.0.3), operating at a centre frequency of 395 kHz. This system generates 256 individual estimates of depth distributed equi-angularly across a swath of constant angle (here, 130°) perpendicular to the longitudinal axis of the ship for each transmission of acoustic energy (‘ping’). This typically translates to a swath of width approximately four times the depth of water. The 7125 also records the intensity of the acoustic energy returned from the seabed after each transmission in order to for a ‘backscatter’ sequence, and can be operated so as to record the backscatter from the whole of the water column rather than just the seabed. Both modes of operation were used during ScapaMAP II.

In order to correct the acoustic measurements for the motion of the ship (i.e., to render them into a locally level vertical reference coordinate system), the ship was also equipped with an Applanix POS/MV 320 V.4 GPS-aided Inertial Motion Unit (IMU) (serial nos. 12541966 (GPS1), 12470852 (GPS2), 394 (IMU sensor) and 2158 (POS Computer System), firmware V3.3.0.2), which computes both attitude and position of the ship using a combination of a pair of GPS antennas and a high-performance motion sensor. Combined with differential GPS corrections from the local Coastguard beacon (in this case from the Sumburgh Head station in Shetland, on 291.5 kHz), derived from a

CSI DGPS MAX receiver (serial no. 0505-19588-0006), positioning accuracy in real-time is typically on the order of 0.5-1.0m (2drms) in the horizontal plane, and attitude is typically on the order of 0.02-0.05° (rms) in all three rotational axes. In order to improve on this in post-processing, the POS/MV 320 was configured to output the required raw data for Applanix POSPAC post-processing environment over a local Ethernet link; the data was recorded on the data capture computer system and archived. Additional information from the Fugro SkyFix.XP Satellite Precise Point Positioning system onboard was not available due to receiver malfunction during the cruise.

Monitoring of sound speed in the water column is essential to correct the acoustic measurements for refraction. Periodic measurements of the sound speed profile were taken during the survey using a SeaBird SBExx Conductivity, Temperature and Depth (CTD) probe deployed from the rear deck of the ship. Since the 7125 is a flat-faced transducer, the effects of sound speed variation are particular significant at the face of the transducer, and a sound speed probe (Reson SVP70, serial no. 22050059) was permanently mounted adjacent to the acoustic array and fed in real-time to the Reson sonar processor.

Corrections for dynamic draught (i.e., vertical offset of the survey vessel with respect to the waterline caused by the motion of the ship) were recorded through a draught sensor installed in the hull (Pressit ND16-60, serial no. ST0871). Applanix TrueHeave measurements were computed at the POS/MV and passed to the data capture computer for storage and post-processing.

The survey suite was configured to send all data to the data capture computer with storage on an external Network Attached Storage (NAS) device. Timing signals were led from the POS/MV to the Reson TPU so that data time-tagged as source could be used for combination of data. The data capture station used Triton ISIS (V.7.0.417.21) to record the MBES data, which was archived in XTF format. Feedback of the planned lines for the bridge was done via a monitor splitter from the Survey Cabin display; communication was via a Clear-Com MS232 intercom (serial no. 747810). For water column data, the volume of data required that the capture be done on the Reson TPU and then synchronised with attitude and position data from the POS/MV in post-processing; this data was recorded in Reson's native S7K format. All files were transferred to the NAS device over a standard Gigabit Ethernet network.

3.1.2 Survey Protocols

Patch-test and bar-check calibration procedures for the survey system were carried out for the MCA survey work immediately prior to ScapaMAP II, and it was judged that they did not need to be repeated prior to the survey. Unless otherwise stated, typical hydrographic survey protocols for data capture and quality control were used since the survey was also intended to be submitted via the MCA to the UK Hydrographic Office (UKHO) for official use. Details of these may be found in the UKHO's survey specifications [3.1].

The survey was planned dynamically as data was gathered, with the basic plan of covering all of the extant Imperial German Navy wrecks with basic bathymetric and backscatter surveys, as well as imaging them with the water column data capture method, and then covering as much of the primary recovery ground in Gutter Sound as possible, followed by the area around the approaches to the Flotta marine terminal. Survey lines for the wrecks were planned using the data from ScapaMAP I, aligning the survey with the primary longitudinal axis of the wreck in each case. Offsets were applied to the lines in order to avoid marker buoys attached to the wrecks by recreational divers. Survey lines for Gutter Sound were determined by the physical orientation of the survey area, and line spacing was determined to ensure a suitable degree of overlap between adjacent lines. The intent with the 'area coverage' surveys was to provide reconnaissance data for less well defined wreckage recovery sites and adjacent wrecks which might require further investigation at some later date, rather than to cover any particular target in detail. The survey around the Flotta marine terminal was laid out to avoid the prohibited areas around the Single Point Moorings (SPM) for tanker loading.

Sound speed profiles were conducted on a regular basis at four hour intervals, whenever the ship moved to a new water body, at the start of the day, and as indicated by monitoring of the surface sound speed reported by the hull sensor at the transducer head. A deviation of sound speed on the order of 4 ms^{-1} or more was considered significant enough to warrant another profile.

For real-time use, predicted tides were used, based on the St. Mary's station. For interim products, observed tides from the harbour office at Stromness were used, provided by the Orkney Harbours Department. Final water level correctors were determined using the vertical component of a Post Processed Kinematic solution from the raw POS/MV data, resulting in depths with respect to the geodetic ellipsoid, rather than to chart datum. Approximate corrections to datum will be constructed from the data in further post-processing.

Ship operations were conducted 16 – 20 October 2006. Due to ship handling limitations, 24-hr operations were not possible, and the ship anchored up for the night at the end of each day. Operations therefore typically commenced 0800BST each day, and terminated at 1700BST.

3.1.3 Data Management

Raw data from the Reson 7125 was recorded on the data capture computer in XTF format [3.2] during the primary data collection effort, and in Reson S7K format [3.3] during the water column data collection; raw data from the POS/MV was recorded in Applanix format [3.4] at all times.

Data were recorded direct to the NAS unit from the data capture computer using the drives exported from the NAS; data from the POS/MV were copied to the NAS on a batch basis between lines to avoid network delays; data from the 7125 TPU were copied to the NAS via the data capture computer between lines due to their size.

The raw data archives were copied from the ship's NAS to a local RAID drive on a separate computer to ensure a complete backup in case of drive failure on either system. Preliminary processing was then carried out on the ship's processing computer, with the end results being copied to the local RAID drive at the end of the survey period. The local RAID drive was then transported to CCOM and downloaded onto an archive disc array that implements an incremental backup policy in order to ensure preservation of the data.

Post-processing of the data is on-going, as detailed in Section 3.2.3. On completion, the data set will be transferred to CCOM by hard disc, and then copied again to the archive disc array. Final product creation will then take place, and an archive data set will be constructed.

3.2 Data Processing

3.2.1 Real-time Data Flow Path

The basic processing of data from the ScapaMAP II survey were done in real-time as the data was being collected. Immediate feedback of survey data and products is essential to ensuring that data of sufficient quality is being collected; it also makes efficient use of the time available during survey. An overview of the processing chain is shown in
Figure 3.3.

After capture and archive, the raw XTF files were converted into CARIS HIPS HDCS format for processing. Offsets for relative position of the transducers and IMU, both linear and angular were then applied. Positioning was obtained from the integrated IMU output, and therefore no further corrections for GPS positions were required. Corrections were then made for sound speed profile in the water column, and the positioning and attitude data were merged with the raw range/angle measurements to provide depths with respect to the ship's waterline. Predicted tides were then merged to provide depths with respect to local datum.

The data were then converted into Fledermaus PFM format [3.5] in order to allow for rapid data quality control. Processing was done using the CUBE hydrographic data processing algorithm [3.6]. After data quality assurance and remediation of any dubious measurements, the data were filtered against the CUBE-derived 'most probable' data surface, and flags were applied to the data. These flags were then exported back to the HDCS data structures for final archive.

Data from the water column investigations were extracted directly from the Reson S7K data using CCOM research software 'MB-Fish', which creates NetCDF [3.7] files for visualisation in GeoZui4D [3.8], CCOM's research visualisation programme. Limitations with file size meant that only limited investigation of this data was possible during the cruise; this was, however, sufficient to determine that the data was being recorded correctly for post-processing.

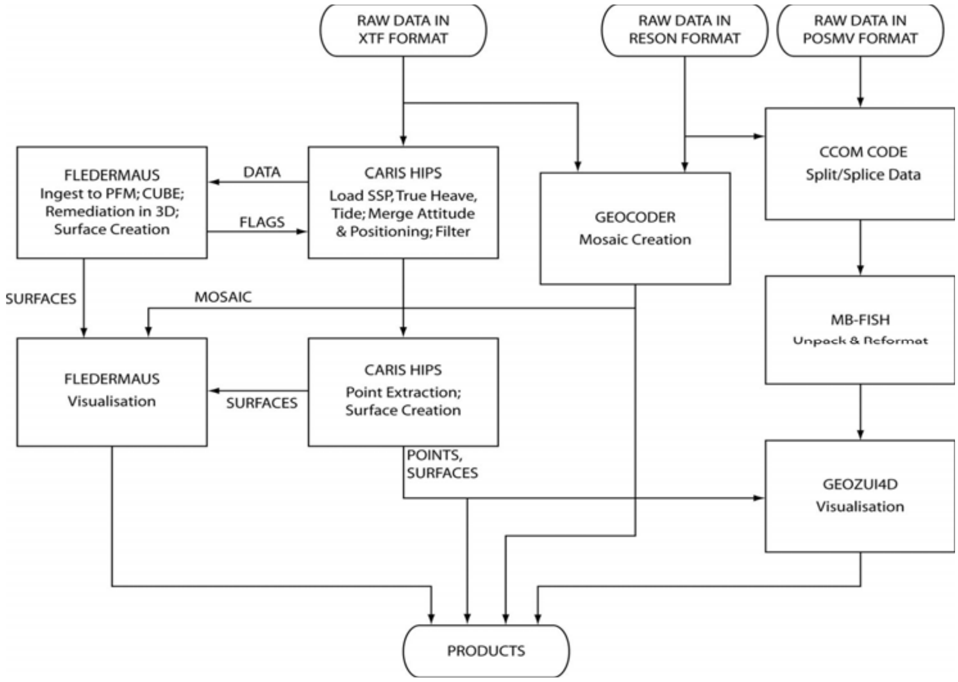


Figure 3.3: **Workflow for data processing during the ScapaMAP II survey. This is a standard hydrographic processing scheme, combining multiple packages to finalise the data.**

3.2.2 Interim Products

During the cruise, a limited number of data products were constructed as feedback and visualisation aids. Point-cloud visualisations of all of the primary wrecks were generated,
Figure 3.4, along with mixed surface/point points,
Figure 3.5. Surfaces of all of the survey areas with full coverage survey were constructed to illustrate the area, Figure3.6. Visualisations of a limited area of water column data were also constructed, Figure 3.7, although they have some technical difficulties in positioning, and should not be relied upon for detailed investigation until these have been resolved.

3.2.3 Post-Processing Stages

Three principal post-processing stages are still required to finalise the data archive and therefore the data products.

First, the raw data gathered from the POS/MV during processing must be post-processed using the POSPAC software from Applanix in order to compute better estimates of position and attitude for the IMU during the period of survey, and therefore better positioning for the soundings and other data products. In any Inertial Navigator, there are limitations to the accuracy of the data produced in real-time: the GPS satellite positions are known only to within the limits of knowledge of the satellites themselves, and only previously observed data can be used to predict the dynamics of the survey platform to determine the attitude. In post-processing, more accurate ephemeredes can be determined for the satellites using information from co-observing ground stations, and measurements of acceleration and gravitation from before and after the time instant of interest can be used to predict the attitude. Positioning accuracies in all three dimensions at the centimetre scale are possible, and the attitude determined is less affected by lateral acceleration, particularly the heave (vertical) component. The horizontal positioning improvement allows the merging of multiple passes over the same object without confusing the small details that are essential to the use of this data for archaeological purposes; the use of vertical GPS measurements (with respect to the ellipsoid) significantly reduces the difficulty in reducing the soundings to a common vertical datum (i.e., avoids the need for a tide observation which is almost always interpolated or extrapolated and therefore is typically of limited – and limiting – accuracy). In hydrographic products, surveying to the ellipsoid is not current accepted in most cases because navigational products have to report depth to the local chart datum (typically Lowest Astronomical Tide in the UK). For archaeological purposes, however, this is not required, and the benefit of better registration of adjacent passes outweighs the benefit of being able to read reduced depths from the products. Since this data is going to be dual-purposed with the UKHO through the MCA, however, products with respect to chart datum will also be available.

Second, the backscatter available from the Reson 7125 has to be geometrically and radiometrically corrected, and then mosaiced so that it may be overlaid on the bathymetry and interrogated. This processing is being carried out using CCOM's GeoCoder [3.9] software, but since the Reson 7125 is a relatively new sonar, some interface code for GeoCoder is being constructed in order to improve the output quality of the mosaic. Once complete, a mosaic of backscatter over the entire surveyed area will be constructed and georeferenced.

Finally, the water column data recorded with the Reson 7125 has to be processed. This data type is relatively new in the field, and there exists no standard processing tool to render it into a useful product. CCOM's research tool 'MB-Fish' was used in this case to make experimental products, but field testing during the ScapaMAP II survey showed that there were a number of limitations with the rendering of the software which resulted in difficulties in the final product. These are currently being rectified; once finished, 4D rendering of the data will be available for the primary wreck sites for investigation using GeoZui4D.

Only the first of these tasks is required for the base data archive required for ScapaMAP II. However the water column data, and particularly the backscatter will be very useful in understanding all aspects of the site. These data products will be developed in parallel with the base bathymetric data, with the intent of delivering them as part of the primary data archive. Since software development and research was involved, however, their has been delayed in their production. They will be forwarded as a supplement to the archive.

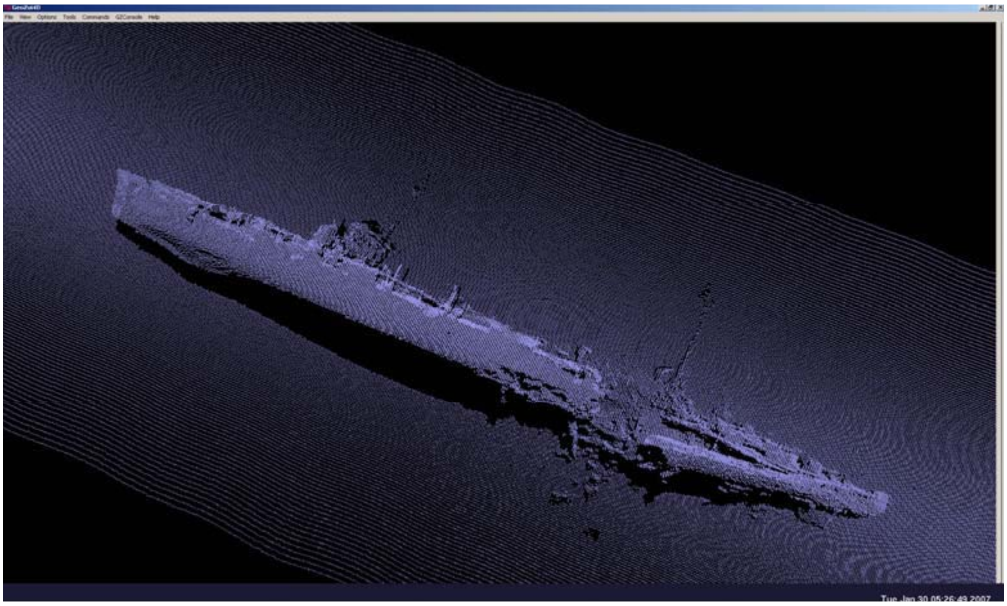


Figure 3.4: An example of data point clouds for the SMS Cöln, showing the high level of data density and detail derived from the Reson 7125. The colour-coding here is intended for non-scientific usage, since most of the detail of depth is lost in the visualisation. Products similar to this, with colour-coding, are used scientifically, however.

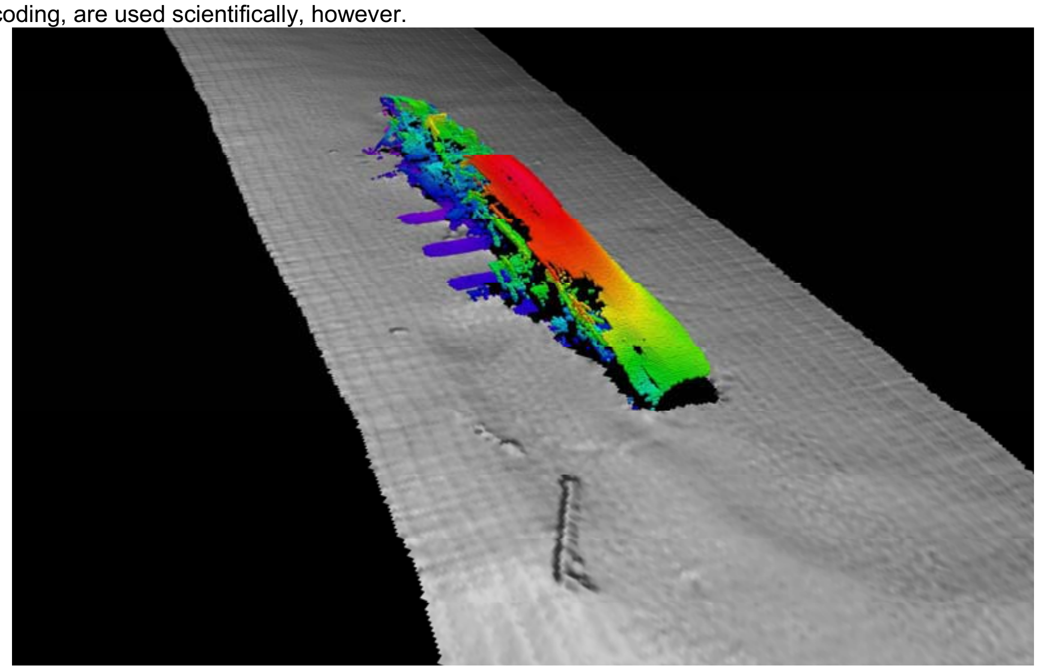


Figure 3.5: An example of a mixed point/surface model for SMS Brummer, highlighting the position of the wreck with respect to the seafloor. This is also intended primarily as a visualisation product.

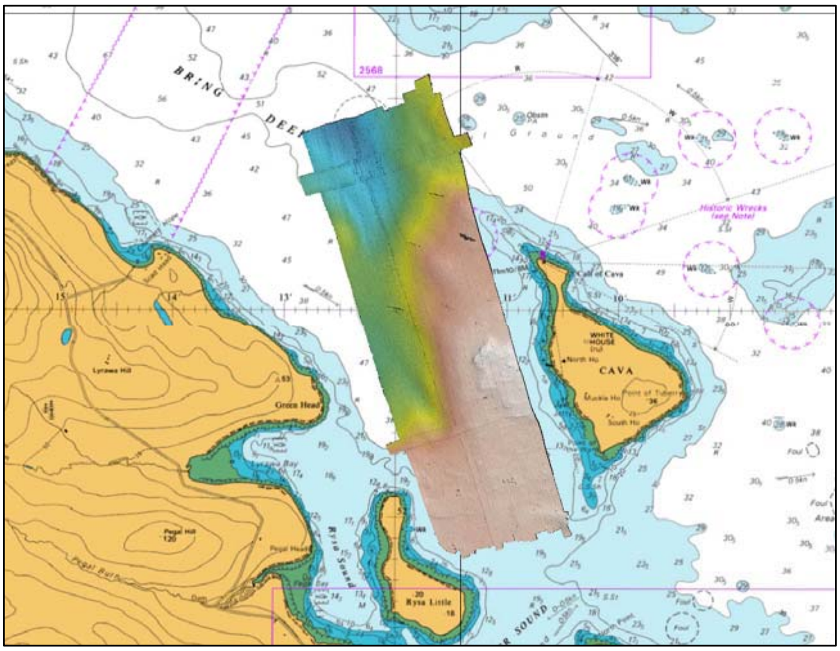


Figure3.6: **Coverage of the area to the west of Cava during the survey. As well as being a summary of the survey effort, these data products are used for planning future work, and for context in development of site management plans.**

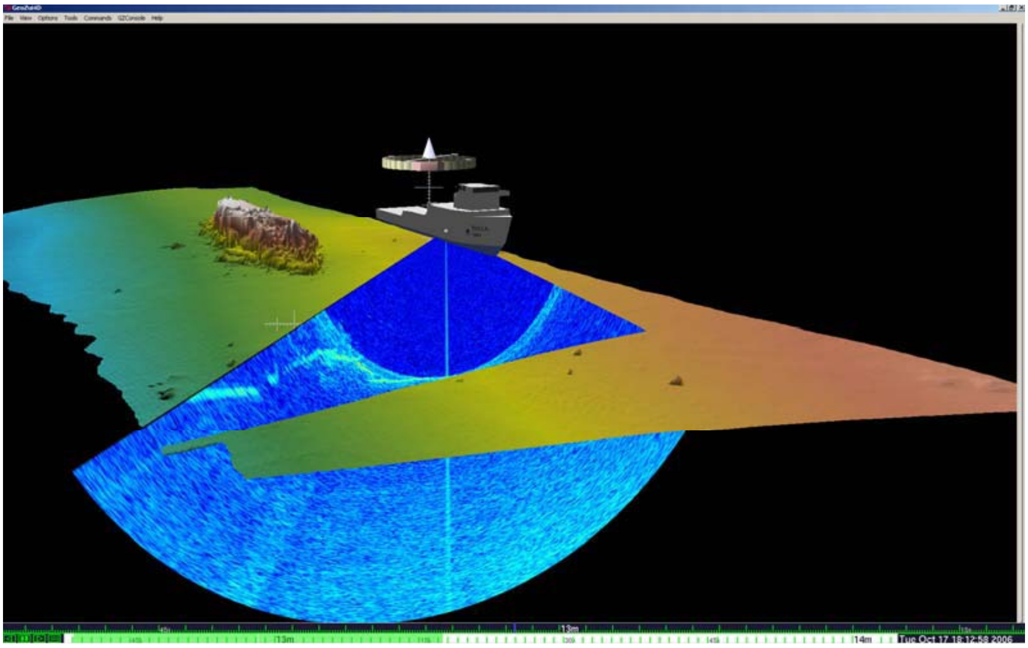


Figure 3.7: **Visualisation of the water column data for the SMS König, showing basic colour-coded bathymetry, a glyph for the ship, and the data observed by the sonar for one ping. The whole dataset is an animation with the ship moving in real-time, displaying the data in the sequence as collected.**

3.2.4 Final Products List

Once all post-processing is complete, final products will be generated for delivery and archive. The expected list of products is:

- Point cloud data and illustrative renderings (TIFF) for all primary wrecks and immediately surrounding areas;
- List of sonar contacts for all surveyed areas (i.e., positions and descriptions of all objects that are not currently marked on the chart);
- Combined surface models and illustrative renderings (TIFF) for all areas from ScapaMAP I and ScapaMAP II;
- 'Presentation' scale large-format illustration (PDF) for the surveyed areas from ScapaMAP I and ScapaMAP II;
- Reprocessed point cloud data from ScapaMAP I for comparison with the current survey;
- Backscatter plot for all ScapaMAP II areas; and
- Water column visualisations for all principal wrecks from ScapaMAP II.

Where possible, multiple formats will be made available (e.g., TIFF and JPEG). In some cases, however, this is not possible (e.g., water column data). In this case, appropriate software to utilise the data will be included in the archive if possible. This software will be appropriate for a Win32 platform.

3.2.5 Data Archival

The archive of data for submittal will include: all of the raw data as recorded, and the processed point-wise data as edited and finalised; the data used in creation of the products; TIFF and JPEG views of all of the visualisations; PDF version of printable products; and freeware visualisation software for the digital products.

Long-term archive of digital data is notoriously difficult. Although the raw binary data itself theoretically is always recoverable, the media and data formats are frequently not so obliging. Currently, the only know way to ensure that data stays available is to keep it spinning on a disc drive array with some redundancy and replace discs as required. For ScapaMAP II, the following protocol will be followed:

- All data as outlined above will be assembled onto a staging area of disc;
- Digital copies of the format documents applicable to the data will be added to the staging area when possible (XTF, S7K, and POS/MV; HDCS does not have a public definition document beyond the library API);
- Software source code capable of reading these formats will be added to the staging area;
- MD5 checksums of all of the files will be computed and recorded into the staging area;

- The data will be copied onto a disc array on CCOM's Storage Area Network (these discs are maintained in RAID 6 configuration, and backed up every night);
- The data will be copied onto three USB 2.0 external discs;
- MD5 checksums will be re-computed on the copies and verified.

Assuming that all of the checksums verify, the discs will be distributed: one to be forwarded to CCOM's off-site storage archive, and two to be transferred to SULA Diving (one for local archive, and one for onward transmission to Historic Scotland as the final submission for the project). In this way, we hope that the data will remain intact for as long as possible since it will in theory be possible to recover all of the data from any one of four sources, with error checking from the MD5 checksums.

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[3.9] Fonseca, L. and B. R. Calder, "GeoCoder: An Efficient Backscatter Map Constructor", Proc. US Hydro. Conf., San Diego, CA, 2005

3.3 Diver Based Surveys

3.3.1 Conventional Survey Techniques

During the initial ScapaMAP project several key areas known to be under rapid structural change were mapped using conventional diving techniques in order that they could be used for baseline monitoring. Initial dives were carried out at the start of the programme to determine how much deterioration had taken place in order that the scale of the survey could be ascertained. Once it was apparent that the remote sensing survey would take place in the late autumn this component of the diving programme was suspended. Effort was then centred around obtaining video records of the areas. Figure 3.8 shows divers conducting a conventional survey on the SMS Brummer.

3.3.2 Video Surveys

Dives were carried out on all the light-cruisers and one of the battleships to give a visual record of the current state of the sites. Effort was concentrated around the areas of known deterioration. In light of the initial findings of the remote sensing survey some additional video surveys were carried out. However, deteriorating underwater visibility due to weather conditions and reduced day length at this time of the year made this work difficult.

Video survey work was carried out using a Sony DCR-PC350E miniDV camera in a Gates underwater housing. In all 11 days diving involving 64 man-dives were carried out. Tapes were duplicated and the original kept as the Master copy. They were also copied to DVD.

3.3.3 Video Mosaicking

Due to the depths involved and the consequent limited bottom time available to the divers video mosaicking techniques were trialled during the initial ScapaMAP project as a means of rapidly visualising sections of the wreck. These proved a rapid method of visualisation and also produced images comparable to the drawings produced by diver measurements.

Information on operator technique and data processing from the 2001 surveys have helped refine protocols for video capture techniques and subsequent processing which were incorporated for the 2006 work.

New software and training was provided by CCOM to mosaic the video for image production.

Due to the varying optical distortions inherent in housed video systems the first stage of the procedure is to calibrate the system. This is achieved by shooting footage of an 8 by 8 black and white checker board. During filming the housing is rotated clockwise and anti-clockwise and tilted in the four main axis. Required images for the calibration process were then captured using VisualDub v1.6.4. and processed using the Matlab Camera Calibration

Toolbox from Caltech. The estimated coefficients were then used to correct the acquired imagery with LensCorrect v1.0.0.1 application.

The video sequence to be used for mosaicking is first captured using public domain WinDV application and stored as an Microsoft AVI file. The capture rate is adjusted at this point to provide a sequential overlap of around 70%. Typically this is every fifth frame (or 6 frames per second). The file is then corrected using the LensCorrect application, cropped to remove black margins and resized to achieve required resolution. The resultant movie file can then be used by the BuildMosaic application to generate the mosaicked image.

Comment [y1]:

Depending on the degree of rotation and vertical separation between the video and target the mosaicked image may exhibit various artefacts: curling and/or shrinking. Based on diver measurements this image can be corrected using a Warp programme to produce a final mosaicked image.

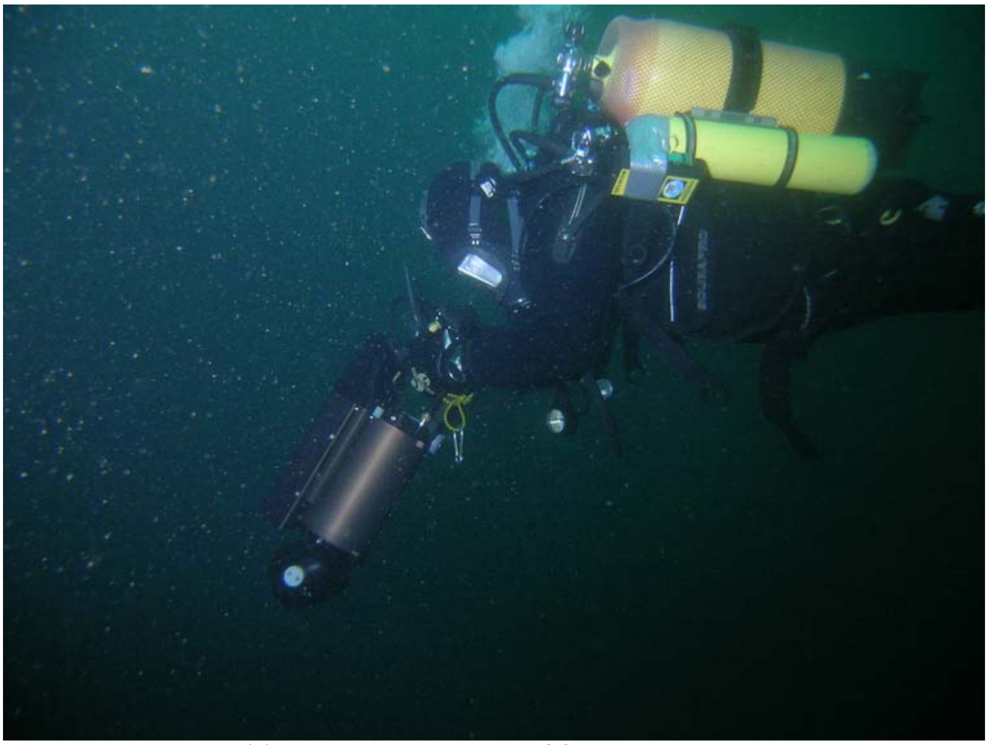
3.3.4 DIDSON Diver Held Sonar

During the survey the opportunity presented itself to use a DIDSON DH100 diver held high definition sonar (figure 3.9(a)) to assess it's' potential for rapid site survey. The unit operating specifications in detection mode are :

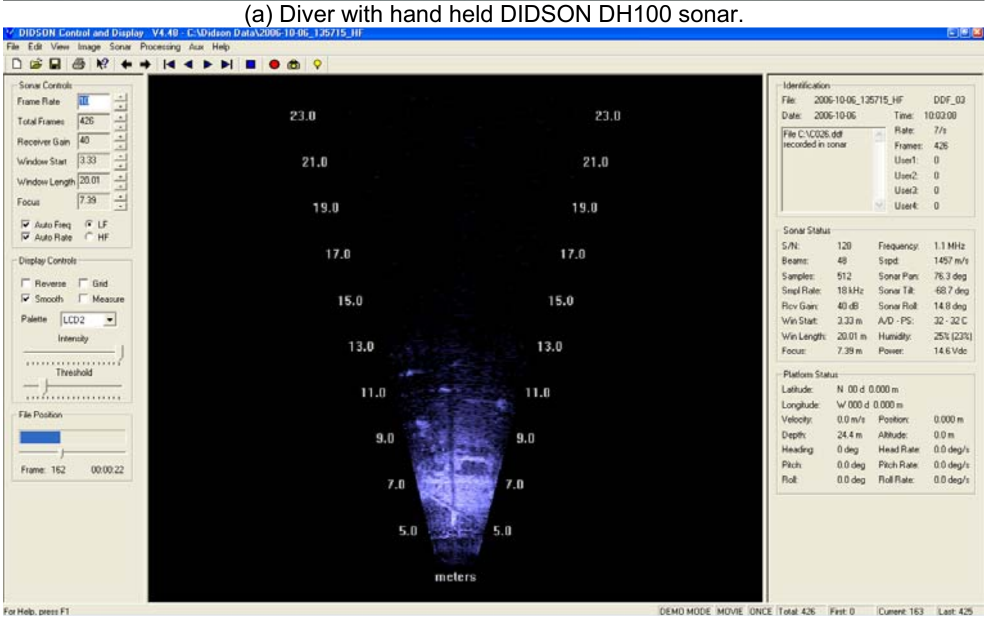
Operating Frequency	1.1 MHz
Beam width (two-way)	0.4° H by 14° V
Number of beams	48
Range	1m – 35 m

Initial trials indicated that for site visualisation (figure 3.9(b)) its application was very promising in poor visibility conditions compared to other techniques. However, considerable familiarisation and evaluation with the unit would be required for this application and was beyond the scope of the current work.

Figure 3.8: Divers conducting conventional survey on SMS Brummer.



(a) Diver with hand held DIDSON DH100 sonar.



(b) Captured frame of DIDSON visualisation of SMS Brummer.

Figure 3.9: DIDSON DH100 hand held sonar was trailed for its possible application in site survey.

4 Results

The position of the Scheduled site are shown in figure 4.1. All but the SMS Karlsruhe lie on the east side of Cava.

4.1 Battleships

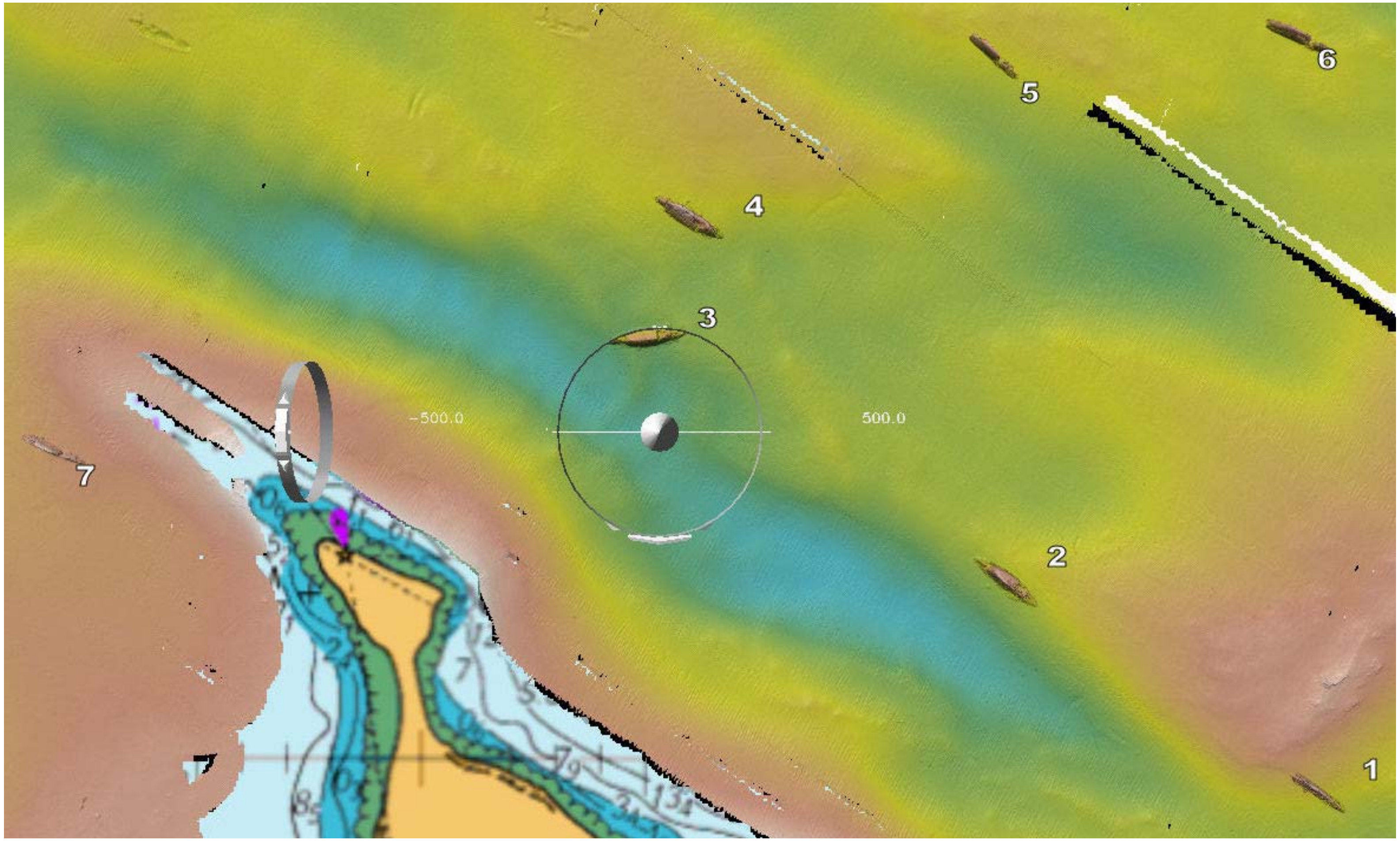
The three battleships SMS Markgraf, SMS König and SMS Kronprinz Wilhelm were König class battleships with a length of 175 metres, nominal draught of 8.3m and nominal displacement of 25,797 tonnes. Visualisations, using data from the 2001 and 2006 surveys of are shown in Figures 4.2 – 4.4 respectively. At this scale fine detail is not apparent. However several key points can be noted:

- All three are almost completely upside down with their superstructure (figure 4.5) impacted into the seabed,
- In all three vessels the hull has broken just forward of the forward gun turret and the bow settled to the seabed,
- Extensive salvage work has taken place in the area of the hull over the engine compartments, more so in the case of the SMS König.

Despite the depth to the seabed the battleships are popular dives as it is possible to see the casement guns (figure 4.6) and main turrets. Many divers also conduct penetration dives due to the many entry points. However, several divers have reported that assess ways previously regularly used are no longer accessible while others have appeared, indicating settlement of the hull as a whole.

Although much of the hull condition at these sites can be attributed to salvage works, general deterioration has occurred since. Figure 4.7 show plate corrosion resulting in loss of material (a) and separation of the plates (b). Plate separation is most likely due to a combination of corrosion and physical strain placed on the riveted joints as the structure settles.

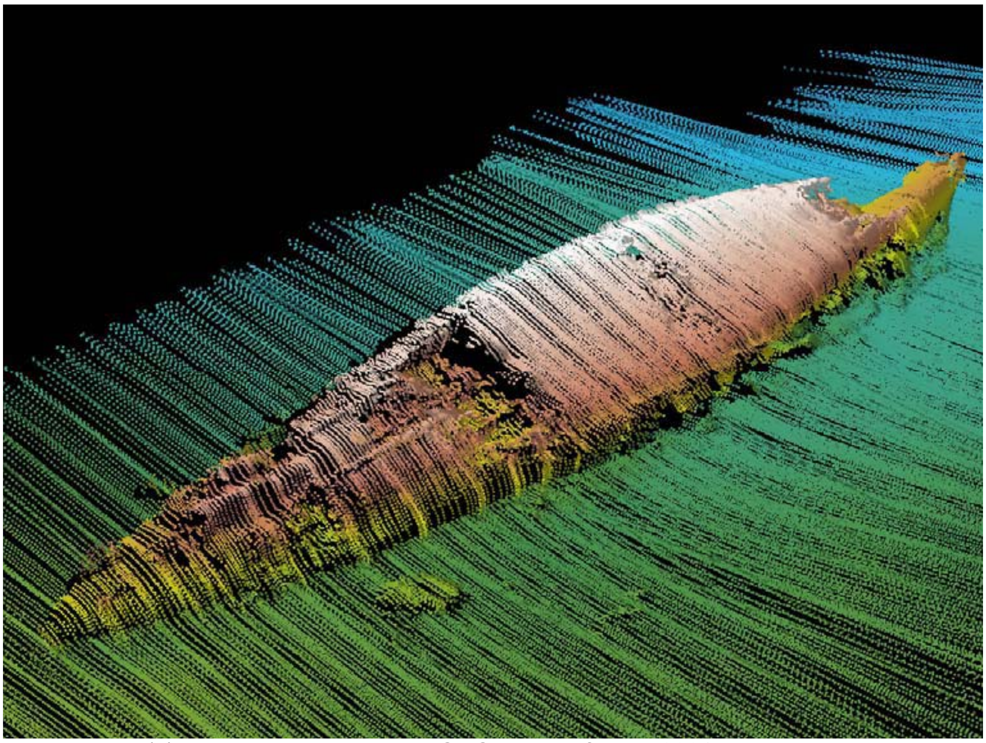
The majority of the surfaces are covered in a layer of encrusting marine growth which can afford a degree of protection to the underlying metal, limiting the corrosion processes. However, once removed either by natural or anthropogenic processes corrosion can take place. Figure 4.7(a) clearly shows the heavy encrusting marine growth that covers the wreck structure with corrosion only visible at the outer edge where this has been removed. Figure 4.7(b) on the other hand shows the degree of corrosion that occurs once this has been removed.



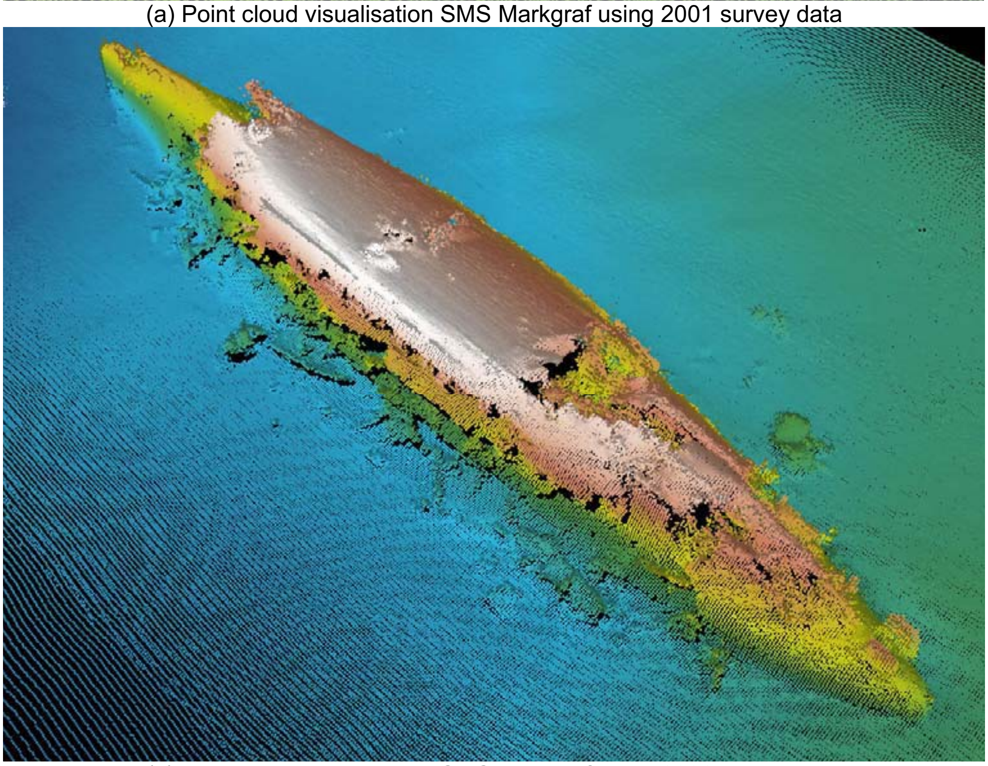
1 SMS Dresden | **2** SMS König | **3** SMS Markgraf | **4** SMS Kronprinz Wilhelm

5 SMS Brummer | **6** SMS Cöln | **7** SMS Karlsruhe

Figure 4.1: Relative position of the Scheduled sites.

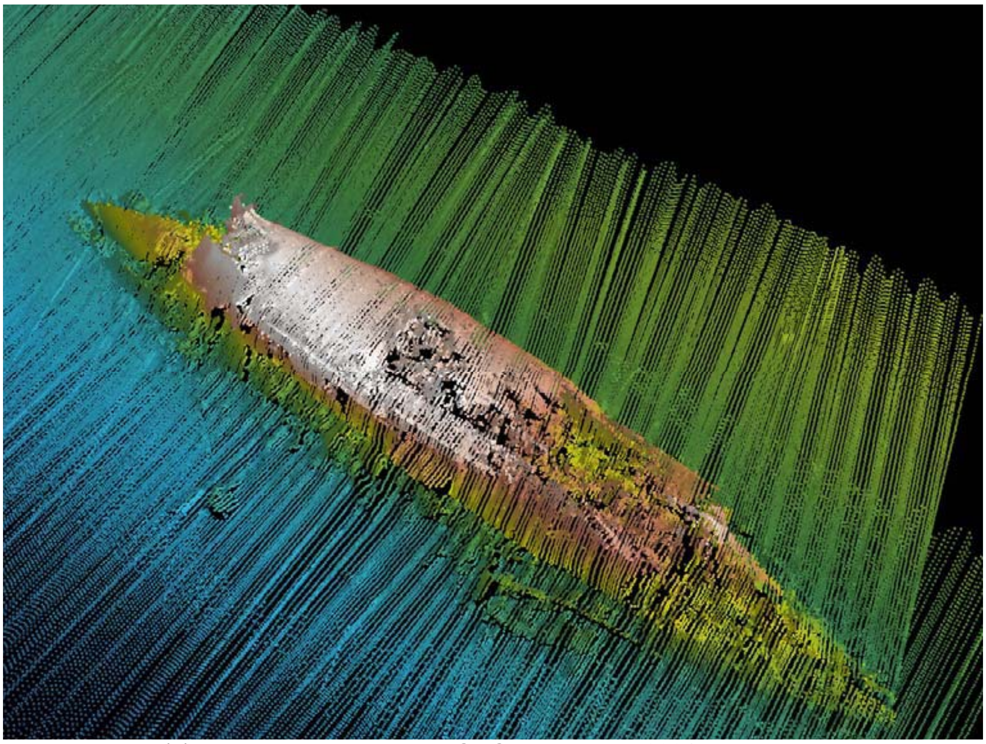


(a) Point cloud visualisation SMS Markgraf using 2001 survey data

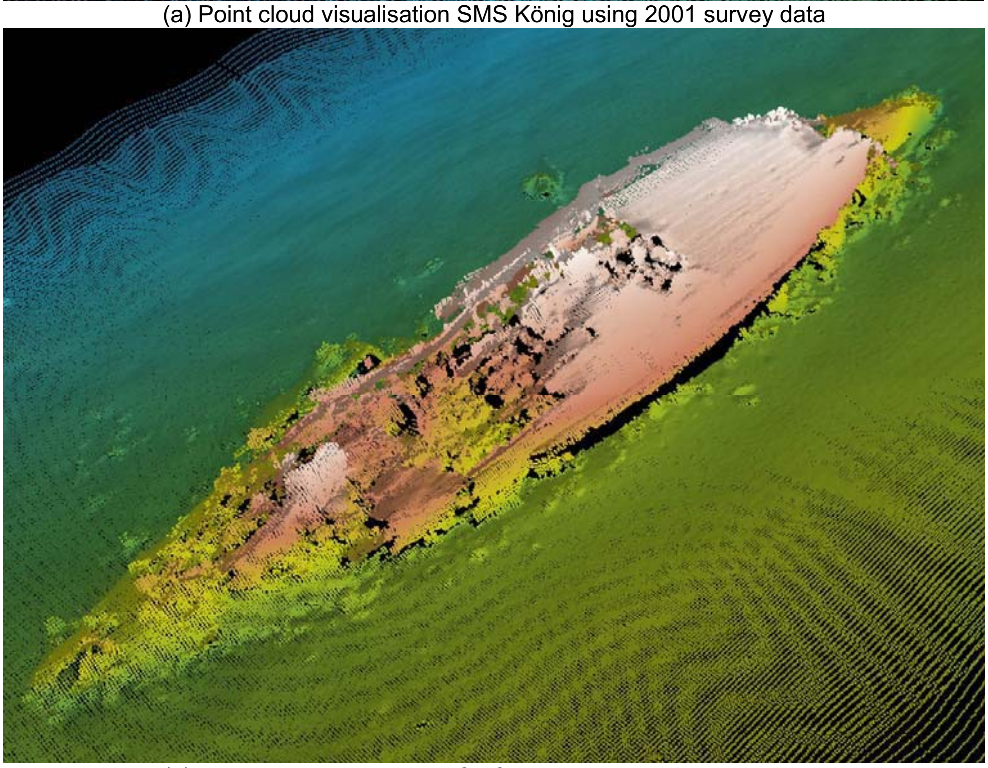


(b) Point cloud visualisation SMS Markgraf using 2006 survey data

Figure 4.2: Point cloud visualisation SMS Markgraf using 2001 & 2006 survey data.

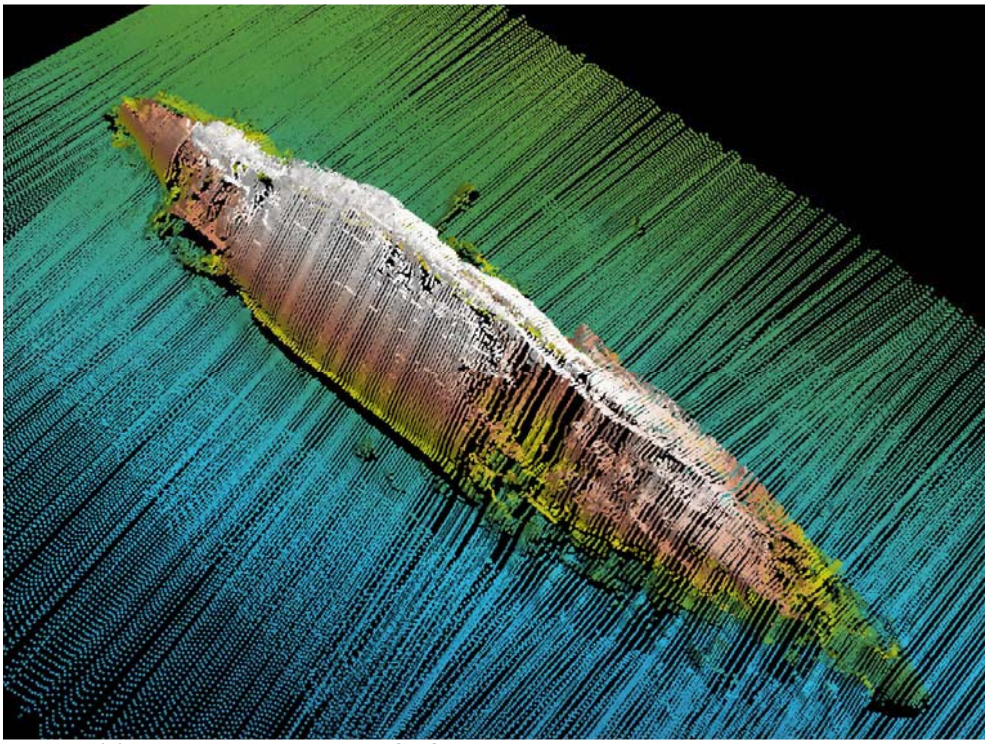


(a) Point cloud visualisation SMS König using 2001 survey data

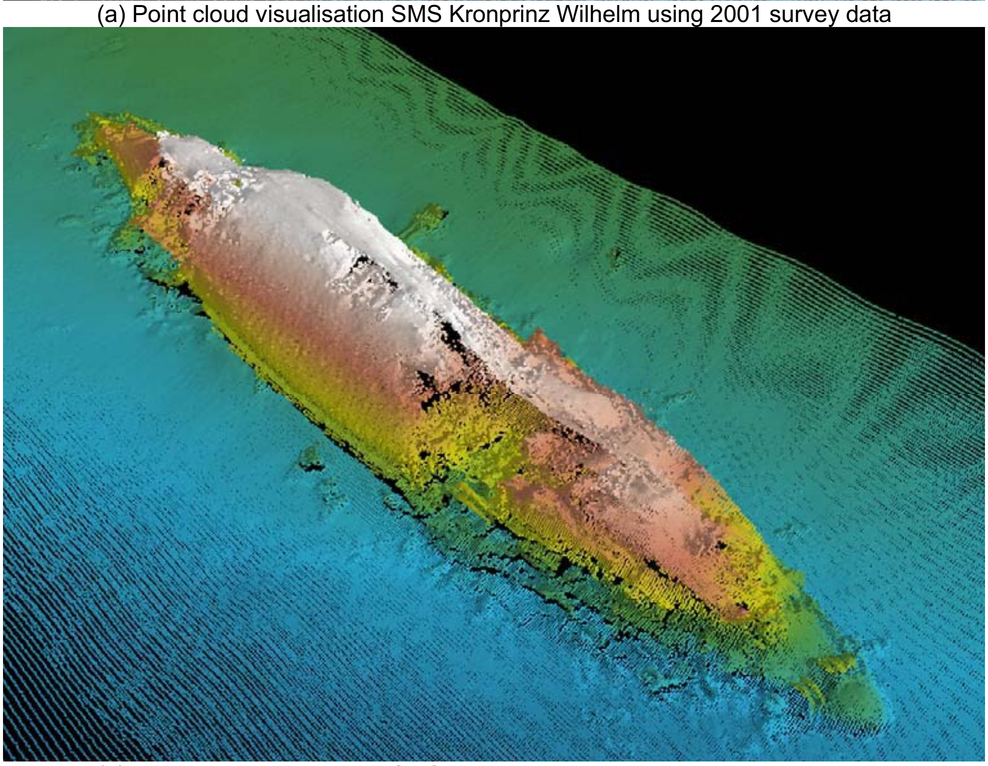


(b) Point cloud visualisation SMS König using 2006 survey data

Figure 4.3: Point cloud visualisation SMS König using 2001 & 2006 survey data.



(a) Point cloud visualisation SMS Kronprinz Wilhelm using 2001 survey data



(b) Point cloud visualisation SMS Kronprinz Wilhelm using 2006 survey data

Figure 4.4: Point cloud visualisation SMS Kronprinz Wilhelm using 2001 & 2006 survey data.

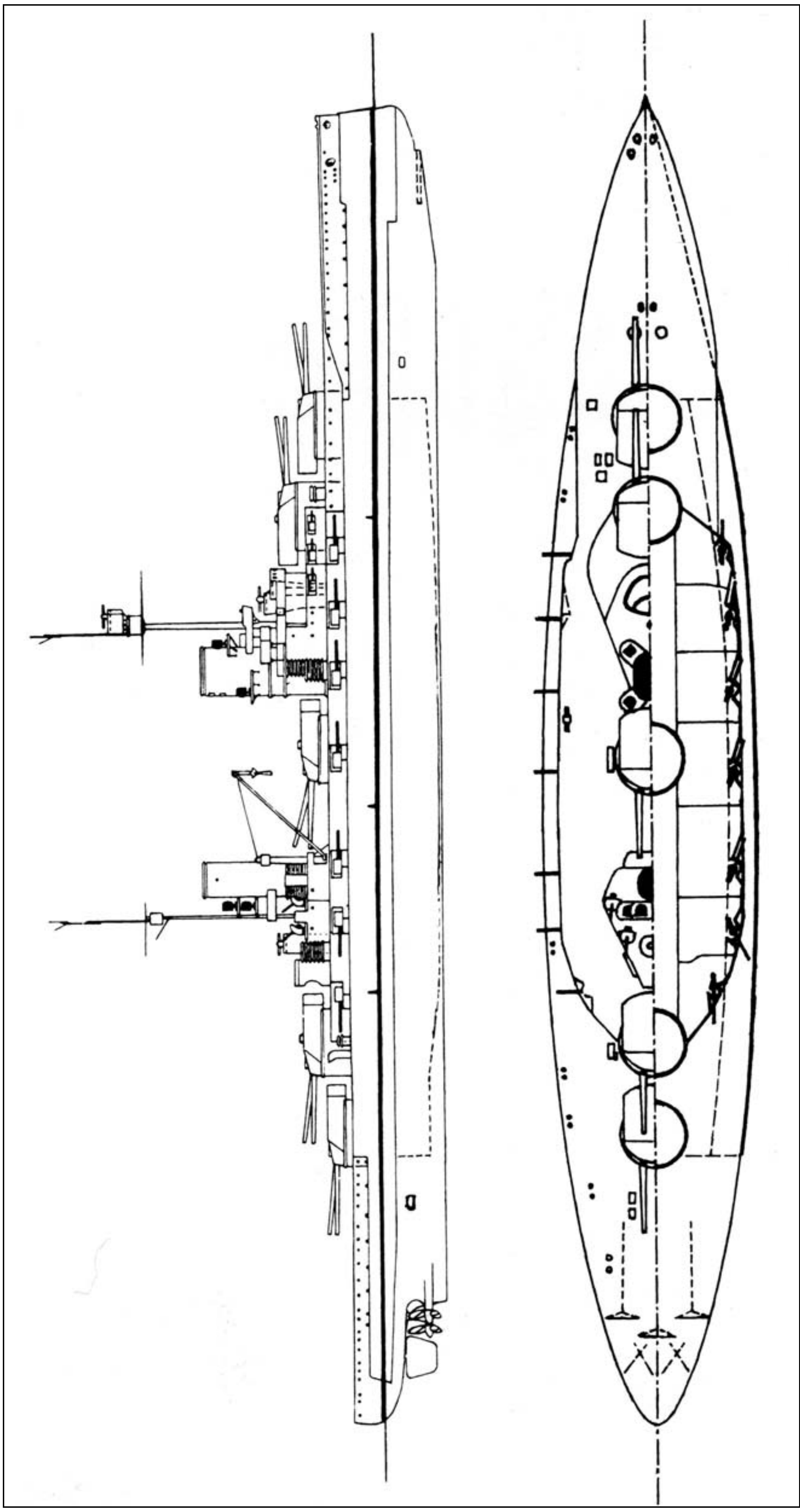


Figure 4.5: Schematic of König class battleship.

Figure 4.6: Mosaic of casement gun on the SMS Kronprinz Wilhelm.

(a) Plates corrosion on SMS Kronprinz Wilhelm

(b) Plate separation and corrosion SMS Kronprinz Wilhelm

Figure 4.7: Images showing general deterioration on the battleships sites.

4.2 Light Cruisers

Visualisations, using data from the 2001 and 2006 surveys for the four Scheduled light cruisers are shown in Figures 4.8 – 4.11. In comparison to the battleships all four lie on their side and are immediately recognisable as warships. The SMS Cöln, SMS Karlsruhe and SMS Brummer lie on their starboard side while the SMS Dresden is on her port side. Table 4.1 gives the specifications of the vessels.

Table 4.1: Light cruiser specifications. [4.1]

Name	Class	Built	Displacement (tonnes)	Length (m)	Breadth (m)	Draught (m)
Cöln	Cöln	1915-18	5620	155.5	14.2	6.43
Dresden	Cöln	1916-18	5620	155.5	14.2	6.43
Karlsruhe	Kongsberg	1915-16	5440	151.4	14.2	6.32
Brummer	Brummer	1915-16	4385	140.4	13.2	6.00

As with the battleships extensive salvage works has taken place in the area of the engine rooms at all four site to remove non-ferrous metals. The sections fore and aft of the engine room remain relatively intact. As can be seen in figure 4.9 salvage work on the SMS Karlsruhe has left the hull in a more broken up condition than the other three light cruisers.

However, it is also apparent, even from this starting point of significant salvage operations and at the scale represented here, that significant changes have taken place in all of the sites between 2001 and 2006.

SMS Cöln

During the 2001 survey divers conducted a detailed conventional survey of an area at the bow were the hull plates were corroding away exposing the inside of the vessel (figure 4.12(a)). During the same survey video mosaicking techniques were trialled as a rapid means of visualising sections of the wreck. An images of this area was constructed and the drawing used to verify the accuracy of a video mosaiced image (figure 4.12(b)). This area was again surveyed and the resultant mosaic is shown in figure 4.12(c).

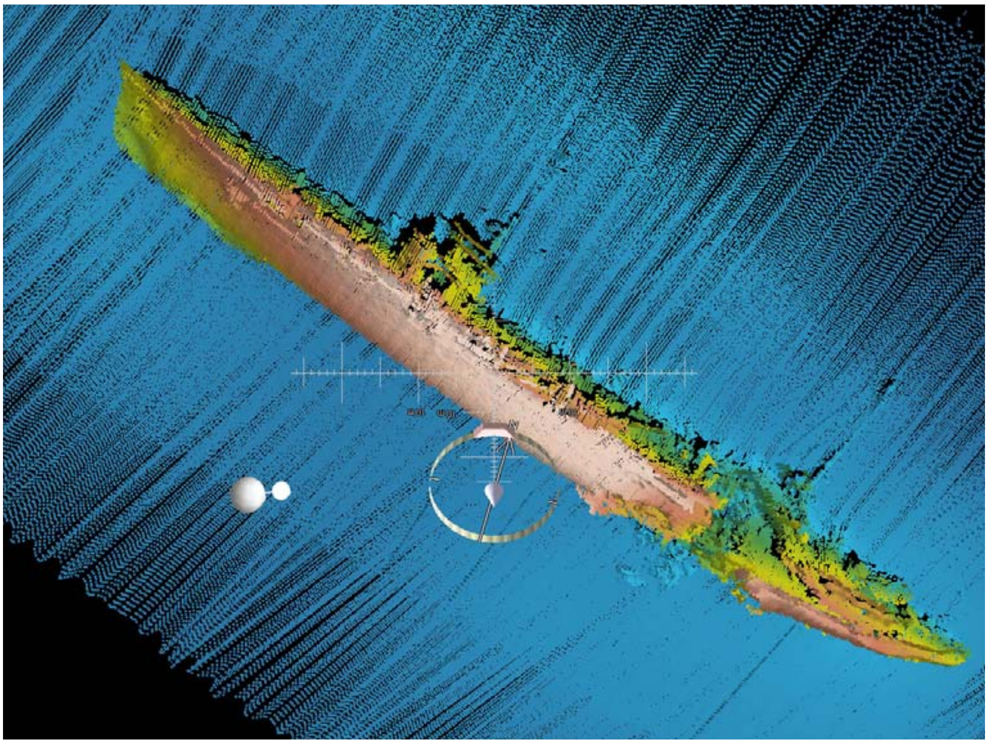
Comparison of the 2001 and 2006 video mosaics show that:

- The overall area of corrosion has increased
- The plate spanning the supports in the centre of the image has reduced in size
- The support to the right of the plate has collapsed
- The hole at the top right of the image has significantly increased in size

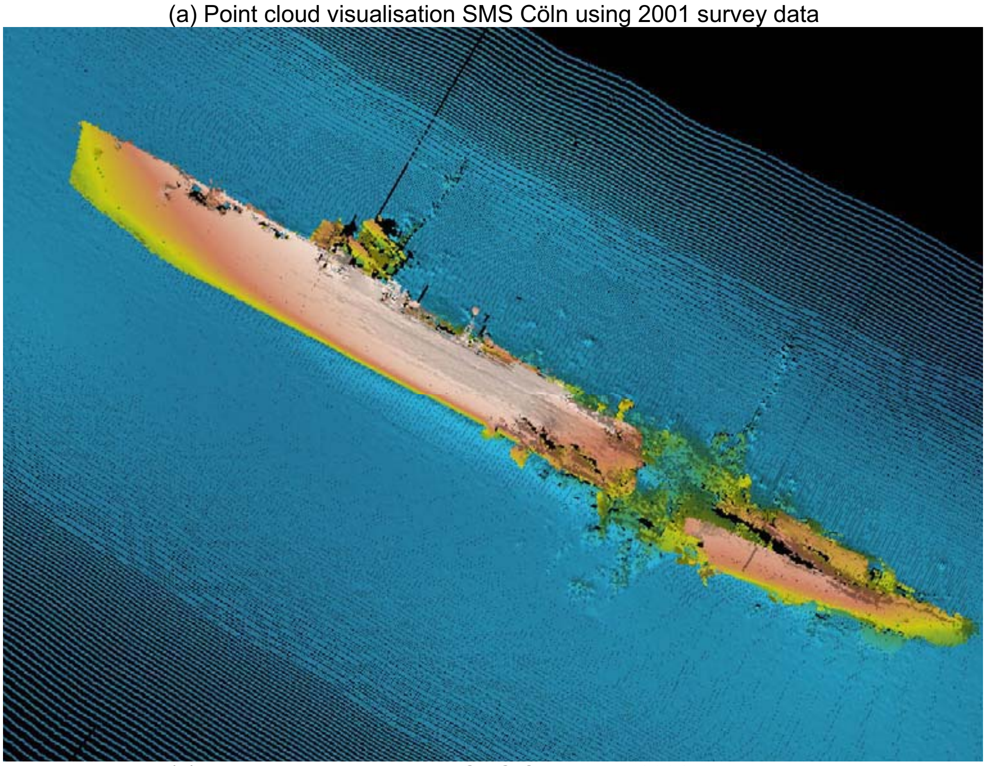
In addition the area immediately forward of this has also increased in size and several of the adjacent deck plates have fallen to the seabed. The area of the hull behind the bridge also shows signs of deterioration. Figure 4.13 shows a section of overlapping plates and the associated encrusting marine growth. On the right of the image the marine growth is undisturbed with no apparent corrosion present. On the left of the image the plates have begun to separate due to settlement of the hull resulting in loss of the marine growth protection, and corrosion is apparent.

Figure 4.14 also shows corrosion at an already active site of deterioration. However, it would appear in this case a section of the plate adjacent to the already formed hole has been corroding away and has then been folded back. It can be seen that the marine growth on the two underlying supports is less nearer the hull plates indicating these were covered and restricted growth. In addition, there is a straight fold line on the section lying on the hull. As there is no wave action or significant current on the wrecks this could only be the result of diver activity. The possible causes are:

- An attempt to shot the wreck catching the edge and pulling it over as the shot is pulled;
- A diver inadvertently snagging equipment on the edge and pulling it over;
- Exhaled gas from a diver inside the wreck can accumulate in large pockets, if these escape suddenly they can damage weakened areas;
- A diver deliberately pulling the section back to allow access.

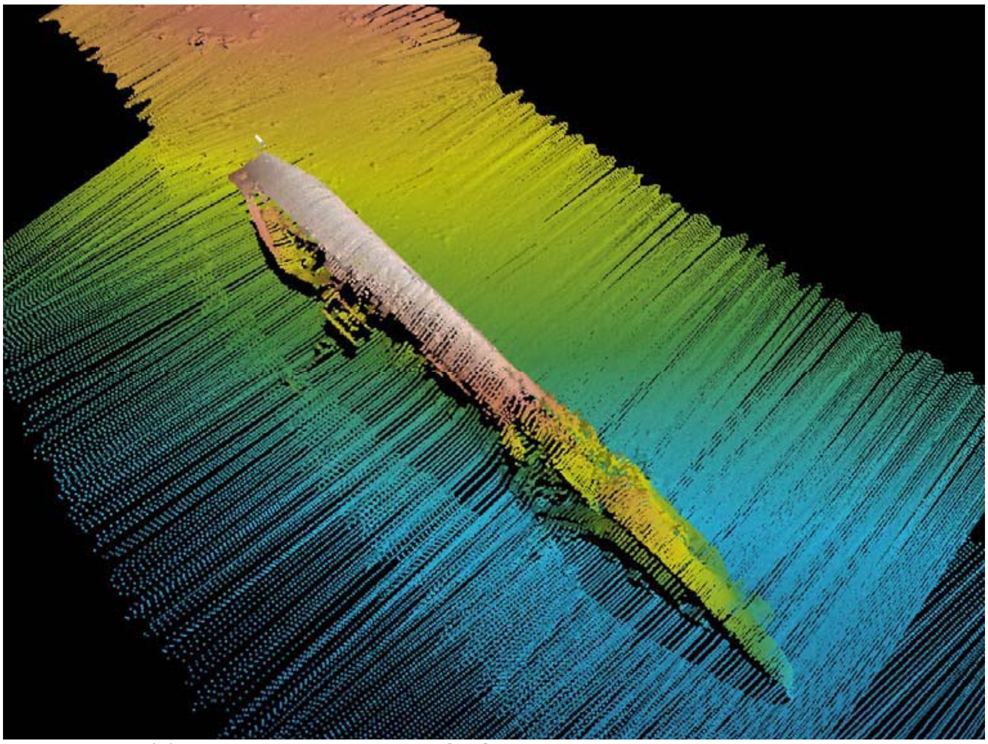


(a) Point cloud visualisation SMS Cöln using 2001 survey data

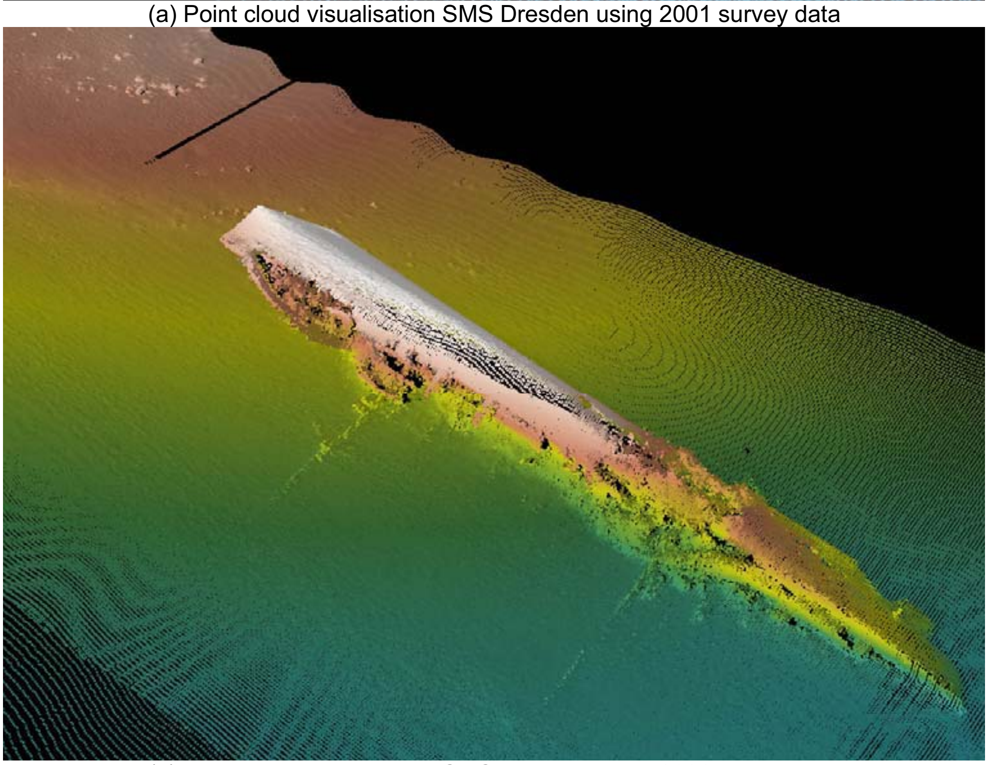


(b) Point cloud visualisation SMS Cöln using 2006 survey data

Figure 4.8: Point cloud visualisation SMS Cöln using 2001 & 2006 survey data.

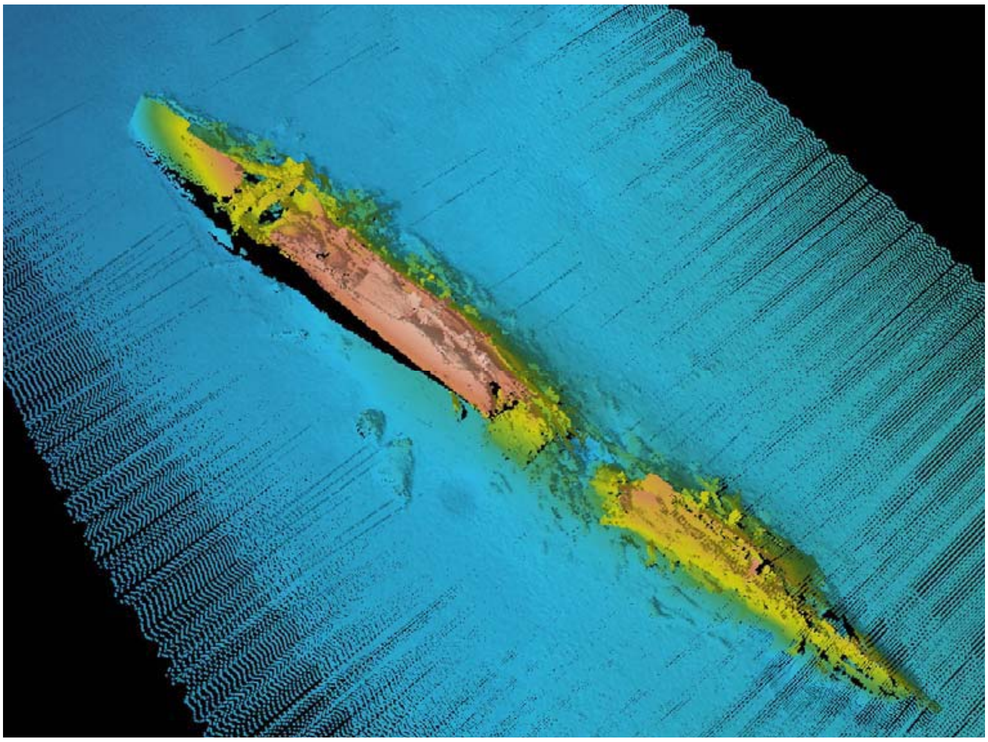


(a) Point cloud visualisation SMS Dresden using 2001 survey data

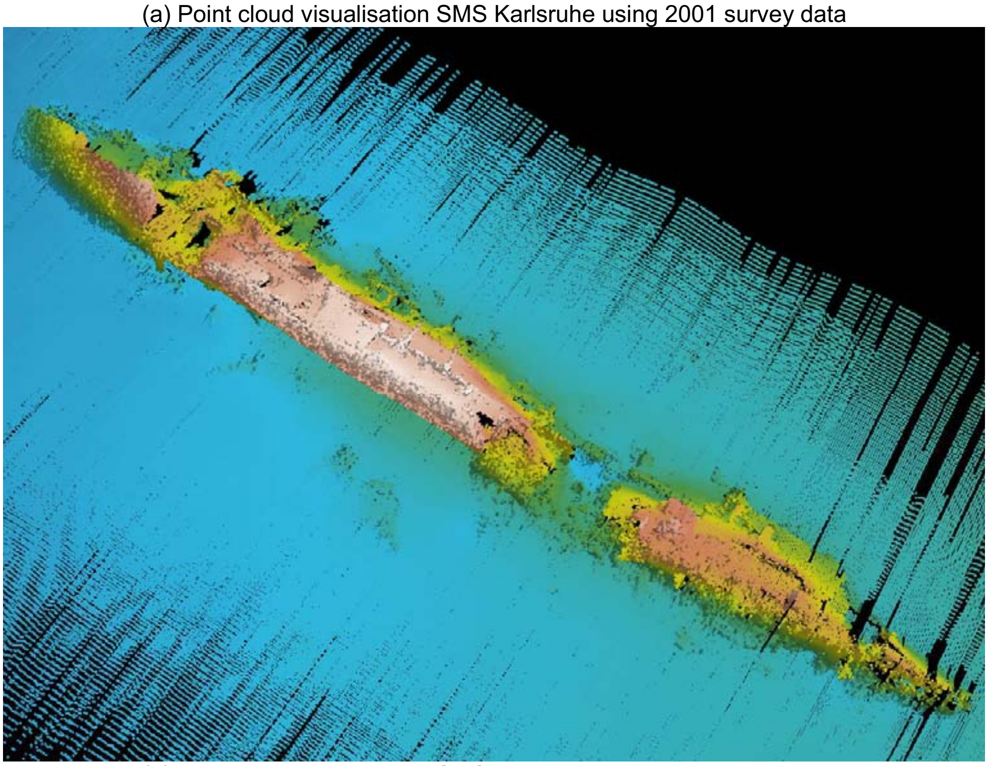


(b) Point cloud visualisation SMS Dresden using 2006 survey data

Figure 4.9: Point cloud visualisation SMS Dresden using 2001 & 2006 survey data.

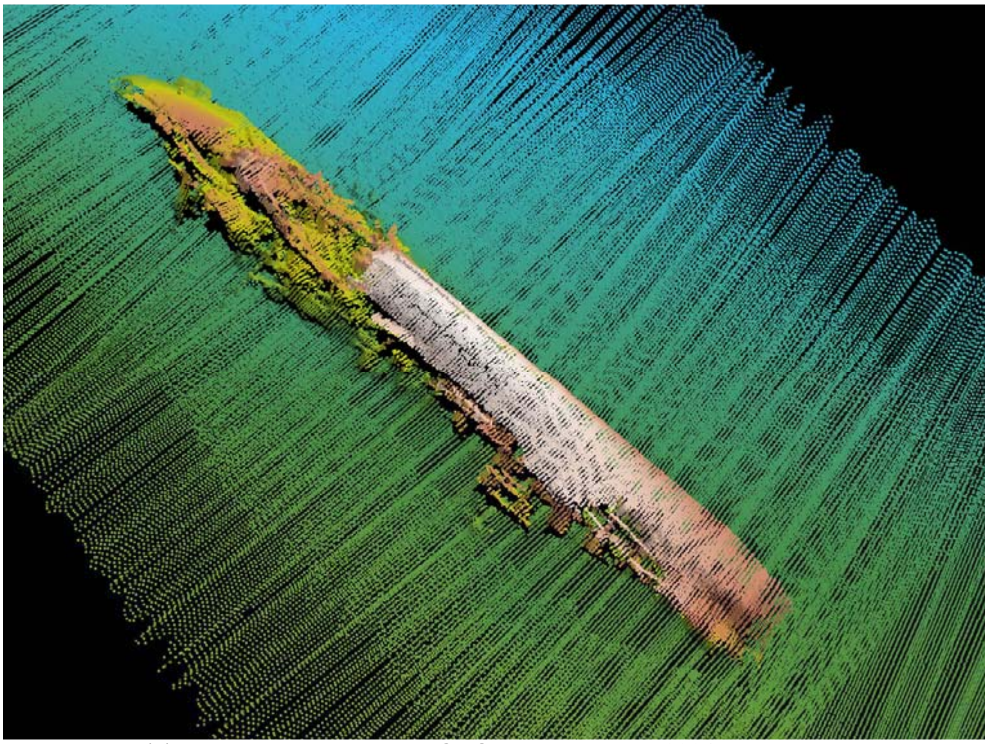


(a) Point cloud visualisation SMS Karlsruhe using 2001 survey data



(b) Point cloud visualisation SMS Karlsruhe using 2006 survey data

Figure 4.10: Point cloud visualisation SMS Karlsruhe using 2001 & 2006 survey data.


(a) Point cloud visualisation SMS Brummer using 2001 survey data

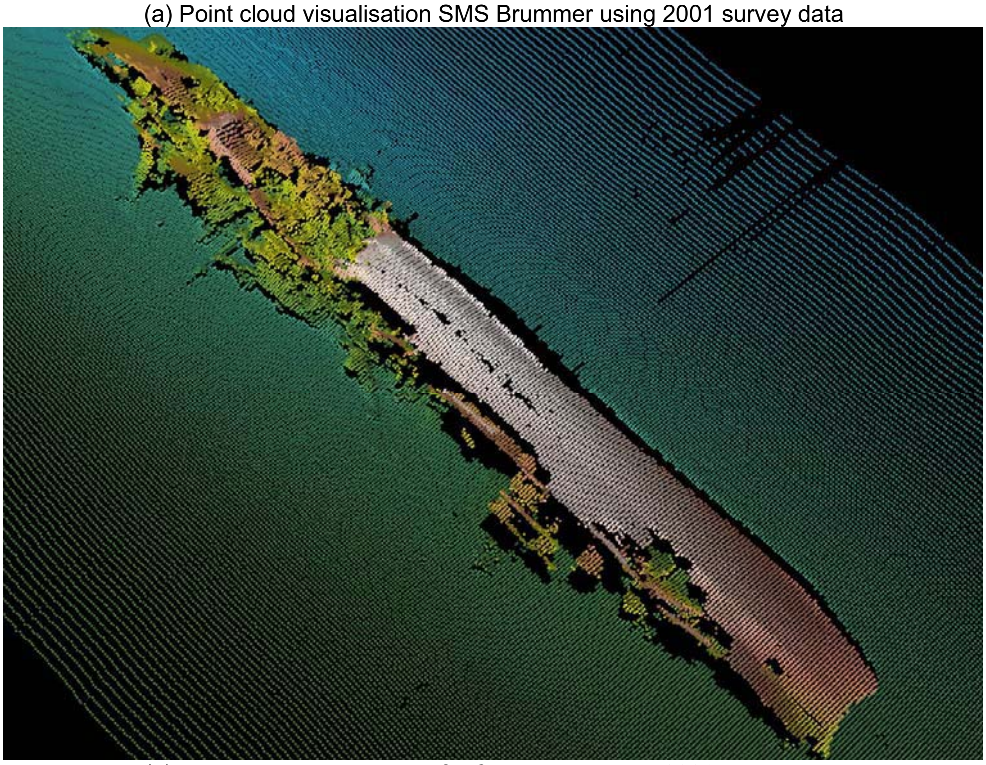
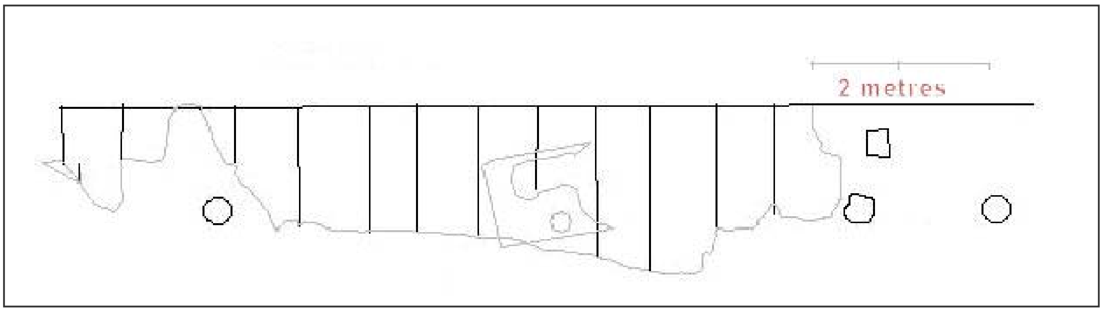
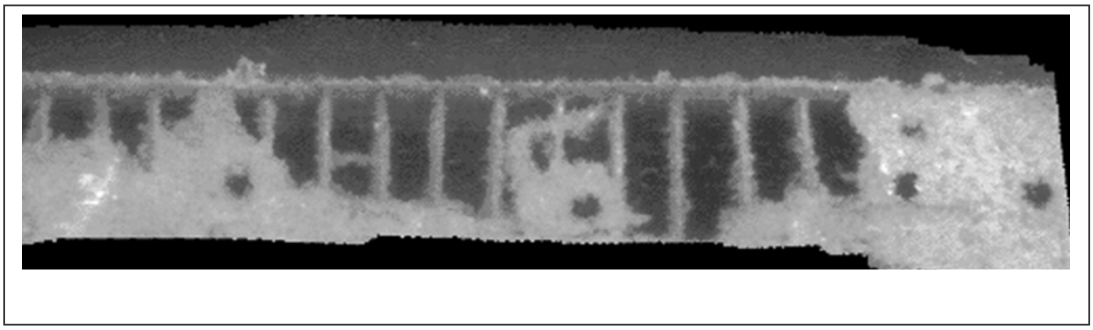

(b) Point cloud visualisation SMS Brummer using 2006 survey data

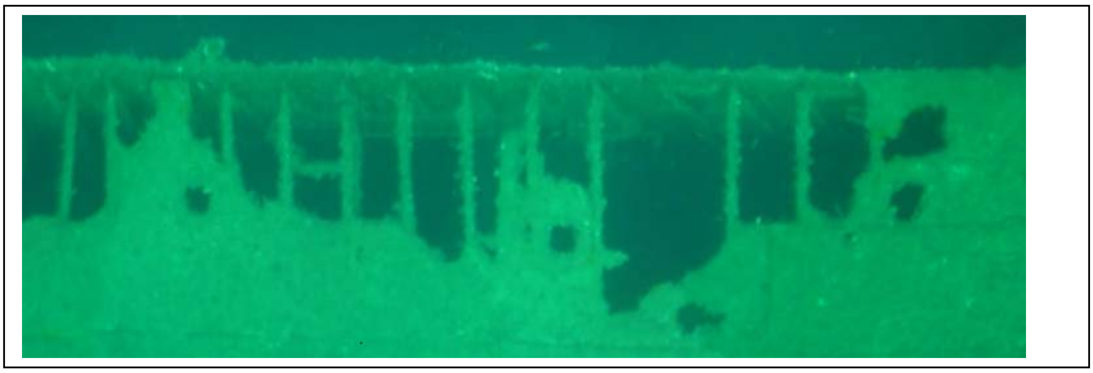
Figure 4.11: Point cloud visualisation SMS Brummer using 2001 & 2006 survey data.



(a) 2001 drawing of corroding area on port side of hull of SMS Cöln forward of bridge.



(b) 2001 video mosaic of corroding area on port side of hull of SMS Cöln forward of bridge.



(c) 2006 video mosaic of corroding area on port side of hull of SMS Cöln forward of bridge.

Figure 4.12: Comparison of corroding area on port side of hull of SMS Cöln forward of bridge. 2001 scale drawing from conventional survey (a), 2001 video mosaic (b), and 2006 video mosaic (c).

***Figure 4.13*:** Image of overlapping hull plates on SMS Cöln showing corrosion where plates have separated.

Figure 4.14: Image showing piece of corroded plate “pulled back”.

SMS Dresden

In September 1994 it was noted that a split had developed along the starboard edge between the main deck and hull from the bow back towards the bridge. At the start of the following diving season this had increased to several metres separation. However, the capstans and their mechanisms were in effect preventing this increasing further. In the 2001 survey the main deck had separated still further and in the process pulled the underlying decks with it. In the 2006 survey this was found to have settled slightly towards the seabed but is still attached at the bow. However the first set of plates along the hull in this area are beginning to detach from the adjacent row as they have little support (figure 4.15)

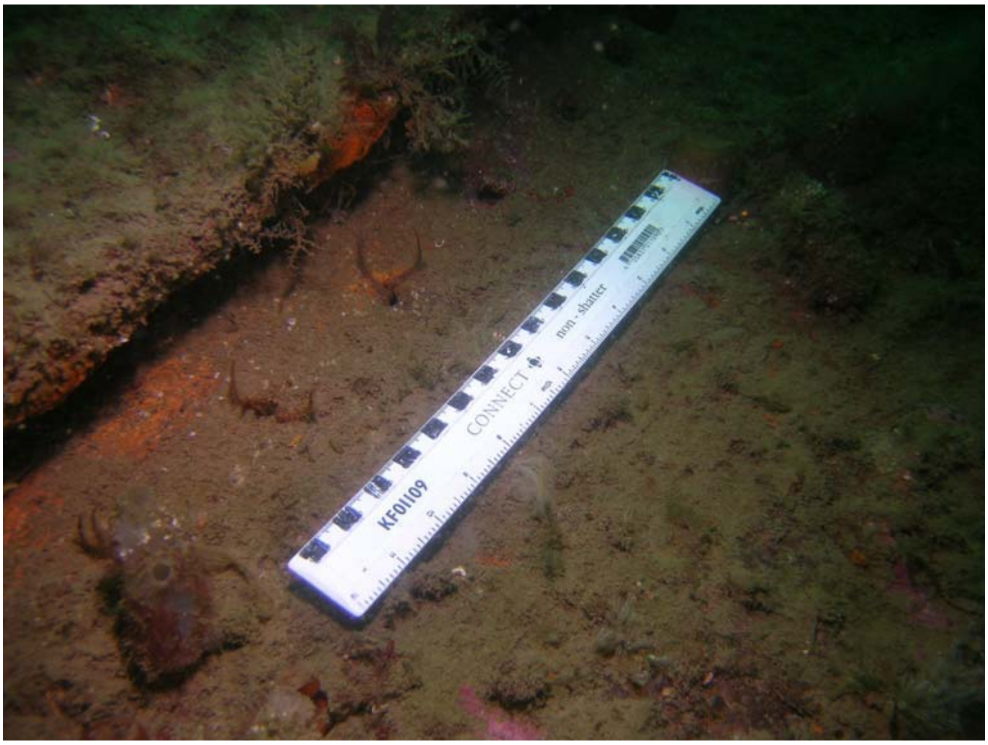


Figure 4.15: Plate separation at bow of SMS Dresden.

Other areas of the hull are also showing signs of stresses at plate overlaps as can be seen in figure 4.16. Figure 4.17 shows an area where corrosion has developed holes through the plates.

Underwater visibility was particularly poor on dives carried out at this site(figure 4.18). However, sufficient video was obtained at the stern of the vessel to construct a mosaic of the aft accommodation (figure 4.19). From figure 4.19 evidence of corrosion around the portholes, door frames and metal work itself is apparent.

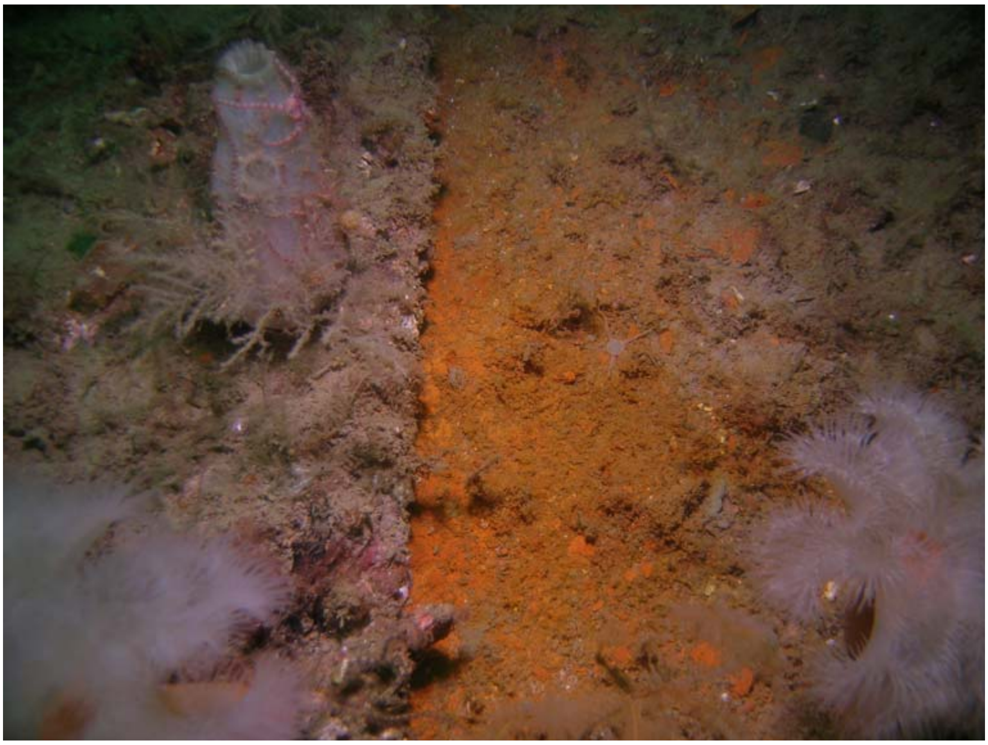


Figure 4.16: Corrosion along overlap indication plates beginning to separate.

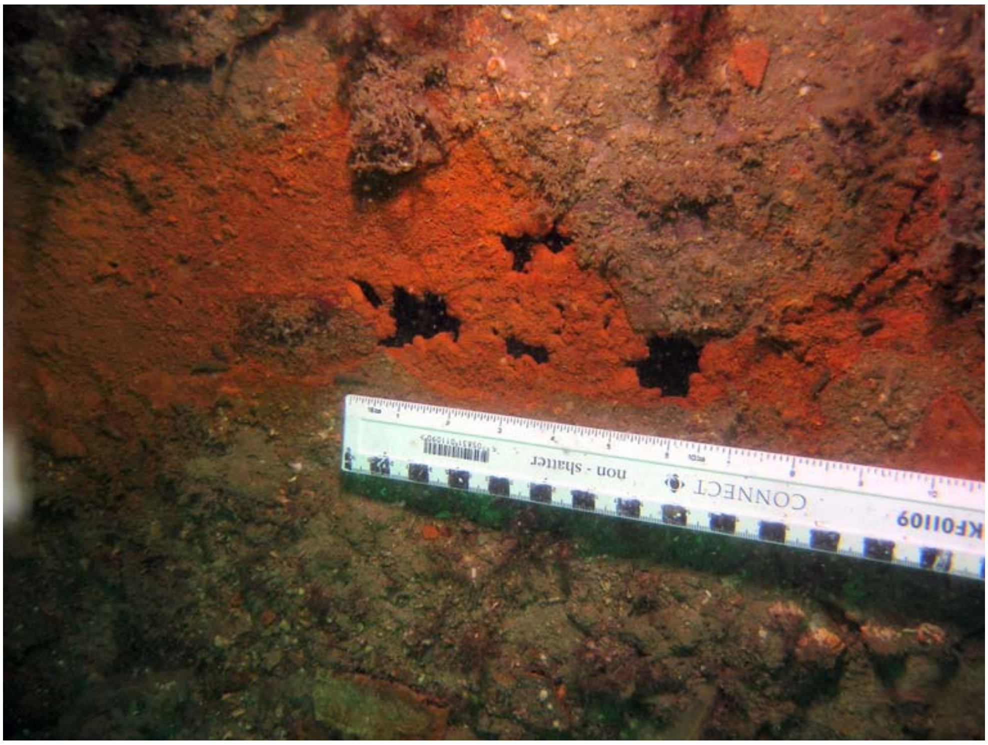


Figure 4.17: Holes beginning to develop in hull plates of SMS Dresden.

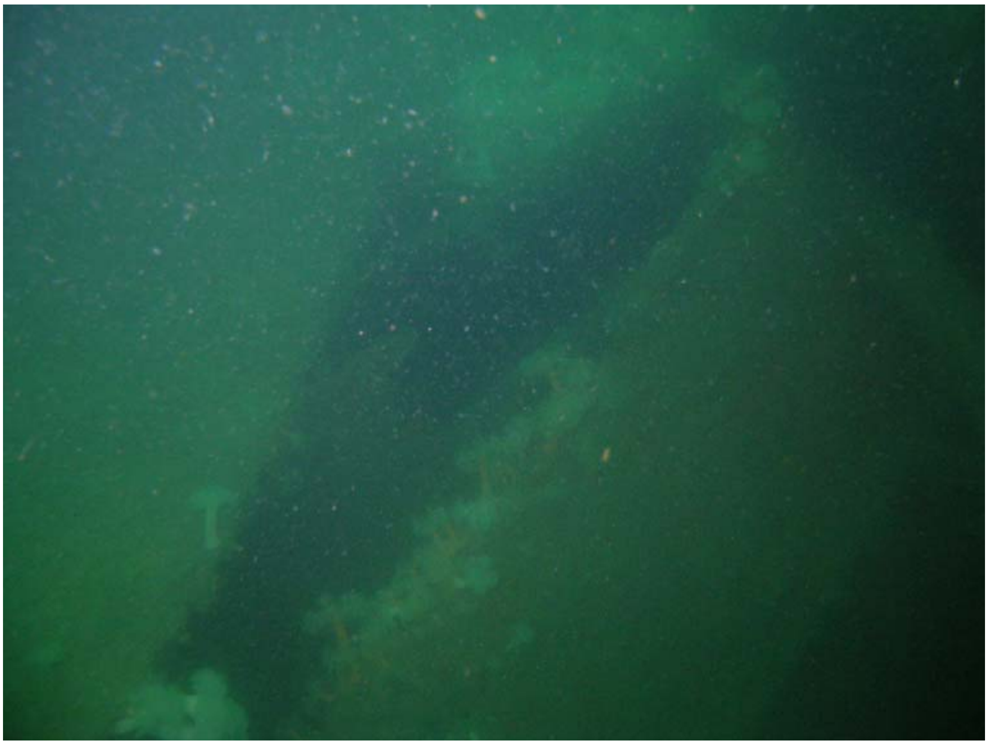


Figure 4.18: Photograph showing the level of phytoplankton in the water and consequent poor underwater visibility.

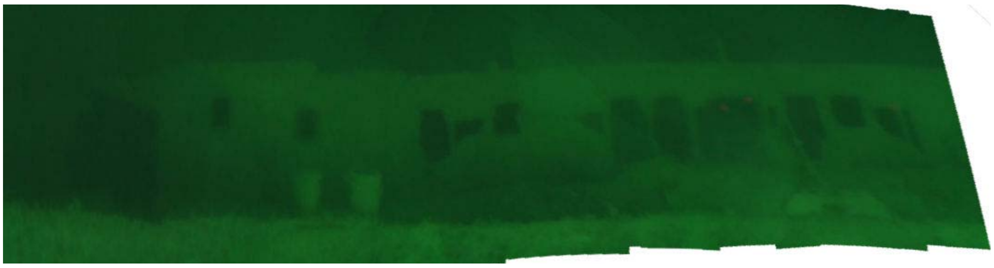


Figure 4.19: Video mosaic of accommodation section at stern of SMS Dresden.

SMS Karlsruhe

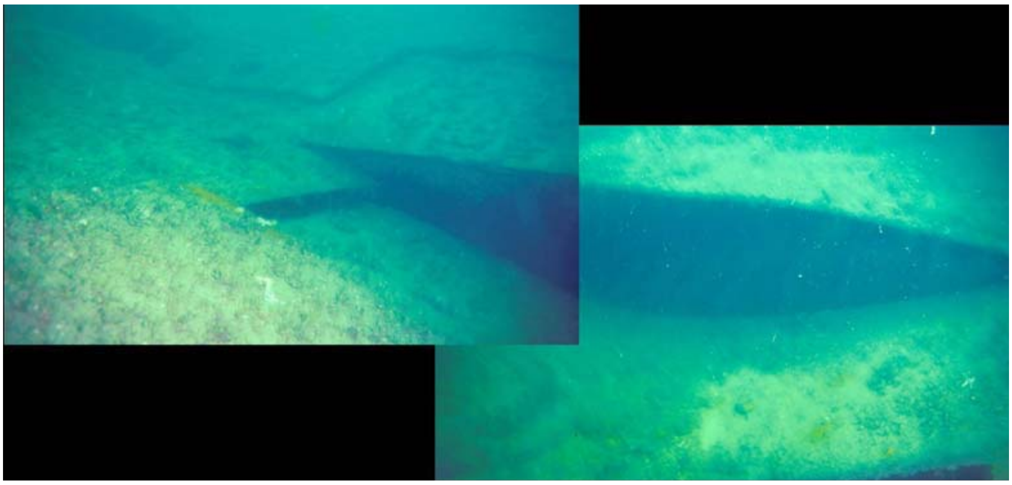
Of the four Scheduled light cruisers this site has undergone the most salvage with the superstructure collapsed to the seabed and the hull badly broken up. The strong vertical relief over short distances at this site results in significant acoustic shadows to make rendering of the data and visualisation problematic. This also presents problems in the video mosaicking process due to motion parallax and the relative distortion of features in adjacent frames.

Diver observations noted that the access used to gain entry for excavation of the postcards (see section 1) had become restricted indicating further settlement of the bow section.

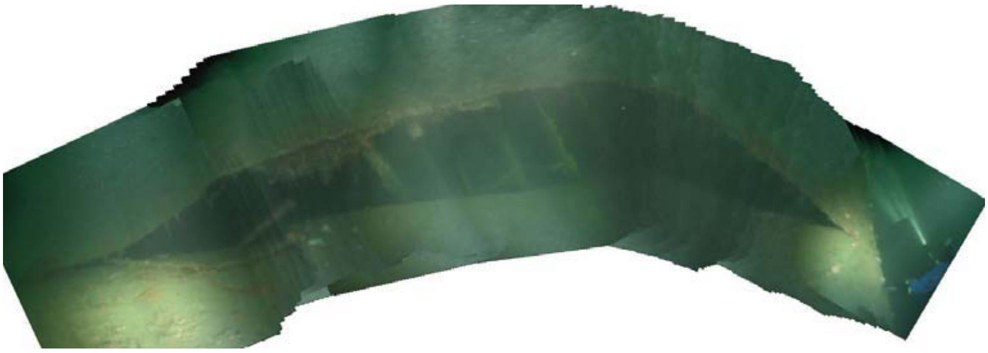
SMS Brummer

Comparison between figures 4.11 (a) & (b) show a number of changes to the site. Deterioration has taken place at the stern section. A section of plate which had started to “peel” away from the hull amidships has now hanging vertical. In 2004 the forward gun collapsed to the seabed pulling the main deck out wards and dislodging several plates. In addition this also resulted in several of the lower decks being pulled out. These changes are clearly visible in figures 4.11 (a) & (b) and are highlighted in section 6, figures 6.3 (a) & (b).

In 2001 it was noted that the plates on the starboard bow section had fallen to the seabed. The resulting loss of structure had caused the port bow section to start to collapse and the plates to separate as can be seen in figure 4.11(a) and the photomosaic, figure 4.20(a). In the 2006 survey this tear has increased in dimension and now extends from the bow itself back to main area of deterioration (figure 4.11(b)). The separation of the plates has sufficient vertical relief to present problems to the video mosaicking software. However, a reasonable result was obtained and shown in figure 4.20(b).



(a) Photo mosaic of separation of plates at bow of SMS Brummer, 2001



(b) Video mosaic of separation of plates at bow of SMS Brummer, 2006.

Figure 4.20: Comparison of the tear in the bow plate of the SMS Brummer, 2001 photomosaic (a), 2006 video mosaic (b).

4.3 Salvage Sites

The majority of the salvage areas of the battleships and battle cruisers are easily identified in the remote sensing data either by the remaining footprint on the seabed or the remains of scattered wreckage. The locations of these are shown in figure 4.21 and are listed in table 4.2. Figure 4.22 shows the position of the scuttled vessels prior to salvage operations commencing (reproduced by kind permission of the UKHO).

Table 4.2: Details of main salvage sites

Nº.	Site	Easting	Northing	Depth (m)	Description
8	Bayern	489769.63	6528774.62	35	Depression & Debris
9	Grosser Kurfürst	490205.63	6528631.20	31	Depression
10	Friedrick der Grosse	489315.94	6528614.14	34	Depression
11	König Albert	488808.82	6528091.26	38	Depression
12	Kaiserin	488620.68	6527648.60	35	Depression
13	Derfflinger	487948.50	6527745.44	40	Depression
14	Prinzregent Luitpold	488479.63	6527091.66	43	Depression
15	Kaiser	488907.42	6527104.22	26	Depression
16	Kaiser masts?	489171.89	6526956.43	21	Debris
17	Remains of destroyer	489246.03	6526281.91	19	Partial hull
18	Seydlitz	489463.80	6525532.56	20	Debris
19	Destroyer	489004.64	6525433.00	21	Debris
20	Destroyer	488976.24	6524957.69	20	Debris

The salvage sites most frequently dived are that of the SMS Bayern turrets and the SMS Seydlitz.

Although the barrels of the guns and a large proportion of the turrets are buried these are a popular dive, as they allow the diver a true impression of the shear size of the guns. Visualisations, using data from the 2001 and 2006 surveys are shown in figures 4.23(a) & (b). As there is little superstructure associated with these no difference can be seen between surveys.

The SMS Seydlitz is a popular second dive due to its shallower depth and the slight current means that there is often an abundance of encrusting marine life and fish as shown in figures 4.24(a) – (c). During a survey dive at this site, recreational divers were noticed fanning sediment away from a partially buried piece of debris, once uncovered the item was moved and a small quantity of oil was released from what was presumably a reservoir of some description.

The remaining salvage sites are also dived but due to the depth and lack of major features, on a less regular basis. The masts of the SMS Kaiser were also dived and discarded shot lines were noted. The mast of the SMS Grosser Kurfürst lies on the seabed at the edge of the depression

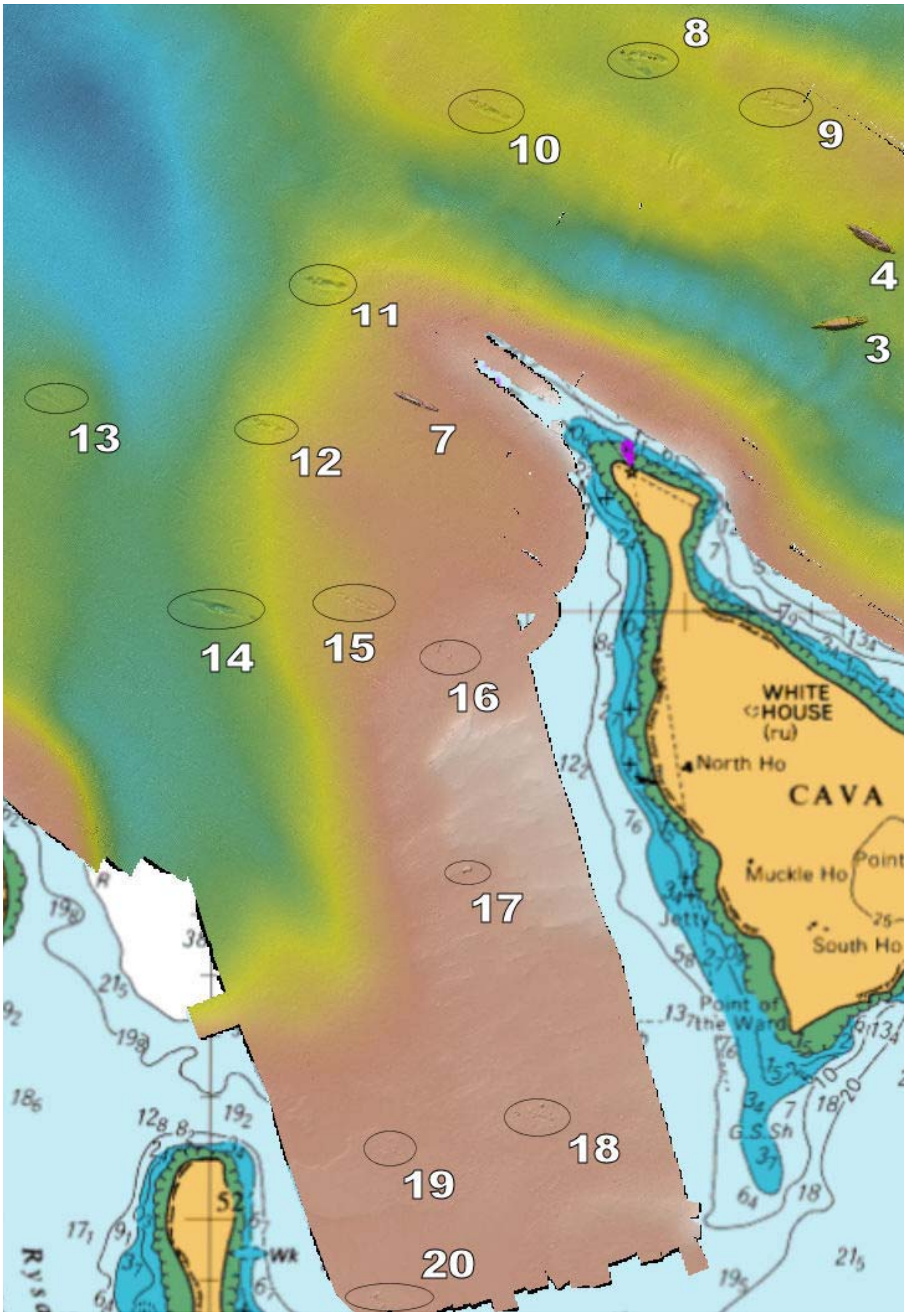


Figure 4.21: Bathymetry of the seabed data to the north and west of Cava where much of the salvage work took place. Salvage areas are recognisable as footprints or remaining debris.

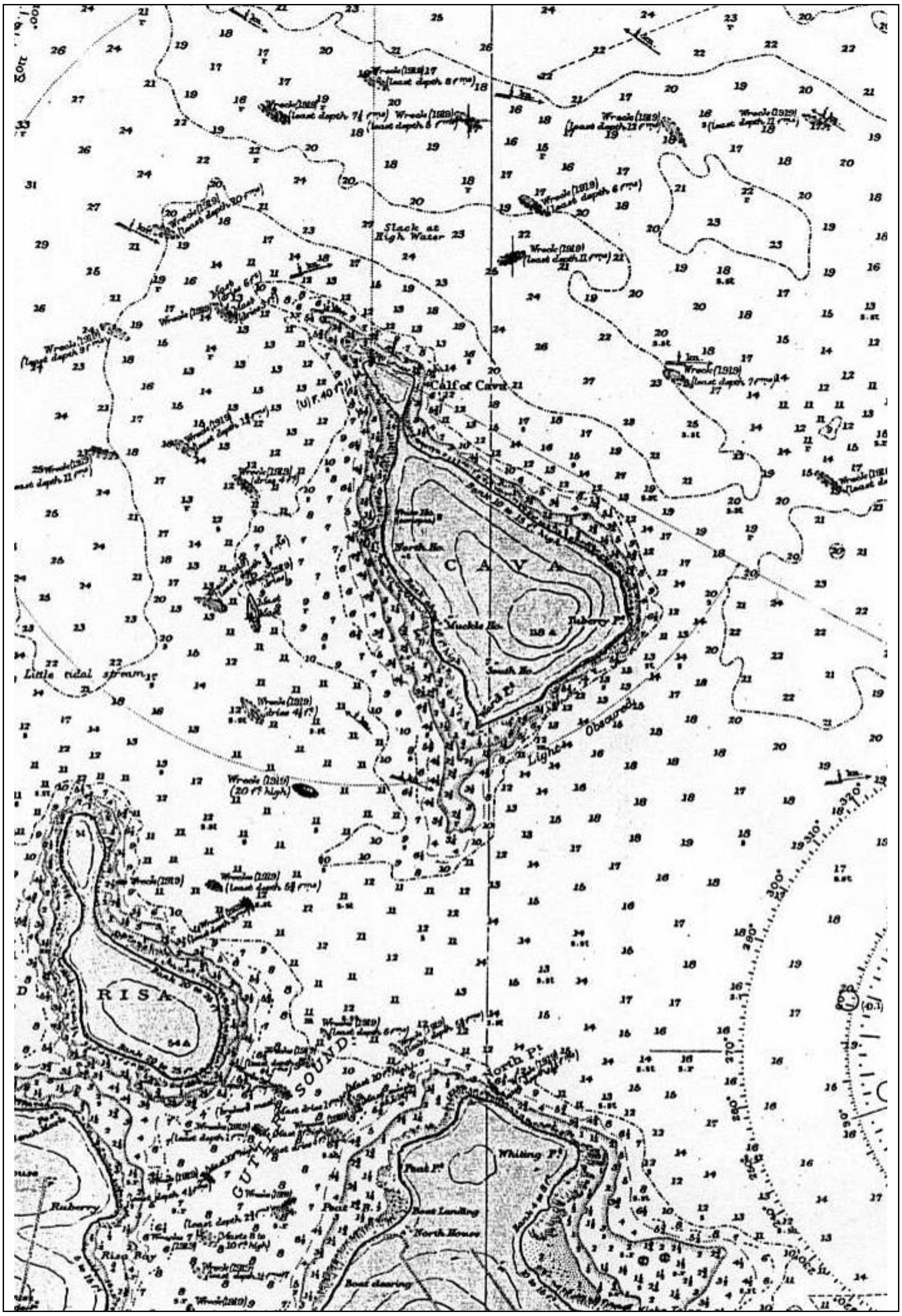
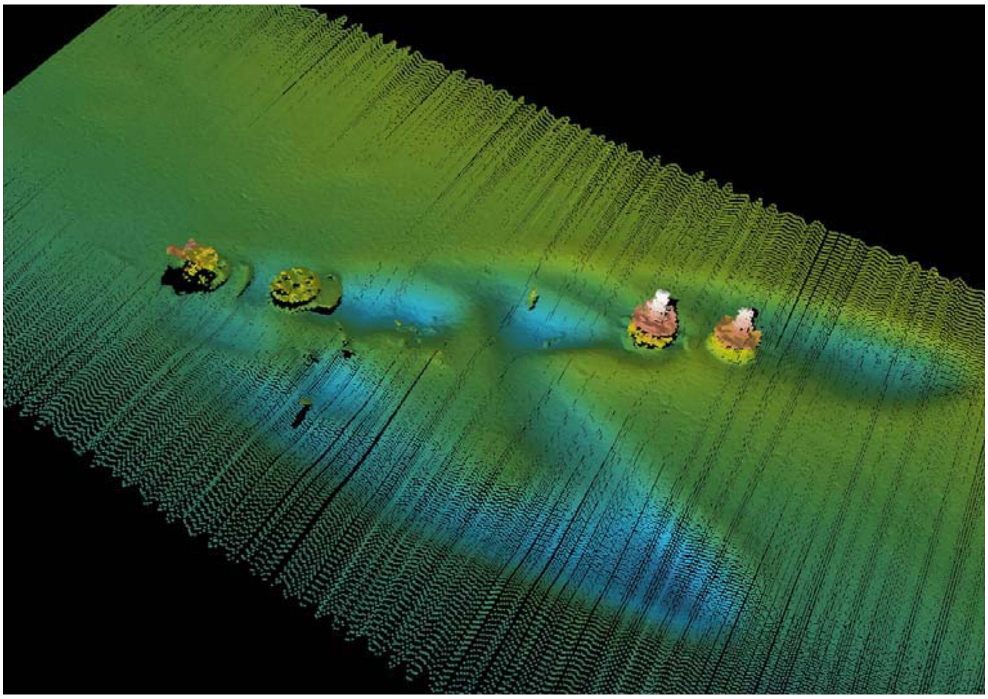
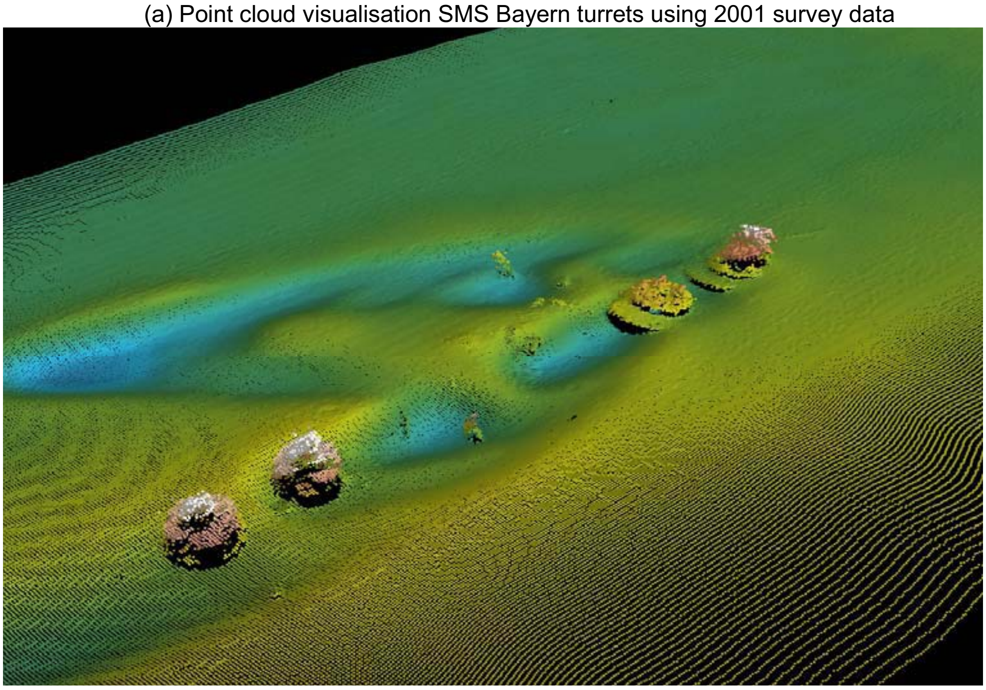


Figure 4.22: Hydrographic chart from 1921 with positions of scuttled vessels. [4.2]

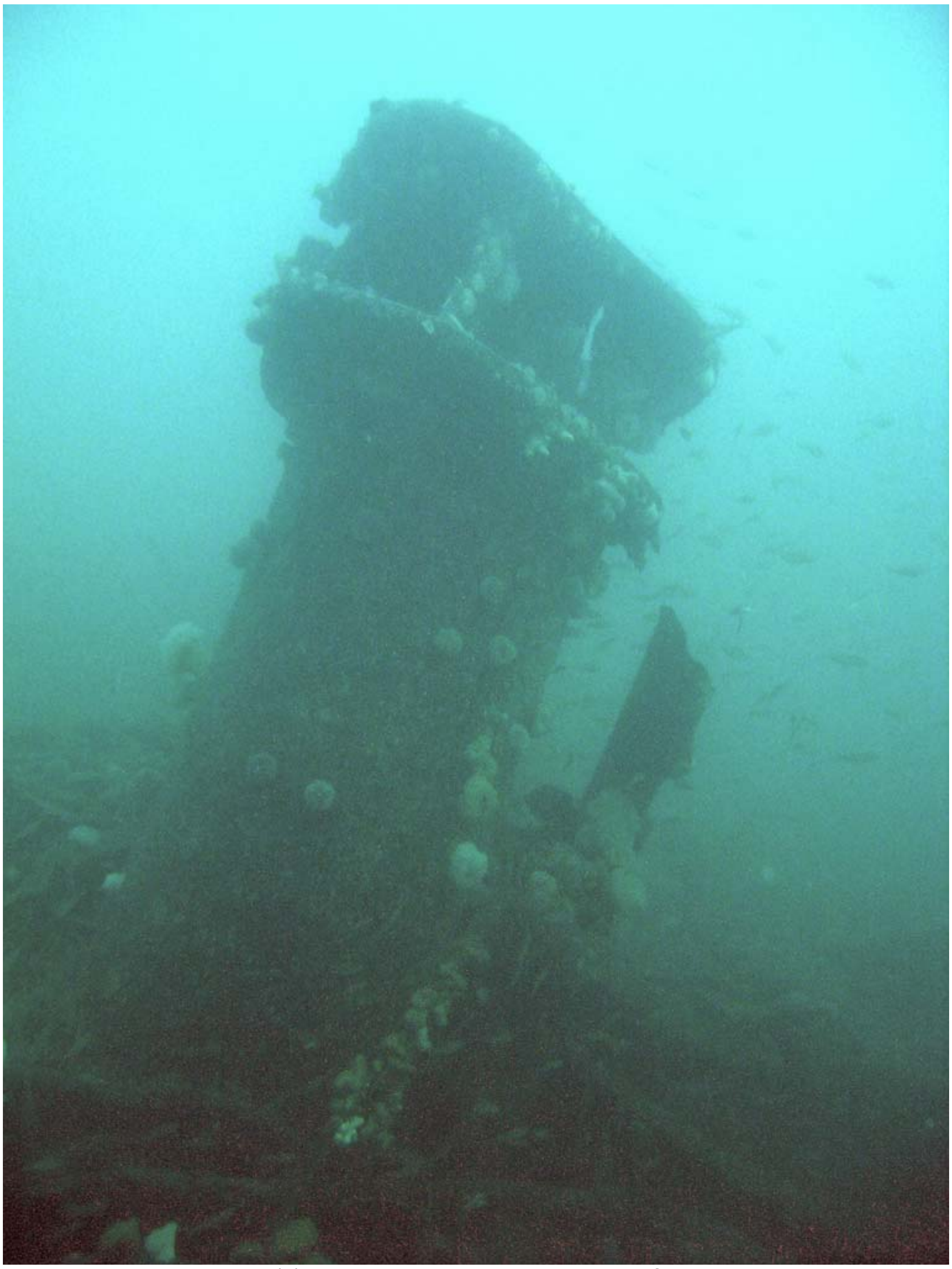


(a) Point cloud visualisation SMS Bayern turrets using 2001 survey data



(b) Point cloud visualisation SMS Bayern turrets using 2006 survey data

Figure 4.23: Point cloud visualisation SMS Bayern turrets using 2001 & 2006 survey data.



(a) Wreckage colonised with marine life.

(b) wreckage covered with the Plumose anemone *Metridium senile and* shoal of juvenile fish

(c) Conger eel.

Figure 4.24: SMS Seydlitz wreckage site is a popular second dive. Due to the shallow depth and slight current there is often an abundance of marine life. Wreckage has been colonised by a variety of species (a), and provides a refuge for juvenile fish (b) and in turn a habitat for predators such as conger eels (c).

4.4 Royal Navy Anchorage

Figure 4.25 shows the bathymetry of the seabed to the north of Flotta extending up to merge with the area covered during the 2001 survey. A band of debris, presumably the old submarine nets extends in a north-south direction. This is marked on the chart as foul ground.

The only other notable features are the crude and ballast line running from the Flotta Oil Terminal out to the SPMs and the scattered remains of HMS Vanguard.

4.5 Comparison of Site Formation Processes

The scheduled sites can be grouped into the battle ships and the light cruisers. As can be seen from the remote sensing images the battleships are almost completely overturned while the light cruisers are on their sides. Structurally, a greater load is placed on the light cruisers compared to the battleships. There are several factors which have influenced the site formation processes to the present date:

- Salvage operations – the use of explosives to remove armour plate and gain access to the engine compartments has caused obvious structural damage to the wrecks
- Corrosion – encrusting marine life offer a degree of protection due to reduced oxygen levels however this is periodically removed by structural settlement
- Diver impact - direct damage through artefact removal
  - inadvertent damage to marine growth
  - elevated oxygen levels within the structure due to penetration dives
  - fluctuation changes to structural loads as a result of migration of divers exhaust gas during penetration dives

Due to the latter penetration dived are now banned on some of Australia's historic wrecks.

In terms of ongoing site formation processes of the most interest are the bow sections of the light cruisers. Due to a combination of structural loading and corrosion the sequence of events would appear to be:

- Parting of the upper edge of the main deck from the hull
- "peeling" away of the deck, this can be accompanied by lower decks
- Settlement of the upper hull

The chronological sequence of this can be seen through the SMS Dresden, SMS Brummer and SMS Cöln

References:

[4.1] Gröner,E. , "German Warships 1815 – 1945. Volume One: Major Surface Vessels" Naval Institute Press, 1983. ISBN 0-87021-790-9.
[4.2] 1921 hydrographic chart of Scapa Flow. UKHO

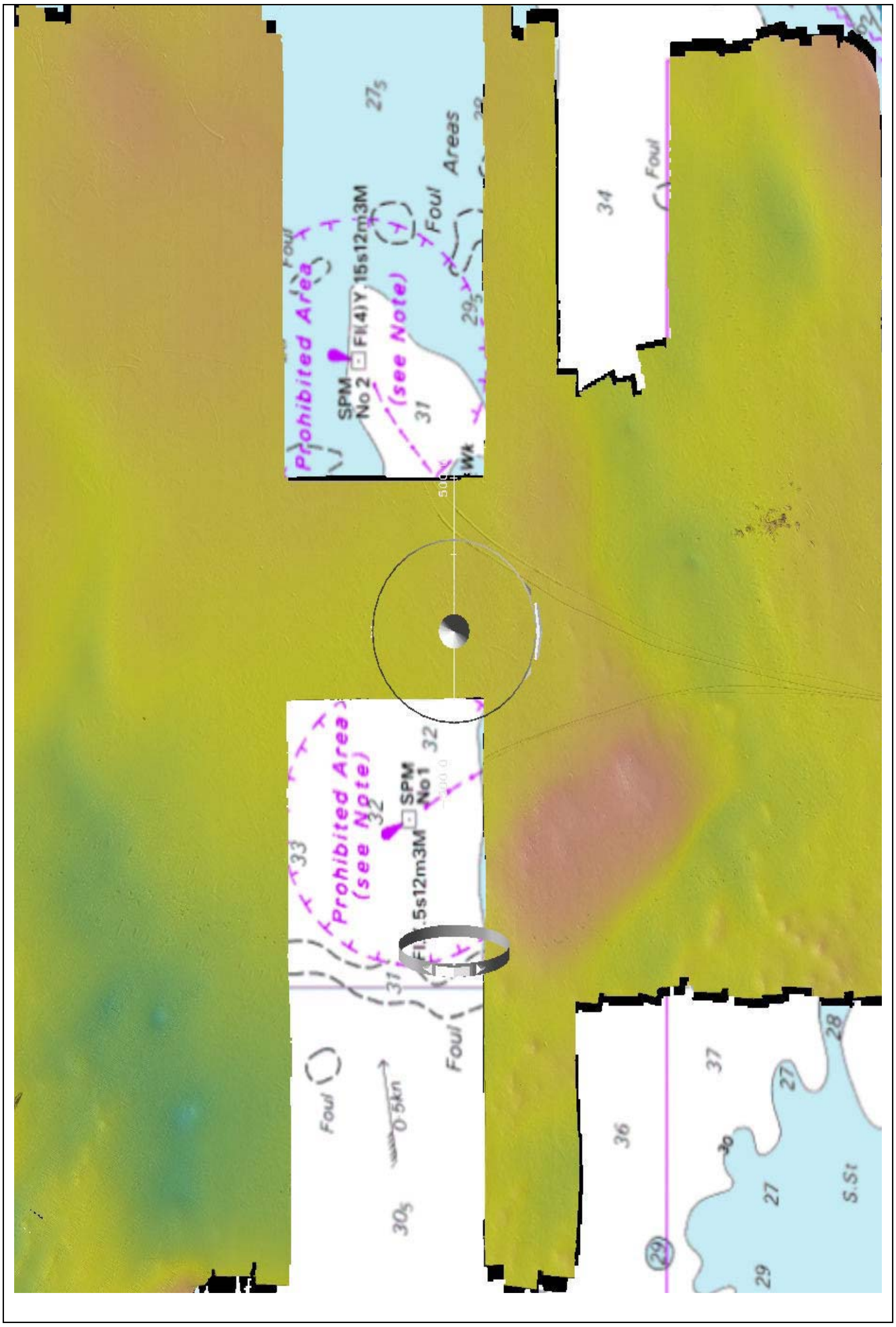


Figure 4.25: Bathymetry of the area north of Flotta extending up to the 2001 survey area. Features include old submarine nets, Flotta oil Terminal Crude and ballasts pipelines and scattered remains of the HMS Vanguard.

5 Discussion

5.1 Remote Sensing Data

Multibeam Echosounders are the primary instrument for high resolution hydrographic survey in much of the world. Measuring depth at many (typically 100-256) points across a wide (typically 120-150° total angle) swath below the acoustic instrument at each measurement cycle, a MBES is typically operated to cover the area to be surveyed in a series of wide tracks that are overlapped by choice of ship position to ensure that all areas of the seafloor are ensonified.

Advances in signal processing technology towards the end of the 1990s resulted in a new generation of MBES systems being developed, typified by the Reson 8125. More powerful DSP capabilities allowed these systems to be dynamically focused (that is, to have the acoustic parameters adjusted continually to keep the seafloor in focus as the system receives backscattered energy), to form more individual beams, and to ping the seafloor more rapidly, resulting in a significant increase in data density for any given depth of water. With receive beam widths on the order of 0.5° at nadir, this allows a nominal acoustic footprint of 0.9% of depth, making the system easily capable of resolving very small targets and therefore feasible for use in survey of wrecks and other objects where the goal is description of the configuration of the wreck rather than just determination of the shallowest point.

As the goals for the survey in an archaeological context are different from those in a hydrographic context, so the methods required for capture, processing and presentation of the results are different. In this section, we discuss the differences from typical hydrographic practice, and illustrate the results with data from the ScapaMAP surveys.

5.1.1 Organisation of the survey

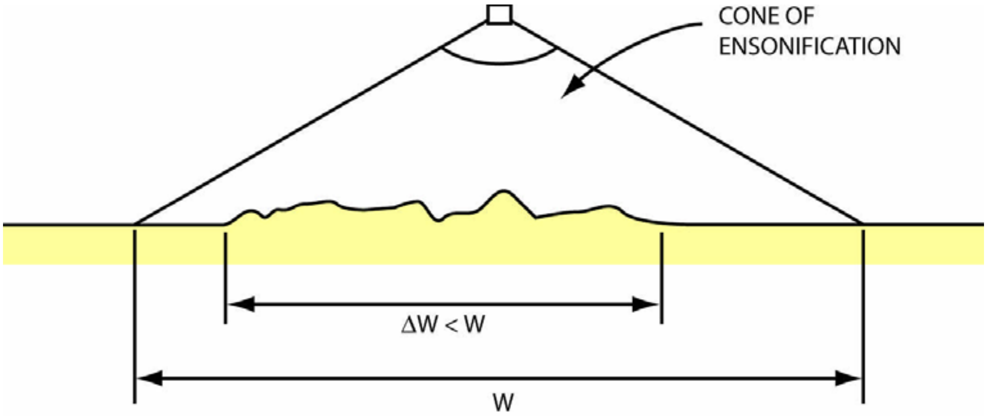
There are two primary goals in any archaeological survey: investigation of the site area as a whole, and documentation of any discrete objects within the site. The former is used to determine sites for the latter, as well as to provide background information. These two modes of operation require different strategies.

Wide scale systematic survey should be carried out essentially as a conventional hydrographic survey, with line spacing of each pass chosen to provide effective overlap with the next. Since the bathymetric data density with most MBES decreases as a function of off-nadir angle, object detection in the outer regions of the swath is less effective, and a higher overlap between swaths than might be used for hydrographic surveys is typical. The concomitant reduction in survey efficiency that this implies can be mitigated by use of appropriately processed backscatter data in some cases, although MBES backscatter is not always ideal for small object detection due to the relatively high grazing angle of observation compared to, e.g., a towed sidescan system.

Item investigation requires careful planning since the goal is to get the observing platform as close as possible to the target (in order to maximize resolution) without causing any potential damage to either survey platform or target. For small targets without significant vertical extent, this can be done simply by laying out a planned track over the centerline of the target (Figure 5.1(a)). For large targets without significant vertical extent, it is more effective to lay out two planned tracks to port and starboard of the target at approximately one third to a half of a swath width away from the centerline, assuming that two swaths are sufficient to cover the whole target (Figure 5.1(b)). For targets with large vertical extent, it is typically difficult to ensonify all areas of the target with a single pass since significant areas of acoustic shadows are formed. In this case, survey lines parallel to the centerline are required, laid out so that the track is over the outer extent of the primary wreck site on either side of the centre (Figure 5.1(c)). This arrangement provides the maximum overlap between the two swaths, allowing for conservative processing of the data to maximize the visibility of features from one swath or the other once the combined object is constructed. Multiple-pass surveys of large objects are only effective if positioning is adequate both vertically and horizontally; this is considered in more detail in the following section.

Scientifically, the composite object formed by multiple swaths of data is most effective in understanding the overall shape of the target. For visualization, however, this is not necessarily the case. Irrespective of how well the merging of the swaths is done, the results are generally not particularly convincing (Figure 5.2). It is usually best to plan and execute a “beauty pass” survey line over the target in order to provide the most compelling image. The placement of this survey line depends heavily on the structure of the target. For example, if the target has an overhang, it might be more effective to survey outboard of the overhang, Figure 5.3(a), so that the superstructure of the target is imaged directly. If, on the other hand, the wreck is up-right, a survey line down the centerline would be more effective since shadowing should be minimized, Figure 5.3(b). Many possible alternatives exist. Whichever orientation is mandated by the target, the survey line should be conducted as slowly as possible while maintaining the survey platform in control, since this maximizes the data density on the seafloor, which significantly improves the visibility of small targets. Regular, stable forward motion of the survey platform is essential in this, however, since excessive yawing or crabbing will result in a confused depiction of the wreck due to the primary geometric structure imposed by the asymmetric along-track and across-track sample spacing, leading to the data being seen primarily as swaths of points, rather than a uniform point cloud.

The sequencing of events during the survey depends on the state of knowledge of the targets before the survey commences. If sufficient information is available to identify all objects of primary interest and their centrelines a priori, the prudent approach is to survey the objects first in case of difficulty later in the process. If, however, little is known of the site, or if the



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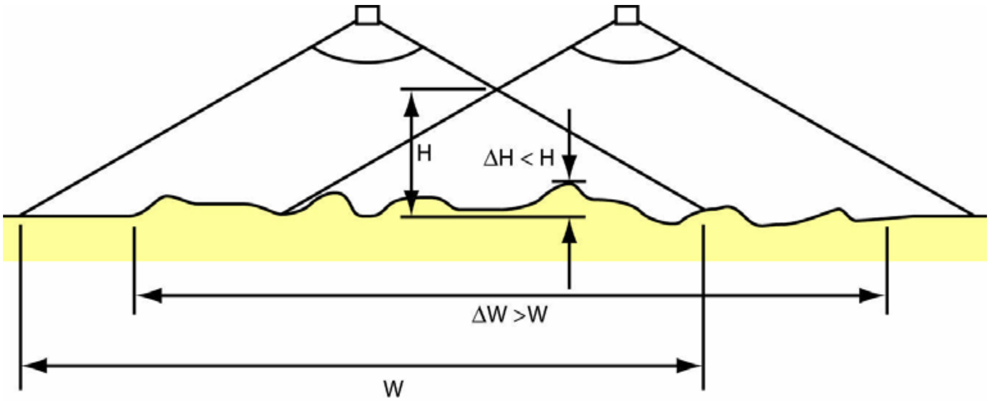
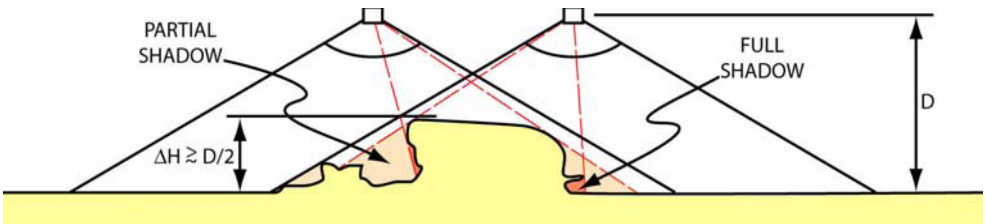
(a) small object with low relief, one line.

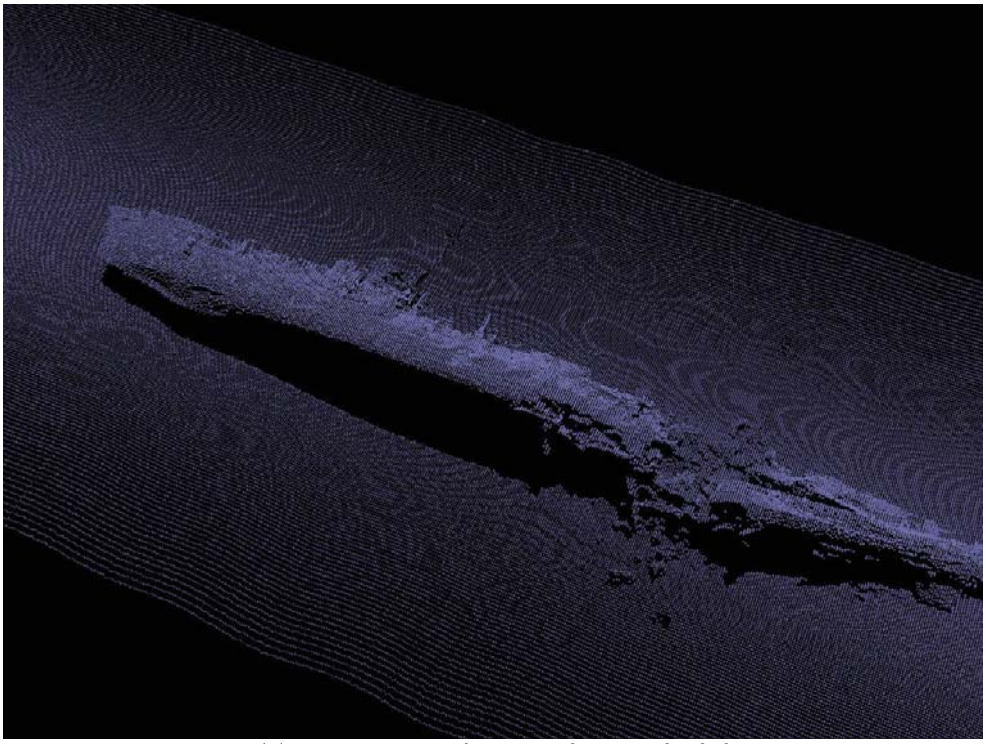


(b) Large object with low relief, two lines

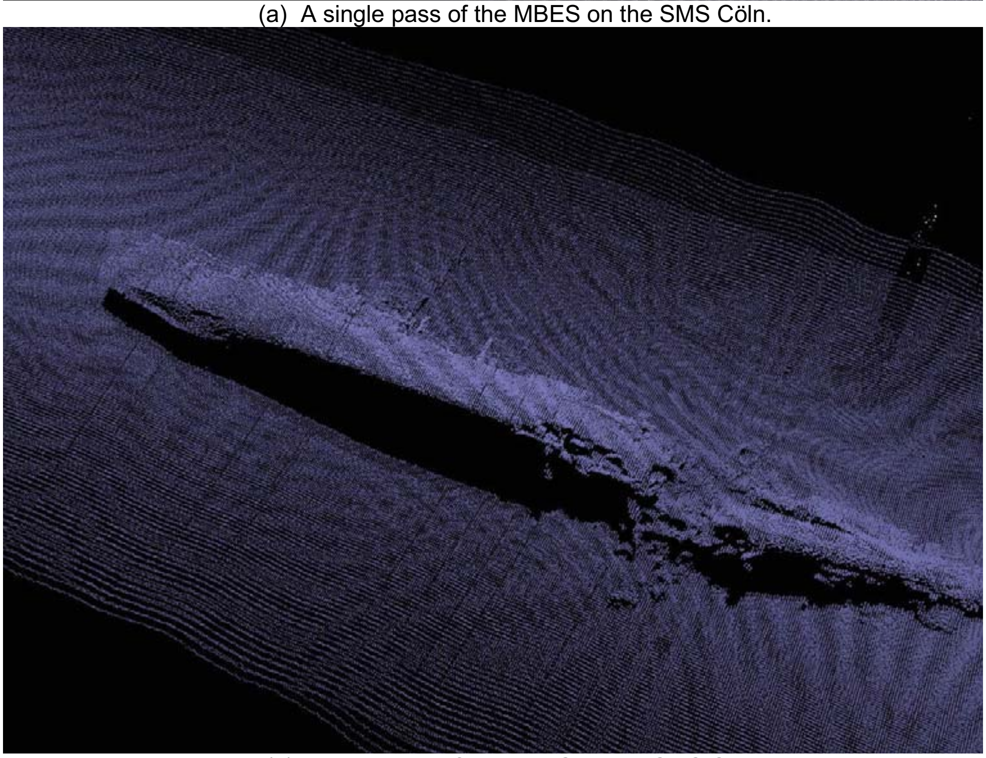


(c) large object with large relief, two lines.

Figure 5.1. Potential line organisation for wreck surveys, which depends on the characteristics of the object being surveyed. For objects with low relief, (a) & (b),, layout depends on horizontal side; for objects with large relief, (c), layout is done to minimize potential acoustic shadowing.

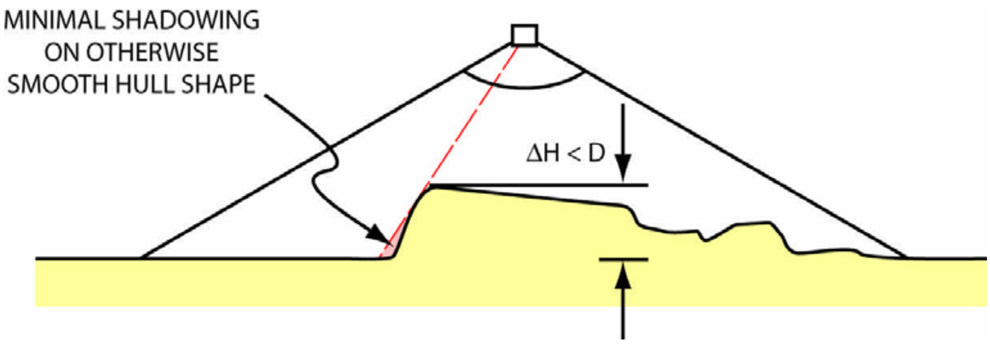


(a) A single pass of the MBES on the SMS Cöln.

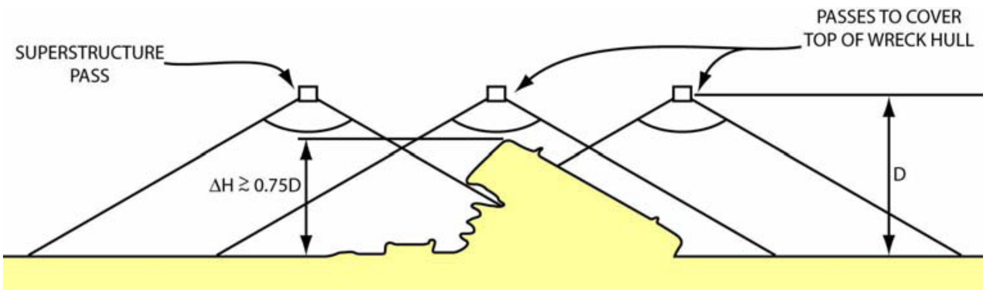


(b) Two passes of the MBES on the SMS Cöln.

Figure 5.2. Effects of visualizing more than one MBES pass over a wreck with high detail level and insufficient accurate positioning. Small inconsistencies in horizontal & vertical positioning result in a "smearing" of the wreck, (b), relative to a single pass, (a).



(a) Low relief object,, one line.



(b) High relief object, multiple lines with one to fill in the superstructure if possible.

Figure 5.3. Layouts for ‘beauty passes’ over objects, intended primarily for public outreach visualization. In the case of high relief, (b), the best view will depend strongly on the configuration of the wreck, and maybe of the superstructure but only part of the hull.

object orientation and/or position are ill defined, reconnaissance/development approach is more useful. That is, the large-scale survey is conducted first, targets are identified and development work is later scheduled on those targets. Whether this development must occur after the primary reconnaissance survey or if it may be interleaved depends strongly on the capabilities of the survey platform, and particularly her operational crew. (The latter is preferred since it develops the most information about known targets earliest in the process.) In either case, an immediate corollary of carrying out target developments is that the data being captured has to be capable of being processed in real-time onboard the survey platform so that the feedback loop can be closed. This has direct implications on hardware, software and personnel availability during the survey. Rapid feedback of results to guide the adaptive development of the survey plan, and sufficient flexibility in the survey plan to allow for this , are essential.

5.1.2 Data collection

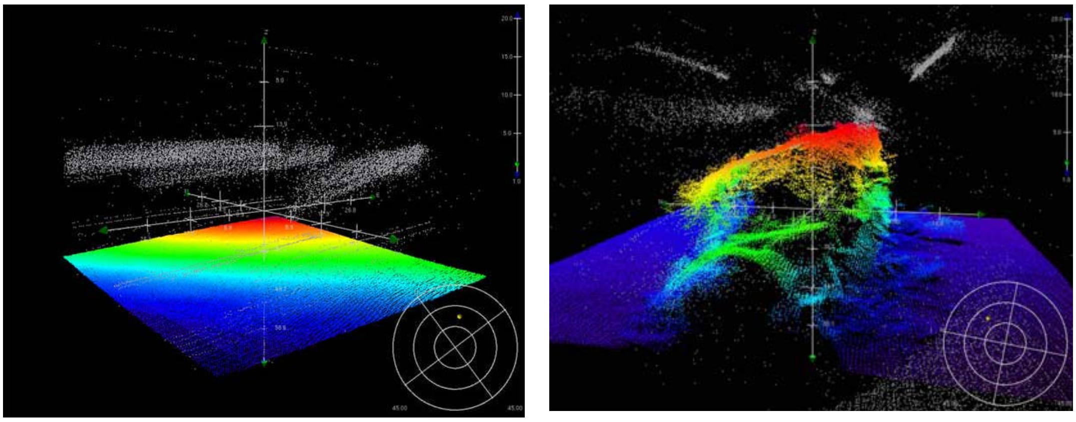
The primary requirements for an archaeological survey are the same as a hydrographic survey: rigid mounting of the sonar transducers to avoid motion artefacts, use of an adequate motion sensor, and careful control and estimation of the offsets of the various components of the s system (linear, angular and temporal). The primary differences in data collection are in degree of significance of some of the measurements that are made.

For all survey systems, understanding the sound speed structure of the water column is essential to application of appropriate refraction corrections. Often, it is possible to diagnose issues with multiple overlapping lines and determine empirical corrections if required. In an archaeological survey, however, it is frequently the case that single passes of objects are taken (as described above), so diagnosis of any unknown refraction due to a local micro -change in water mass can be extremely difficult. Since much of the analysis of the data is about shape, and particularly the likely changes in shape over a significant portion of the swath, inappropriate refraction corrections could result in different interpretations of the state of an object. Typically, therefore, an archaeological survey will require more frequent sound speed profile measurements than would be normal for a hydrographic survey, and especially before doing any high-resolution work around a particular feature of interest. The actual frequency required will depend of course on the particular survey area; if the area is particularly shallow and well mixed, fewer measurements may be required, but a protocol of one profile every hour and before each significant target is not unusual.

Hydrographic surveys typically spend a significant amount of time determining the appropriate corrector to reduce the depths measured to an appropriate datum, typically the chart datum for the local area (often Lowest Astronomical Tide or Mean Lower Low Water). Archaeological surveys have both looser and tighter requirements for water level correctors. In most cases, the absolute depth of any feature of the objects being investigated is unlikely to be particularly important. There is therefore no reason to tie the measurements to an absolute datum, since the majority of the information required is about the change in shape and relative position with time. Relative vertical positioning, however, is very important if the object being investigated cannot be covered in one pass of the sonar: small variations in the predicted or observed vertical correctors can significantly affect the coherence of the multiple passes being merged into a composite structure. In extreme cases, problems with vertical correctors could result in a misinterpretation of small structures within the object. Since these objects can be on the order of a few centimetres different in depth, very tight control of relative vertical correctors is required. For both of these reasons, it makes more sense to conduct archaeological surveys on the ellipsoid with Real Time Kinematics (RTK) or Post Processed Kinematics (PPK) GPS measurements, and only connect to a local datum if the data is intended to be dual-use, or needs to be connected to the nautical chart of the area for some reason. This is not uncommon in archaeological surveys, where a quid pro quo agreement with hydrographic surveying agencies can support or defray much of the cost of the survey.

Horizontal positioning is a significant concern irrespective of the surveying application. The use of RTK/PPK positioning for vertical correctors generally resolves this issue adequately, however, and no other constraints are required. If RTK/PPK positioning is not possible, however, then careful use of a Wide-Area Augmentation Service (WAAS) or Globally-Corrected GPS (such as StarFix, C-Nav, or GIPSY) would typically be required to achieve the sort of horizontal uncertainty required to adequately merge multiple passes into a coherent object structure.

Cleanliness of data is important in all surveying applications. In general hydrographic surveying, however, it may be considered acceptable to allow some beams of the swath to be intentionally noisy in order to optimize some other property of the system. A typical example is to artificially decrease the maximum range of the SONAR, sacrificing some of the outer beams, in order to increase the achievable ping rate and therefore increase the along-track data density over the centre of the swath. Where the target of interest is a mostly smooth seafloor, this is generally acceptable since it is relatively straightforward to identify the anomalous soundings (Figure 5.4(a)). In the context of an object with large vertical extent and very complex structure, however, this can be significantly more difficult (Figure 5.4(b)), leading to a very difficult subjective decision making process (see Section 3.3). Given that the observation time for even large objects is very small (on the order of a few minutes), but the processing time for dealing with noise over such objects can be very large (on the order of an hour), if higher data density is required it makes economic sense to make multiple passes over the object rather than attempt to artificially increase the density of one pass. As long as sufficient vertical and horizontal positioning control is available (as outlined previously) then the data should still be able to be merged in this case into a composite object. Archaeological surveys therefore require even more attention to dynamic operational tuning of the MBES in order to ensure minimal outlier 'noise'.



(a) Noise readily distinguished from data

(b) Noise too close to object of interest.

Figure 5.4: Examples of hydrographically 'acceptable' data noise (a) which is readily distinguished from the true surface data, and archaeologically challenging data noise (b) which is very difficult to subjectively separate from the 'true' structure of the wreck due to the very small nature of the structure components being considered.

Although the bathymetric measurements made by the MBES are the primary goal of the survey, other observational data is often available. Most systems provide some measure of the backscattered energy from the seafloor, and modern systems often now provide the ability to capture acoustic backscatter data from ping transmission continuously (i.e., to image the water column in addition to the seafloor). These measurements can be used to develop new data products that illustrate features of the sites that are not otherwise visible in the bathymetric data (see Section 5, for example). However, in many survey suites they are not routinely monitored during acquisition, and may not be fully preserved into the data set archived for post-processing. To a certain extent, choices made to optimize the data for bathymetric quality as outlined above run counter to the requirements for backscatter quality. Adjusting the transmit power in order to achieve reliable detection on the outer beams, for example, can cause the backscatter to be saturated, while rapidly changing the power and/or gain can result in backscatter artefacts that are difficult to recover later. Recognizing that bathymetric information is typically the most important, archaeological surveys should at least monitor the backscatter being developed during the survey, and should ensure that all relevant data and metadata are being archived. Frequently, this last is difficult to achieve without testing a component of the data being captured. It is therefore essential that all required processing tools are available in the field, and that the data is examined immediately after capture to ensure completeness.

5.1.3 Processing strategies for wreck data

As with data collection, the processing strategies for wreck data typically follow the protocols used in modern hydrographic processing schemes. This typically involves a data flow path where raw data is transformed quickly into a surface representation, frequently with auxiliary data layers such as standard deviation, data density or uncertainty among others, which is then used to guide the effort of removing the data observations that are not consistent with the hydrographer's interpretation of the configuration of the seafloor. In some instances, automatic or semi-automatic methods of processing are used to construct the surfaces; in other cases simple distance weighting is used. After remediation of the inconsistent data by manual or semi -automatic means, the data is summarized either as a surface or as a collection of 'raw sounding' observations as dictated by the hydrographic agency contracting the data.

For archaeological survey, these methods are sufficient for areas where general reconnaissance survey is being undertaken, prior to any detailed investigation of an object. We have found that remediation utilizing a three-dimensional representation of data points in an area-based editor is by far the most effective method for dealing with wreck data, primarily because it allows for the detailed visualization of the vertical structure of the wrecks in context with the dubious observations. For investigation of particular objects, it is often the case that the most complex part of the editing task is deciding whether a particular sounding is erroneous, or simply a very small part of the wreck: wrecks often have small pieces of superstructure or hull only marginally attached to the main wreckage, depending on the state of decay. In this instance, we have found it effective to use small 'subset' slices through the wreck's hull aligned with the primary longitudinal axis of the wreck. This helps to establish 'inside' from 'outside' of the wreck, and delineates the primary hull or superstructure more clearly. As with all subset editing applications, it is essential to ensure that sufficient context remains that objects are not removed as erroneous because only the part within the slice is considered. Having an 'overview' of the data in 2D or 3D (which is preferred) helps to ensure that the detailed view is not too selective.

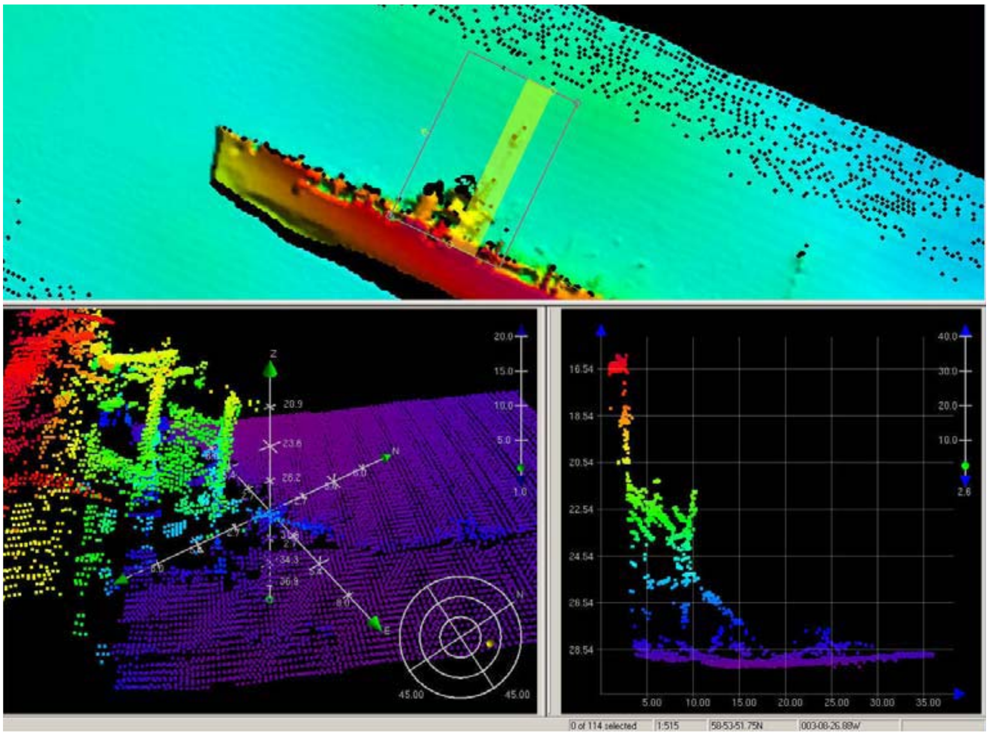
In hydrographic data processing, the most common goal is to retain the shoalest point in any data set, which preserves the observation most significant to surface navigation. Some leniency in removing deeper coincident points is therefore natural. In archaeological data processing, however, deeper points could represent sub-decks that are exposed by gaps in the upper plating and imaged by some other beam. It is essential, therefore, to be especially careful when reviewing the data within the wreck structure to ensure that significant detail is not removed. This is not always trivial. Good practice for this is to prioritize time for investigation of the detailed structure of the wreck within the processing stream, to visualize the structure appropriately as outlined above, and to build a mental picture of the structure 'through the noise' before starting on the editing task. We have found that this last is usually possible due to the human ability to see structure clearly past visual distracter points, and greatly aids in decisions as to what to keep.

Visualization of the structure of the wrecks is essential in making suitable decisions for editing. In particular, there are significant limitations to DTMs of a wreck to represent many of the overhanging objects that wrecks frequently manifest, such as lifeboat davits or masts, Figure 5.5 (see Section 3.4). We have found that the level of detail of the bathymetric data generated from modern surveys is more than sufficient to allow details of objects to be identified from pictures of the ships before they were sunk, if available, and editing with respect to the known structure of the wreck prior to sinking can be extremely beneficial in deciding what is likely noise, and what significant archaeological detail.

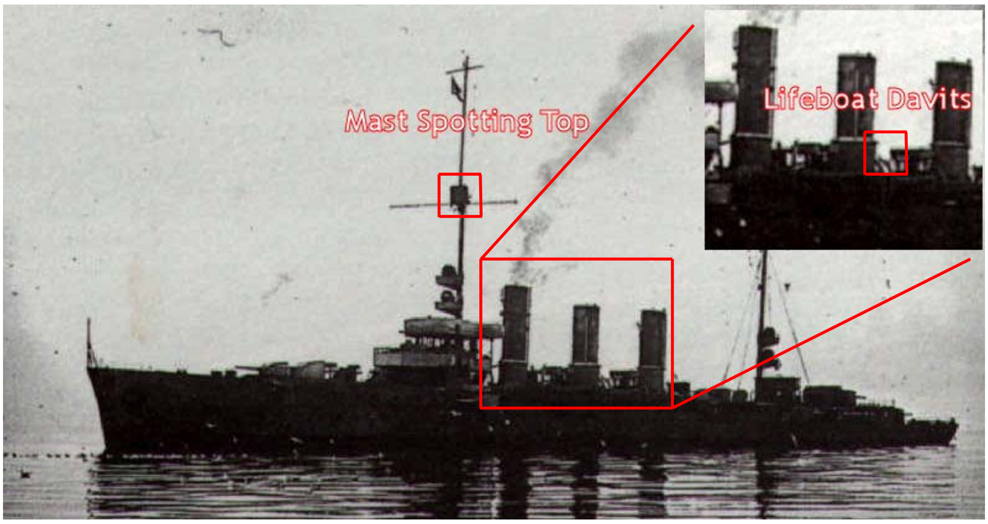
5.1.4 Presentation of wreck or object data

The essence, and primary difficulty, of visualization of the data from archaeological surveys is in balancing efficiency and easy of interaction against scientific veracity and interpretability. The two primary modes of display are as either a point cloud (i.e., a representation of direct observations with one glyph for each) or as some form of surface model, whether DTM or TIN. The correct answer is properly a combination of the two types of visualization depending on the goals and users.

The simplest form of visualization for spatial data is as a surface model. Simple to compute and fast to render, they readily provide geo-spatial context for the site, and are easy to interact with using common tools. There are some limitations, however, the most important of which is the implicit assumption that there is a continuous surface to model. In the case of general bathymetry,



(a) The SMS Cöln in 2006



(b) The SMS Cöln in 1919

Figure 5.5: The ability of a DTM to represent overhanging features is limited, but their importance can be archaeologically very significant; visualization of these from, e.g., images of the ship before it was sunk can be very important in understanding the visual structure and therefore what to retain in the data during the editing process.

this is acceptable: in most cases there is a continuous seafloor, and if there is an overhang the primary interest is in the shallowest part of it. Even with wrecks, in the hydrographic case, the shallowest part of the wreck at each location of interest can be summarized by the shoalest point, or shoalest probable depth according to preference. For an archaeological investigation, however, we would like to preserve interior inclusions and overhangs as inherent properties of the object, which cannot be done with a simple surface model of the type commonly used, Figure 5.6. More complex models are certainly possible, such as full CAD models with photo-realistic rendering, but the time required to generate such models, the costs of the associated software, and the limits on interaction with the data due to rendering delays make them unlikely as adjuncts to rapid scientific investigation of sites. These limitations suggest that while a surface model may not be the final source for detailed investigation of the interior of an object (or at least such of the interior as can be seen), it does have a role to play to provide for rapid interaction with data and site context in the larger sense.

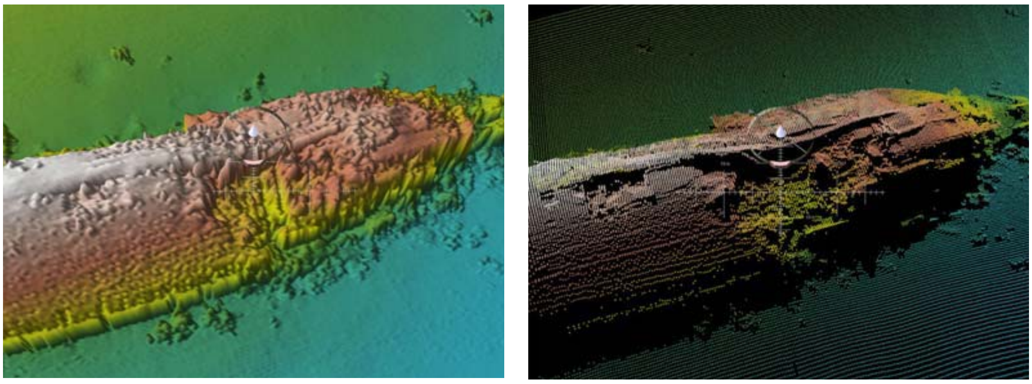
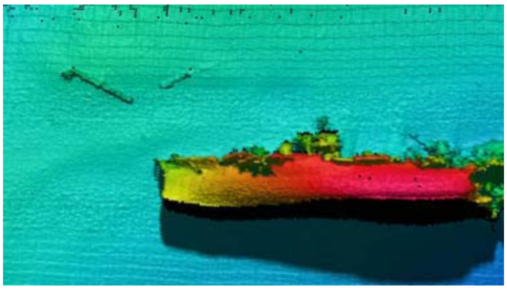
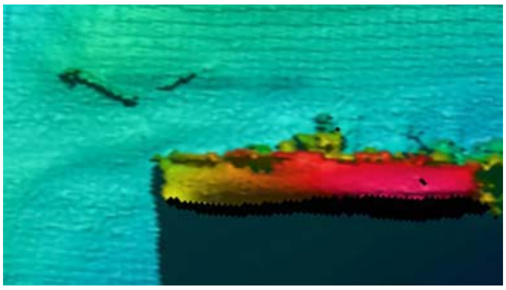


Figure 5.6: Surface representations of wrecks (here, the SMS Kronprinz Wilhelm) and other data with significant interior inclusions or overhangs cannot maintain fidelity due to the assumption of a single contiguous surface, which does not map well to this type of data. Point clouds allow this, but are difficult to manipulate.

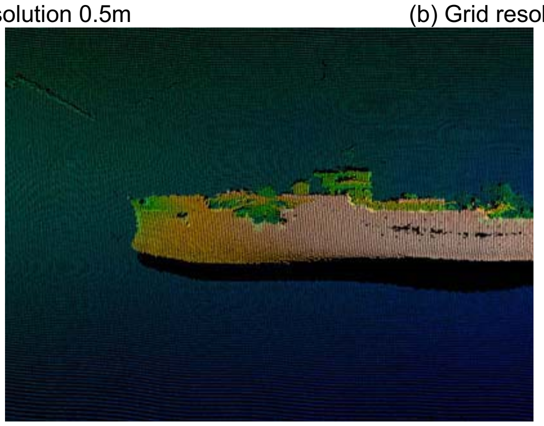
In order to generate effective surface models, however, some other potential limitations have to be considered. The primary concern is one of resolution: at what level of detail should the object be constructed? To a certain degree there is a free hand with this choice, since we acknowledge that the surface object is primarily for large scale context, so preservation of small detail does not overly concern us. (We note in passing that algorithms based on a simple mean of all points in a neighbourhood will almost always result in poor renderings since any interior inclusions will cause 'pits' in the data where the upper surface is actually intact, changing entirely any estimate of the state of the wreck. A simple shoal biased surface resolves this issue, although it can cause others due to unedited outliers.) However, if the resolution is set inappropriately low, then significant details of the object will be lost, and along with them the visual cues that would incite further investigation of the object. In Figure 5.7, for example, the detail of the frontal hull collapse of the SMS Brummer would result in significantly different interpretation in the version constructed at 1.0m resolution; possibly sufficiently that the area might not receive detailed investigation as would be the case from visualization of the 0.5m version. Both, of course, fail to show the detail in this area of the point cloud version of the same area from approximately the same vantage point, but it is interesting to note that while both surface representations fail to properly highlight the mid-line hull collapse points clearly visible in the point cloud, which are significant to the understanding of the hull stability (and hence likely longevity) of the wreck, they do make it significantly easier to see the linear structures on the seabed off the bow of the wreck, which are likely the remains of the foremast. Complementary roles of surfaces and point clouds are clearly indicated.



(a) Grid resolution 0.5m



(b) Grid resolution 1.0m



(c) Point cloud

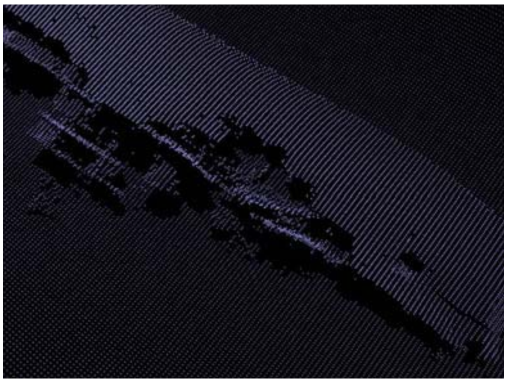
Figure 5.7: Surface resolution is essential in visual identification of areas of the object that require further investigation in the point cloud model of the data. Grids at 0.5m and 1.0m tell a very different story about the state of preservation of the bow of the SMS Brummer, with the 0.5m being closer to the detail found in the point cloud.

Points resolve many of the issues of surfaces outlined above, but come with a significant performance penalty. Counter-intuitively, although each sounding point is much simpler than a surface, to allow each point to be illuminated it has to be drawn in most cases as a geometric cube rather than a simple point, requiring that all six faces be lit and rendered; the combination of a few hundred thousand of these can give even modern graphics cards sufficient work to slow the achievable frame rate below that which is acceptable for an interactive data manipulation experience. This may be reduced to some degree by suitable visualization techniques such as only drawing a subset of all points while interacting with the data, and then redrawing the rest when the viewpoint stops moving, or by careful selection of which cubes to draw and optimization of the drawing primitives. At some point, however, interactivity of point clouds becomes limited, making them suitable for small-scale detailed investigation of parts of an object, or pre-rendered non-interactive views of large objects (e.g., as a video showing particular parts of the data).

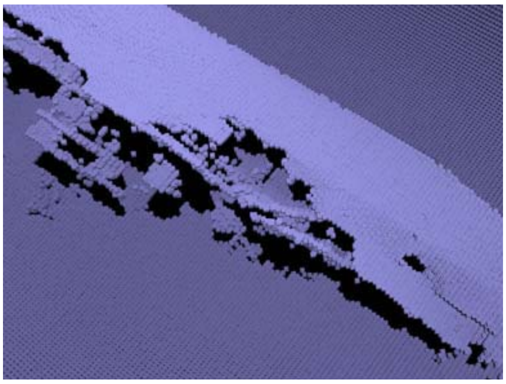
For points, the principal visualization controls are point size and colour. Point size is mostly a matter of taste, although too large a point size results in merging of structures, and can obscure details in the data (Figure 5.8(a)-(b)); some interactive choice is appropriate since this varies with object. Colouring of points depends on the application. In publicity work for outreach applications, monochromatic rendering (Figure 5.8(c)) can be very atmospheric, but does not convey the scientific information that can be colour-coded onto the points such as depth, Figure 5.8(d). Technically, the depths of the observations should be evident from the size of the points in the projected visualization space. It is common to have difficulty in determining this in close points that differ in depth significantly but which are rendered close together due to the perspective of the interactive viewpoint. One promising technique for providing a halfway-house between a fully rendered model and a point model is the use of oriented facets, Figure 5.9. Here, normals are computed for each sounding based on the vector mean of the normals for the triangular facets between the sounding and its immediate neighbours (i.e., immediately adjacent beams within the same ping, and the same beams in the previous and next pings). The soundings are then rendered as small quadrilateral patches, coloured by depth and oriented with respect to the mean normal. The effect is to generate a pseudo-surface which is readily lit and renders quickly, and which can also be used to occlude soundings which are 'behind' the nearest surface to some extent (simply by culling soundings with eye-point angles greater than 90°). Since these are still soundings, however, they can be time-tagged and therefore combined in a 4D sense with other data, such as the water column and ship trajectory information shown here.

Visualization difficulties with points can be reduced considerably by the use of animation. Relative motion of near and far points against each other (motion parallax) triggers strong depth cues in the brain, allowing the viewer to build a mental impression of three dimensional shape of the wreck that allows for more complete understanding of the structure even when the animation stops. So strong is the effect that it is even effective to 'shake' the viewpoint slightly around a nominal view vector in order to understand the local structure being examined. Similar effects can be had with pre-programmed animation sequences summarized in a video clip, but our experiments with these show that they are not as effective as an interactive experience. Heuristically, we believe this is probably because the pre-planned flight path does not allow the user to focus on the data that interests them, or that which they find particularly confusing. Since these effects are different for all users, a pre-planned sequence is less than ideal. Even if the data are lower resolution during the interaction, or are not rendered as well as they might possibly be in a non-real time method, information transfer about the shape of the object is higher when interactive.

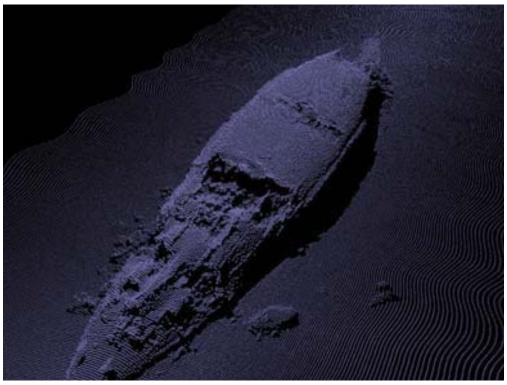
These observations highlight the differences between data products generated for scientific use, and those generated for communication to the public (a very important mission in most archaeological surveys). While the latter are required to be visually compelling, but static; the former are required to be scientifically informative, quantitative and interactive. These requirements dictate the constraints of visualization. The monochrome representation of Figure 5.8(c), for example, does not carry the information inherent in Figure 5.8(d), but it does have more visual impact. Our experiments suggest that colour differences are less important for static visualization, and may even be deleterious to the 'solid surface' illusion in point clouds that make the objects much more 'solid' in a static view. For scientific work, colour-coding and the ability to rapidly change colouring is essential. In both cases, animation is essential, although in the case of scientific work easier to arrange.



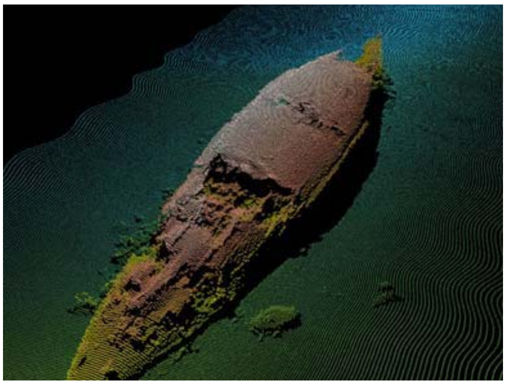
(a) SMS Brummer, 0.1m



(b) SMS Brummer, 0.4m



(c) SMS Markgraf, duotone



(d) SMS Markgraf, coloured by depth

Figure 5.8: Variation of point size and colour can results in significant differences in visibility and utility of the data. Increase of point size (a), (b) can improve some rendering, and/or obscure some details of the object. Monochromatic colourings can be very dramatic, (c), but do not contain the scientific data inherent in a colour-coded data set, (d), here showing depth.

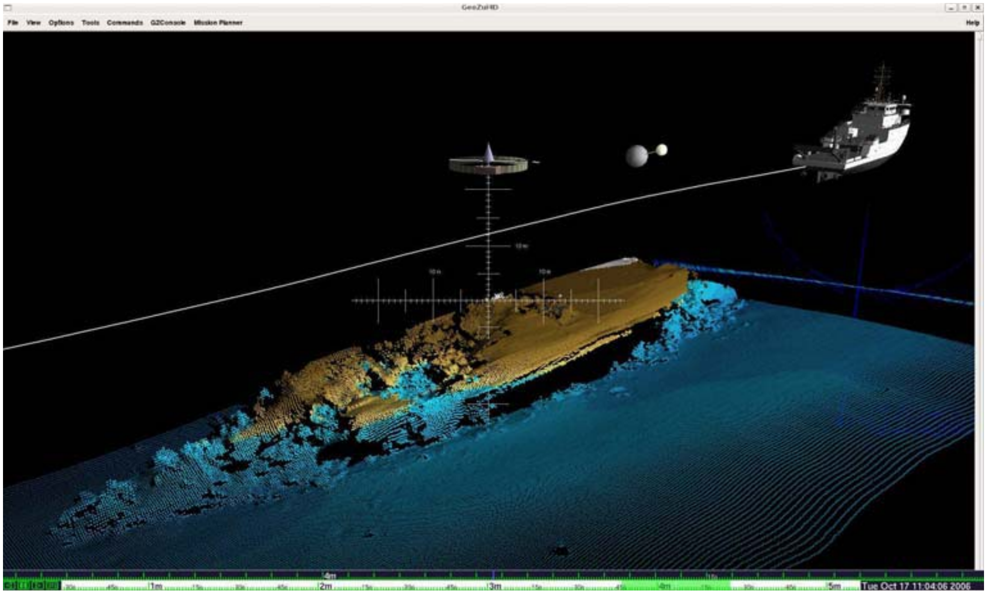


Figure 5.9: Alternative rendering of point data (here, of the SMS König) as oriented facets using the mean normal for triangulated patches between soundings and their immediate nearest neighbours. The data points, colour-coded by depth, are represented as small quadrilateral patches which are fast to draw and readily lit and rendered. The data is still inherently point-based, however, and therefore can be integrated with other 4D (i.e., spatio-temporal) data. (Image source: Roland Arsenault, Data Visualization Research Lab, CCOM/JHC).

5.2 Site Monitoring Through Repeat Surveys

The primary aim of the ScapaMAP II survey in 2006 was to answer the fundamental question of whether there is sufficient repeatable detail in the remotely sensed description of a wreck or other object that the data could be used for monitoring of the object over time. This might be considered to be an obvious assertion: the remote sensed data are extremely compelling because they are instantly recognizable as wrecks, but a great deal of this information is filled in by the human observer, rather than being inherent in the data. It was not initially clear that the repeatability of survey would be sufficient for scientific investigation of the sites, and therefore monitoring.

On the macroscopic scale, sites of any size above approximately 1m^2 can trivially be recovered using conventional navigational equipment, and in that limited sense, the survey is repeatable. Direct comparison of data at the macroscopic scale, Figure 5.10(a) & (b), clearly shows that similar features are seen in the two surveys which are five years apart in this case. In many instances, even small details can be compared side by side; in Figure 5.10, the armour plating along the central longitudinal axis of the SMS Brummer are evident in both cases, an example where a detail that could be dismissed as a data anomaly in one survey is confirmed by the second. This feature was not observed in the data from the other like cruisers. Observations by divers revealed that on the other light cruisers armour plating increased down the hull in two steps while on the SMS Brummer in only one, giving a sudden change in hull profile.

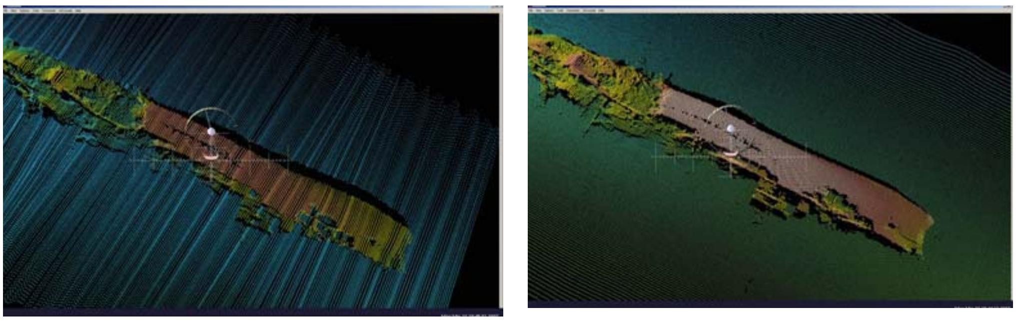


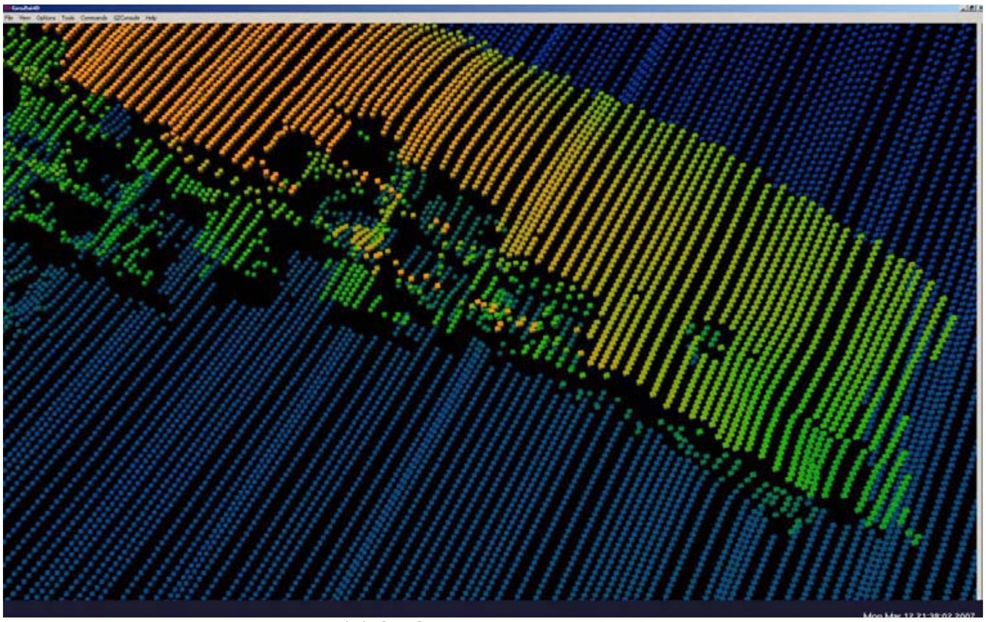
Figure 5.10: Overview of the SMS Brummer surveys from 2001, (a), and 2006, (b). Although the data densities are different, and the motion compensation from 2001 is not ideal (the MBES was deployed on a pole mount with limited rigidity), the two surveys are directly comparable, and details such armour plating on the longitudinal centreline and salvage recovery points are maintained between surveys.

The results of the survey also show that detailed descriptions of the wrecks may be formed from pairs of surveys compared side by side. In the detailed view of the bow of the SMS Brummer in Figure 5.11, for example, it is possible to estimate the progress of the hull plate and subdeck collapse into the body of the hull, and towards the superstructure further aft. Repeated sufficiently often, such surveys would allow estimates of the rate of collapse as well as continuous monitoring of the current configuration of the wreck.

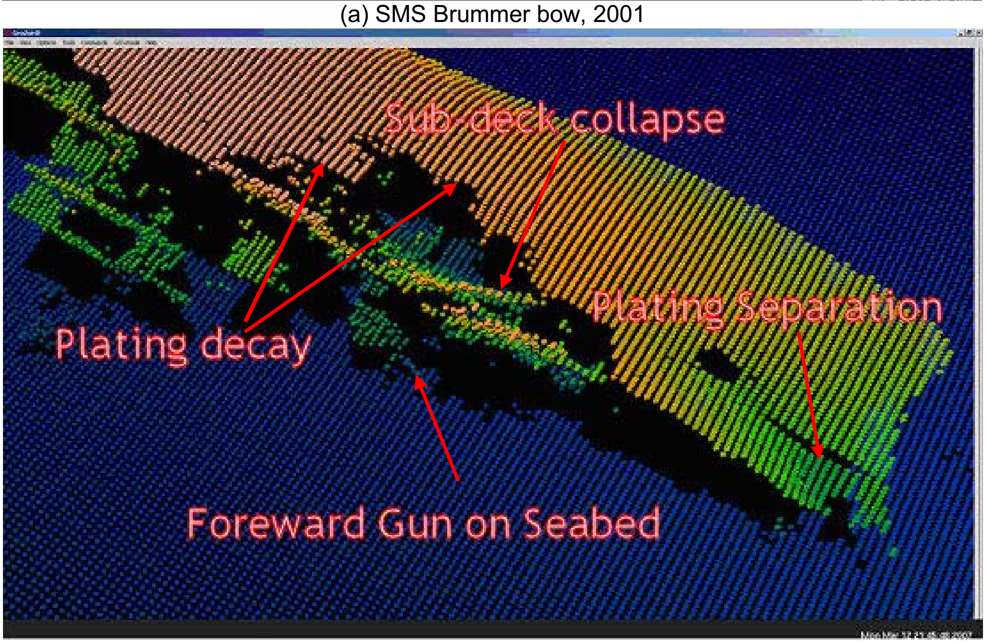
Care is required in interpretation of the results of the repeated surveys, however. Increases in MBES performance generally result in higher data density, which is evident in Figure 5.11 in the short period of time between 2001 and 2006. Elements of the wreck which seem to “appear” in subsequent surveys should be treated with suspicion, therefore, since they may just represent details which were not evident in the prior survey. In addition, slight changes in survey platform trajectory can result in very different shadowing patterns on objects with significant vertical extent (such as wrecks), which might be (over-) interpreted as important differences. (Both of these effects are evident in Figure 5.11(b) where the data from 2006 shows better definition of, e.g., the thin longitudinal remains of the sub-deck support members, which therefore anomalously “appear” in the later survey, but is also missing the main deck bulkheads between the forward gun director and the main superstructure, most likely due to shadowing rather than actual collapse.)

Methods for more quantitative estimates of the differences between two surveys are quite limited. The simplest is to compute the difference between two coincident surfaces constructed from the separate surveys, although this inherits all of the problems of dealing with surfaces as outlined previously and in general is only useful for gross differences. Directly computing a difference of two point sets is not well defined since there is no direct definition of interior and exterior spaces in the data. Experiments in using stereo rendering of pairs of surveys show that it is difficult to ‘fuse’ two images that are not from the same survey, since small changes in shadowing (e.g., due to trajectory), data density and swath orientation significant affect the rendered images. In our experiments, the viewer fixated one or the other survey, rather than seeing any differences between them. More complex visualization techniques might render better quantitative methods for comparison, but it is likely that this problem is formally as difficult (and closely related) to the problem of forming the semi-random points into a coherent 3D surface described previously: something that is not readily soluble by automatic methods.

The primary limitations in doing any comparisons are the achievable horizontal and vertical positioning accuracy, both of which limit the degree of fusion that is possible with pairs of surveys; small changes will be completely masked if there is a systematic bias in either dimension such as might be formed through variation in GPS satellite constellations or differing vertical datums. The positioning requirements for this type of repeat survey are in general even stricter than they are for standard hydrographic surveys because here the measure of success is the relative uncertainty rather than the (typically more generous) absolute uncertainty that is commonly required. That is, in a hydrographic survey, we might be content to position a shoal to within 5m (2drms) repeatably, allowing an adequate margin by which satellite constellation changes may be accommodated. In an archaeological survey, however, a constellation change that resulted in a horizontal offset of 2.5m in a random direction would result in a complete inability to compare the results reliably. For similar reasons, care in correction for motion of the platform is paramount, since small residual motion artefacts (e.g., induced heave on the centimetre to decimetre scale) can result in obscuration of significant features. To a certain extent the wider application of RTK or PPK GPS measurements and tightly coupled motion sensors and features such as delayed heave estimates will result in these difficulties being of lesser significance in the future. The requirements for the survey that they imply will remain, however.



(a) SMS Brummer bow, 2001



(b) SMS Brummer bow, 2006

Figure 5.11: Detailed view of the bow of the SMS Brummer in 2001, (a), and 2006, (b). The progress of the hull plate and sub-deck collapse towards the keel and superstructure are evident, showing the sequential monitoring of the state of preservation of the wrecks can be supported by remote sensed data of this type.

5.3 Survey with New Data Products

Backscatter data, typically from a towed sidescan system, has been a staple of wreck investigation for many years. There is a difference in the task of detecting an object, for which this is ideal, and some careful investigation of its morphology, however: in the case of very large wrecks, the prevalence of shadowing is so high that much detail of the hull shape is often obscured, Figure 5.12. In addition, the lack of bathymetric data results in difficulties in correcting this data for positioning which further distorts the morphological indicators that are useful for monitoring the object’s condition.

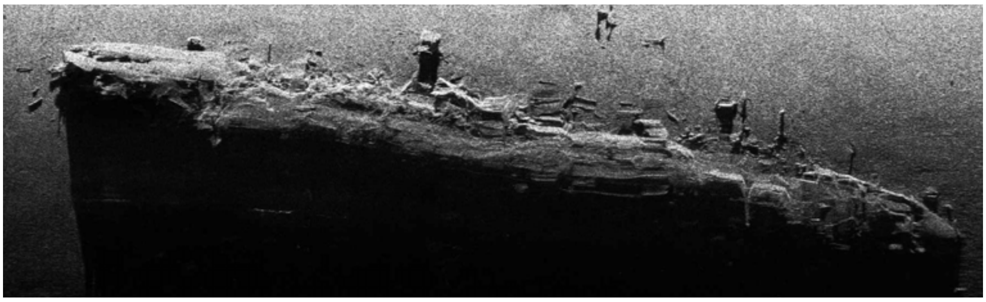


Figure 5.12: Sidescan imagery of the SMS Kronprinz Wilhelm, collected with a Klein 2000 in 1999. The vertical extent of the wreck results in significant shadowing, and consequent difficulty in recognizing morphological indicators useful for assessing the state of the wreck. Although ideal for detecting wrecks, towed sidescan is not always ideal for monitoring.

Addition of bathymetric information does not significantly improve behaviour of MBES backscatter over large wrecks, however; the fundamental limitation of shadowing is still present, and attempts to geocode backscatter coherently over a large wreck are unconvincing.

In our experiments, the most compelling use of backscatter is in its conventional survey mode; that is, to map changes in sedimentation around the areas of interest, or significant objects. In Figure 5.13, for example, a section of Gutter Sound, Orkney where the backscatter shows a significantly anomalous return for which there is no bathymetric explanation (even when the backscatter is heavily vertically exaggerated and strongly shaded as here so that centimetric artefacts become obvious). It is unknown whether this anomaly represents a difference in seabed surficial sediment, or whether it is a result of material left on the seabed due to salvage operations at some time in the past. However, the ability to map these changes, especially since this data is essentially ‘free’ from the bathymetric survey, can help in the rapid-response and baseline mapping segments of archaeological site investigation.

A newer capability in MBES systems is to capture data for the entire water column, rather than just the bathymetry and seabed backscatter. Potentially, this allows for greater detail of investigation of the data in a post-processing mode, since the data is not reduced to just the seabed backscatter, or one data point per beam, Figure 5.14. Comparison of the water column data to the detected bathymetric data is also useful, particularly where small features (e.g., masts, lifeboat davits or guns) are present, since the water column data

(b) Backscatter

(c) Colour-coded, shaded, bathymetry

***Figure 5.13**:* Multibeam backscatter and bathymetry for the same section of Gutter Sound. The backscatter shows a significant anomaly that has no bathymetric expression, although the data agree on the objects in the top right of the imagery. Use of backscatter to identify sediment variabilities, for example due to differential erosion or pollutant absorption is a useful 'collateral' tool derived from baseline bathymetric surveys.

may show more detail, or finer detail, than can be resolved even in high resolution bathymetry. There is a significant cost in this type of analysis, however, since the data volumes for this type of data can be very high (on the order of several gigabytes per minute). The cost of storing, processing and presenting this data will mean that for the immediate future only very small sections of data are likely to be collected and processed, implying that very careful targeting of this type of data is required. For archaeological surveys, therefore, this is most likely to mean targeted passes on already well established objects, rather than use in rapid reconnaissance.

Methods for processing and display of water column data are still very much in their infancy. Future techniques might include volume rendering of semi-transparent displays, multiple object detection and tracking within the water column, and volumetric reconstruction of data. It remains to be seen, however, whether this can be done in anything like real-time, and what the computational cost will be.

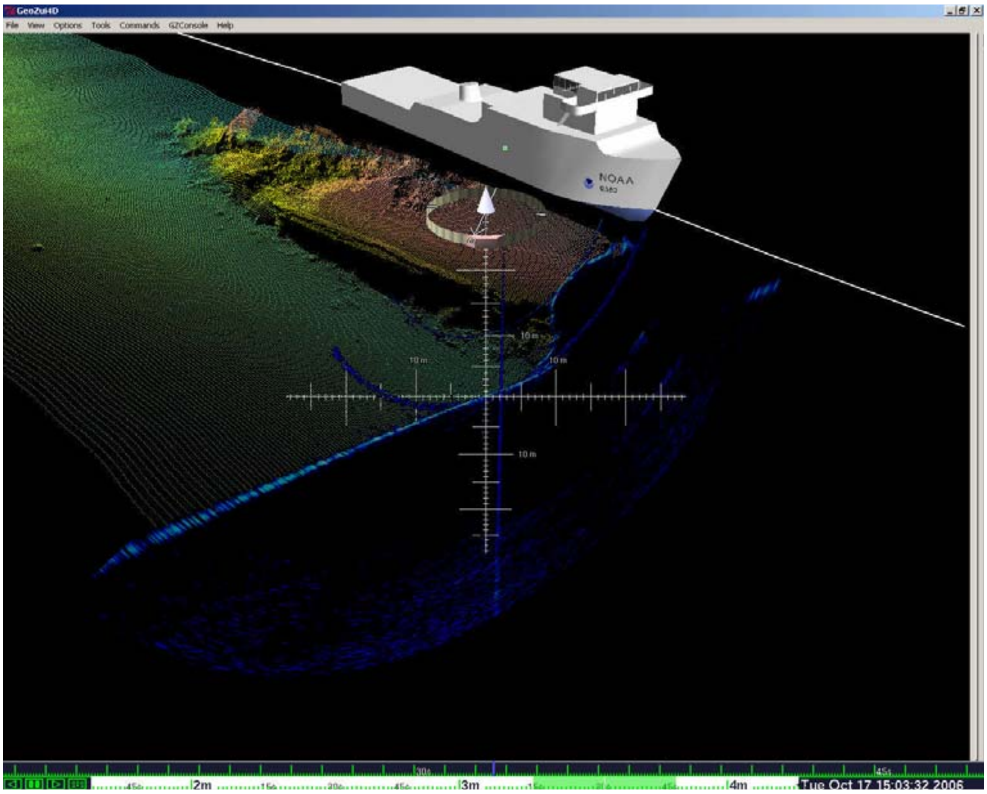


Figure 5.14: Snapshot of a video sequence showing the bathymetric points and water column data with respect to the survey platform while imaging the SMS König. Water column data can reveal more about the structures of a wreck and allows for comparison of detected bathymetric points against observed acoustic data, but volume of data and difficulties in processing mean that this data type needs to be targeted to known objects rather than being applied uniformly across the survey area.

5.4 The Role of Survey in Site Management Plans

The reality of most marine archaeology is that there will rarely be sufficient funding for an investigation of the site to the level of detail that is really required to fully document the state of preservation. This is not to say that funding is not available; for some sites, such as the wreck of the MONITOR, large, well-funded projects have been launched. For every site of this kind, however, there are maybe hundreds more with just as significant a cultural impact, which are unlikely to receive serious study. The cost of any marine investigation, and the difficulties of mobilizing human observers to the location means that there is a necessity for methods to rapidly, but perhaps approximately, gather information on a site.

Survey technologies fill this niche. Remote sensing of bathymetry has been shown, here and elsewhere, to produce compelling descriptions of the 3D structure of archaeological sites, and can be done in significantly less time than would be required for a diver-led investigation of the site. In addition, the precisely geo-referenced data can act as a means to prioritize use of more expensive or limited resources, such as diver time. For example, in the case of the SMS BRUMMER, Figure 6.2, knowledge that the front deck plates have changed significantly would be cause to vector divers to the site for more detailed investigation *in situ*. Repeatability of survey methods is now sufficiently good that repeat surveys make sense, and provide an enticingly economical method to monitor particular objects as a function of time.

There are therefore two primary roles for high resolution survey in a marine archaeological context: rapid pre-investigation surveys to establish a baseline efficiently, and continuous monitoring of the site to establish decay rates or the effects of intermittent external drivers, e.g., hurricane damage. The arguments for both of these are essentially economic, although efficiency of time in observation and safety of the observers are also factors.

Clearly, however, remote sensing is not a complete solution for marine archaeology; there remains no substitute for a human observer for the finest scale observations. This may, of course, be mediated through a remote technology such as a Remotely Operated Vehicle with cameras to do the observing, but the purposeful investigation of a trained observer is still necessary. In the future, more exotic technologies such as AUVs might extend the limits of what is now possible, but no matter how close the remote platform is brought to the site, and the frequency of the observing system, there are fundamental limits to the resolution and precision of the data that can be achieved. Like all tools, therefore, survey systems are only a part of a coordinated site management plan.

6 Future Management Strategies

The last decade or so has seen a significant change to our attitudes towards submerged cultural resources. Once only the province of a few divers, the tremendous expansion of recreational diving in the late 80s and early 90s has seen the need for knowledge and access by this group and the general public rise exponentially. Management of this heritage is, however, a delicate balance between exploitation and conservation. The remains of the Imperial German Fleet in Scapa Flow are a particular example of this. The wrecks, due to their unique nature, relatively shallow scuttle depths and close proximity to one another have been active recreational dive sites for more than twenty years and form a significant portion of the island economy. Visit Orkney surveys indicate that divers account for 2% of the visitors to Orkney but represent 8% of the income generated through tourism. This is also evident by the number of specialist books on the history of Scapa Flow as a military base, salvage operations and specialist dive guide. The most recent of which contains images of the Scheduled sites from the 2001 ScapaMAP survey.

Even without intentional damage to the wrecks by divers (which is actively policed by the local dive-boat operators), dive pressure, like ‘boot erosion’ on land, has a significant effect on the wrecks, making them a non-renewable resource. Any reasonable management strategy must therefore understand the implications of restrictions on use of the resources, and temper this with a desire to preserve the resource for the future.

Several landmark publications [6.1, 6.2 & 6.3] have come out in recent years on the topic of submerged cultural resource management. Although a variety of strategies have been adopted by different countries to tackle these issues the primary theme which has emerged is also evident in the current work.

It is clear that the current legislative framework designed to protect the sites while allowing access is inadequate. The most effective option for preservation of a site is to stop access. This is clearly not an option. The experience from other locations indicates that the only true solution to this issue is by education which is achieved through community involvement, effective interpretation and active management.

6.1 Community Involvement

ODBOA have taken the lead in this respect by developing their Code of Practice and developing their Voluntary Conservation Zone policy. Unfortunately not all visiting dive operators are members of ODBOA and therefore follow these guidelines.

Another difficulty with submerged cultural resources has been that as these are “out of sight” of the general public they are generally “out of mind” and therefore not perceived in the same manner as their terrestrial counterparts. In terms of visitor numbers the Scheduled site rank in the top five archaeological sites visited in Orkney. Any future management plans should aim to address this.

6.2 Effective Interpretation

Following the 2001 ScapaMAP project posters were produced for ODBOA to promote the project and the need for cultural heritage protection. An associated website, where free images can be downloaded, has been hosted by CCOM. Presentations have also been given on both projects at local, national and international venues.

A variety of methods have been used by other conservation groups elsewhere, aimed both at the general public and diving community. Materials range from printed media, such as brochures and guides, to mass media such as DVD/CDRom, magazine articles and the world wide web. An example of how this may be done is given on the attached CD. Data has been rendered using CCOM's GeoZui4D software and captured as an AVI file.

Future management plans should therefore look to update the existing information and expand the range of formats this is produced in. An updated poster incorporating both surveys has been produced as part of the current work as an initial step in this process.(Figure 6.1)

6.3 Active Management

At present there is no active management strategy in place that would be found at a terrestrial site of similar significance or at submerged cultural sites in other countries. Such a programme is need.

One of the key elements of this would be an ongoing monitoring programme and the involvement of the diving community in this. The present work clearly indicates the value of remote sensing in this aspect but for the need of more conventional approaches on a more detailed scale. One strategy would be to conduct remote sensing surveys every five years with a rolling annual diver lead programme centre on key areas at each site. Such an approach could be carried out through the Nautical Archaeology Society scheme. Alternatively, it could be achieved on an *ad hoc* basis by encouraging divers to submit information to a central database.

Regardless of the route is chosen the stages should be:

- Dissemination of the current ScapaMAP data to a wider public audience through museum displays and the internet'
- Develop a diver lead monitoring programme though a central scheme to enhance the current data and monitor ongoing site formation processes. Given the current data this should largely be centred around the SMS Cöln
- Conduct remote sensing surveys over the sites an a greater time frame.

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[6.2] Spirek,J.D. & D.A.Scott-Ireton Eds, 'The Plenum Series in Underwater Archaeology. Submerged Cultural Resource management. Preserving & Interpreting Our Sunken Maritime Heritage', Kluwer Academic, 2003, ISBN:0-306-47856-0
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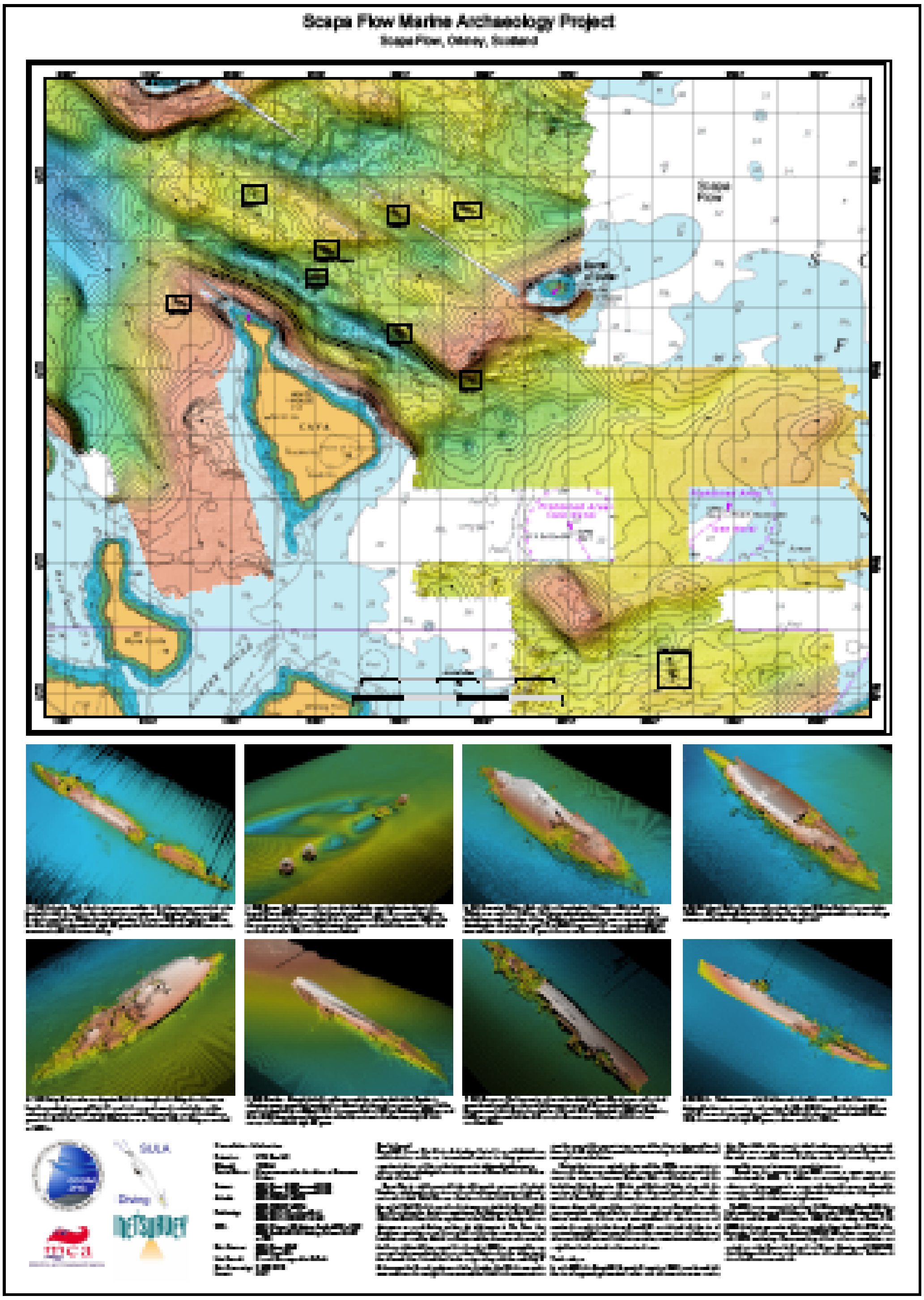

Figure 6.1: 2006 ScapaMAP poster