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**THE KOREAN SOCIETY OF UNDERWATER
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2023년 울릉군 연안바다목장 수산자원량 추정조사 연구

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A Study on the Estimation of Fisheries Resources in the Coastal Marine Ranching Area of Ulleung-Do, 2023

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In this study, the spatiotemporal distribution and biomass of fish were estimated during both daytime and nighttime in June, August, and October, using underwater acoustic surveys in the Ulleung-do coastal marine ranching area. Analysis of the echograms indicated that fish schools were primarily distributed in the surface and midwater layers. However, catch data showed a predominance of benthic species. Dominant species included bottom-dwelling fish such as the parajulis (*Halichoeres poecilepterus*) and redfin velvetfish (*Hypodytes rubripinnis*). Midwater species that typically form schools, such as Japanese jack mackerel (*Trachurus japonicus*), were relatively scarce in the catches. This discrepancy suggests that the distribution of midwater fish could not be fully characterized with the current methods. Therefore, improvements in sampling gear capable of covering the entire water column are necessary. In addition, the acoustic backscattering strength a critical parameter for accurate estimation of fish biomass requires further study to enhance the reliability of biomass assessments.

Key words: Ulleung-do, Marine ranching area, Fisheries resources, Estimation

Running title: 울릉군 연안바다목장 수산자원량 조사

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서론

우리나라의 연안은 무분별한 해안개발, 양식어업의 증가, 자원 남획, 어장 오염에 따른 평균 어획량은 점차 감소하였고, 1982년 UN의 200해리 배타적경제수역 (EEZ) 협정 확대에 의하여 어장은 축소되었다 (MIFAFF, 2009). 바다목장 사업과 수산자원 관리 사업은 2001년 통영을 기점으로 전국 각 해역별 맞춤형 바다목장 생성으로 동해 울진군에는 관광형 바다목장, 남해 여수에는 다도해형 바다목장, 서해 태안에는 갯벌형 바다목장 그리고 제주도엔 관광 체험형 바다목장 해역을 시범바다목장으로 지정하고 조성하였으며, 그 결과를 바탕으로 전국 각 해역별 특성에 적합한 바다목장 모델을 개발하고 조성하여 관리하고 있다 (Lee et al., 2012). 앞서 선행된 시범 바다목장의 노하우를 바탕으로 수산자원의 회복과 효율적인 관리를 위한 목표를 가지고 정부에서는 2006년부터 연안바다목장 사업을 통하여 지속적인 생산력을 유지를 위한 바다목장 조성 사업을 추진하고 있으며, 2011년에는 수산자원관리공단이 설립되어 바다숲 사업을 기반으로 포괄적인 수산자원관리사업을 전담하고 있다 (Kim et al., 2011; Lee and Kang, 1994).

바다목장에 정확한 상태를 평가하고 진단하여 효율적인 수산자원 관리를 수행하기 위해서는 서식하는 수산자원의 현존량을 정확하게 조사해야 된다. 수산자원의 현존량을 조사하는 방법에는 자망, 통발 및 조망등과 같은 어구를 이용한 조사방법, 잠수부 또는 CCTV를 이용한 수중카메라 촬영법 그리고 어군탐지기를 이용한 방법 등이 있다 (Kang et al., 2008).

조사어구를 이용한 방법은 종을 명확하게 규명할 수 있는 장점이 존재하나 환경적 영향에 따라 어구를 설치하는데 어려움이 존재하고 전체 해역을 조사하는 것은 시간적, 경제적 어려움이 존재한다. 잠수부 및 CCTV 등을 활용하여 직접 촬영하는 조사 방법은 현장의 수질, 수심의 한계성 및 어류의 회피본능 자극 등을 이유로 정량적인 데이터 수집에 대한 어려움이 따르나, 수중음향 조사기법은 상대적으로 짧은 시간동안 넓은 해역 전 수층을 조사할 수 있다 (Oh et al., 2010; Hwang et al., 2004; MIFFAF, 2008). 수중음향 조사기법은 조사해역의 우점어류의 음향산란강도 (Target strength, TS)와 현장조사를 통하여 얻어지는 체적산란강도 (Volume back scattering strength, SV)를 기반으로 수산자원 현존량을 파악할 수 있으며, 이 조사방법은 이미 노르웨이, 캐나다 등 여러 선진국에서 널리 사용되는 기법 중의 하나로써, 수산자원을 평가하는 도구로써 활발하게 사용되고 있다 (Ohshimo, 2004; Kang et al., 2008).

따라서, 본 연구에서는 연안바다목장이 조성된 울릉도 연안바다목장 해역에서 수중음향을 이용하여 서식하는 어류의 분포 및 현존량을 파악하여 어민의 소득 증대 및 지속가능한 어업의 활용 방안으로 사용하고자 한다.

재료 및 방법

조사해역 및 조사선 설계

본 조사는 음향을 이용하여 연안바다목장이 조성된 울릉도 바다목장해역에 서식하는 어류의 분포 밀도 및 현존량을 파악하였다(Fig. 1). 조사일자는 1차는 2023년 06월 16일, 2차는 2023년 08월 30일, 3차는 2023년 10월 26일 총 3회 수행되었다. 조사 면적에 따라 조사 라인을 설정하였고, 조사해역 범위 내에서 Algen (1983)의 DOC (Degree of coverage)의 식 (1)을 이용하여 설정하여 조사하였다.

$$DOC = \frac{N}{\sqrt{A}} \quad (1)$$

여기서, N은 조사 정선의 길이, A는 조사해역의 면적이다, 조사정선의 길이는 약 16.1 km이고 조사면적은 약 4 km²이었다. DOC의 값이 6이하가 되지 않도록 하고 수평으로 평행하게 하여 조사선을 설정하여 각 해역별로 주, 야간 각 1회씩 정선 조사를 실시하였다.

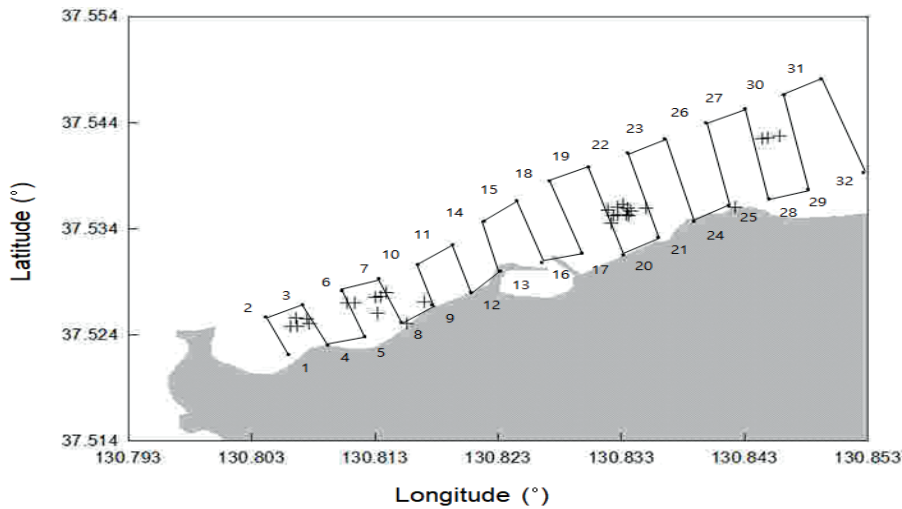


Fig. 1. Acoustic transect lines for hydroacoustic survey at Ulleung marine ranching area, Korea

가. 조사 시스템 및 자료 처리 방법

음향을 이용한 바다목장 현장조사는 과학어군탐지기 split beam 방식의 120 kHz 주파수를 사용하여 음향 데이터를 수집하였다 (EK-60, Simrad, Norway). 어군탐지기는 크게 3가지 부분으로 분류되는데 송수파기 (Transducer 38&120kHz), 표시기 (sens p560, Samsung, Korea), 제어기 (GPT 38&120kHz) 부분으로 분류된다. 송수파기 부분은 지지대를 이용하

여 선박의 현측에 부착하여 조사하였다(Fig. 2).

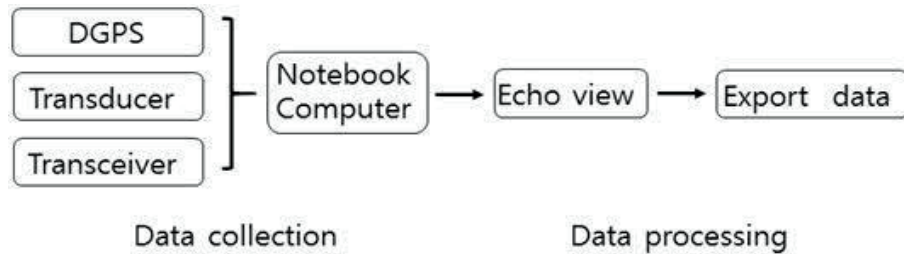


Fig. 2. System configuration used for hydroacoustic survey at Ulleung marine ranching area, Korea

음향조사 특성상 선박이 항주 중 발생하는 기포의 영향을 많이 받기 때문에 수면에서 1.5~2 m 아래에 설치하였고, 선속은 5~6 knots 유지하며 조사를 실시하였다. 음향자료 수집 시 어초와 해저부분의 탐지능력을 높이기 위하여 음파의 펄스폭을 0.512 m/s 설정하였고, 펄스 반복주기는 1초로 설정하여 데이터를 취득하고, 표시부에서 실시간으로 확인하며 하드디스크에 저장하였다. 현장 좌표는 정확성 높이기 위해 DGPS (DGPS, SPR-1400, Samyoung, Korea)를 사용하여 음향데이터와 같이 하드디스크에 저장하였다 (Fig. 3).

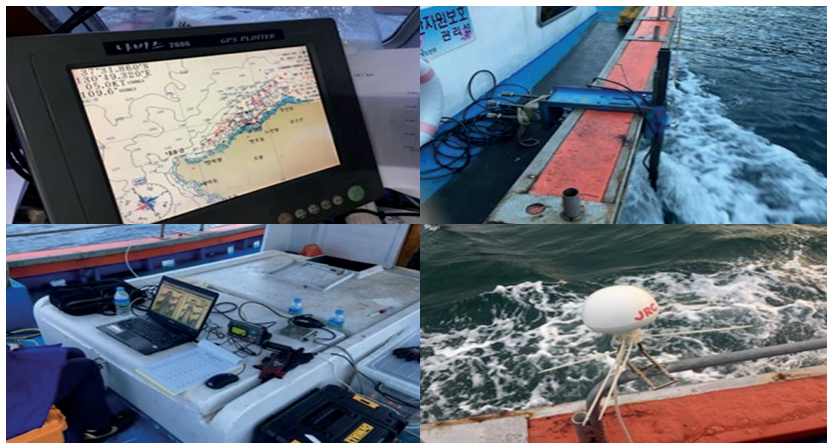


Fig. 3. Hydroacoustic systems used for the fieldwork

이와 같이 수집된 음향자료는 음향데이터 분석소프트웨어 EchoView version 8 (Myriax)를 이용하여 분석하였다. 해수면 3.0 m 해저면 부분을 제거한 다음 0.1 n.mile 의 EDSU (Elementary Distance Sampling Unit) 간격으로 추출하여 적분값 으로 표현된 면적산란계수 (Nautical Area Scattering Coefficient, NASC, $m^2/n.mile^2$) 값으로 나타내어 표현하였다(Fig. 4).

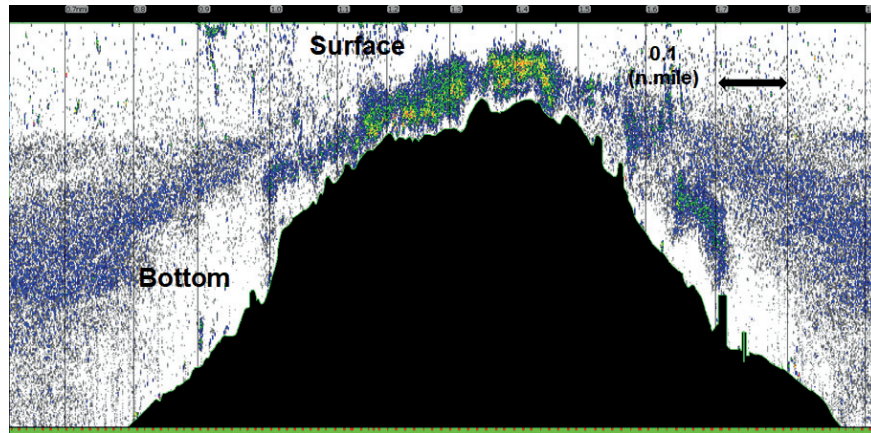


Fig. 4. Echogram of acoustic data for extracting fish abundance.

나. 수산자원의 현존량 추정법

본 연구의 목적인 과학어탐을 이용하여 각 조사 해역별 어류의 현존량을 파악하는데 있기 때문에 현장에서 수집한 체적산란강도 (Volume backscattering strength, SV)의 데이터를 0.1 n.mile 간격으로 적분하여 NASC 값으로 변환하여 이용하였다. 변환하는 관계식은 식 (2)와 같이 나타내었다.

$$NASC = 4\pi 1852^2 \int_{r_1}^{r^2} Sv dr \quad (2)$$

과학어군탐지기에서 탐지 되는 각 개체의 TS값과 현장에서 수집된 데이터의 변환 값인 NASC값을 역으로 계산하면 어군의 밀도 (ρ , g/m³)를 산정할 수 있다 (McClatchie et al. 2003; Simmonds and MacLennan. 2005). 여기서, 대상 어류의 체장 (L, cm)에 따른 TS 와 후방산란단면적은 각각 식 (4)와 (5)와 같이 나타낼 수 있다.

$$NASC = \rho \cdot TS \quad (3)$$

$$TS = 20 \cdot \log_{10}(L) + TS_{cm} \quad (4)$$

$$\sigma = 4\pi 10^{\left(\frac{10}{TS}\right)} \quad (5)$$

서식하는 어류의 체장 (L, cm) 및 체중 (w, g) 관계식은 다음 식 (6)과 같이 나타낼 수 있다.

$$\omega = aL^b \quad (6)$$

따라서, 조사해역에 분포하는 어류의 밀도 ρ 를 구하는 식은 식 (4), (5)의 값에 의하여 식 (7)을 분석하여 조사 해역의 밀도를 파악할 수 있다.

$$\rho = \left(\frac{NASC}{\sigma} \right) \cdot \omega = aL^b / 4\pi 10^{\left(\frac{10}{TS} \right)} \cdot NASC \quad (7)$$

그리고, 어군의 밀도(ρ)는 식 (7) 와 같이 0.1 n.mile간격으로 적분값인 NASC를 어군의 TS (0) 값을 나눈 다음 어체의 중량 (ω)를 곱하여 값을 구한다. 그리고 식 (7)의 우변에서는 NASC를 제외한 나머지 부분은 어류의 TS의 특성과 체장-체중을 고려한 부분으로 음향자료로부터 밀도를 계산하는 변환계수 (Conversion factor CF)로 각 해역별 계산된 변환계수로 나타낸다.

펄스에코법을 사용하는 과학어군탐지기로 수중생물을 탐지할 때, 이 펄스와 음향 빔의 지향각으로 정의되는 수중의 공간적 범위 내에 포함되는 모든 에코신호는 하나의 레벨로 수신된다. 또한, 앞에서 언급한 바와 같이 에코적분법은 음향신호가 개체어의 에코이든 어군의 에코이든 상관없이 적분하게 되므로, 과학어군탐지기에 수신되는 에코신호에는 여러 어종이 포함되어 있다할지라도, 이를 각각 어종에 대해 분리할 수 없는 경우가 대부분이다. 그러나 조사해역에 대하여 어종들의 분포 특성이 어획조사 위치와 동일한 특성을 가진다고 가정할 수 있다면, 어획조사로부터 얻은 어종들의 구성비와 각 대상어종의 음향산란특성을 고려하여, 음향적분의 값을 각 어종별로 배분할 수 있다. 어종에 의한 면적산란계수를 NASC라 하면, 그 값은 다음의 식 (8)로 추정된다.

$$NASC_i = \frac{w_i < \sigma_i > NASC}{\sum_{k=1}^n w_k < \sigma_k >} \quad (8)$$

여기서, NASC는 전체해역에 대한 면적산란계수, n 은 어획된 어종의 수, w_i 는 어종 i 의 어획비율, $< \sigma_i >$ 는 어종 i 의 평균 음향산란 단면적을 나타낸다.

$$B = A \cdot \rho \quad (9)$$

식 (9)로 조사해역의 어군 평균 밀도 (ρ)를 구한 후, 조사해역의 면적 (A , m^2)을 곱하여 어류의 현존량을 계산하였다 (Jolly and Hampton, 1990).

결과 및 고찰

1. 음향조사 결과

1) 2023년 06월 16일 주간에 어류의 수직분포

음향을 이용하여 울릉도 해역에서 주간에 조사한 어류의 수직 분포를 Fig. 5와 같이 나타내었다. 가로축은 시간과 정점의 변화를 세로축은 수심의 변화를 나타내었다. Fig. 5 아래의 Scale bar는 어류의 강도를 나타내었다. 어류의 강도가 높아질수록 빨간색으로 낮

을수록 회색으로 나타난다. 조사해역의 수심분포는 3~100 m였고, 조사해역의 저층에서 긴 띠 형태로 분포하였고 어초 주변에 분포하는 것으로 나타났다. St. 1~3, St. 8~9, St. 12~15, 정점의 저층에서 중·소형 어군이 분포하여 나타났다.

2) 2023년 06월 16일 주간에 어류의 시·공간적 분포

주간의 시·공간적 분포 특성을 파악하기 위하여 수직으로는 해수면에서 해저면까지 수평으로는 0.1 n.mile의 EDSU 마다 적분하여 얻은 NASC값으로 어류의 분포를 나타내었고, “+”표시는 어초가 설치된 위치를 표시하여 Fig. 6과 같이 나타내었다. NASC값은 어류의 음향학적 밀도를 표시하는 것으로 ($50\text{m}^2/\text{nmi}^2$, $100\text{m}^2/\text{nmi}^2$, $500\text{m}^2/\text{nmi}^2$, $1000\text{m}^2/\text{nmi}^2$, $2000\text{m}^2/\text{nmi}^2$)을 기준으로 분류하여 표시하였고, 원의 크기 및 색깔별로 그 값의 크기를 표시하였다. 2023년 6월 16일 주간에 어류의 밀도는 조사해역에서 아래쪽으로 많은 분포를 하였고, 조사해역에서 대부분 강한 어군의 강도가 나타났다. 전체 NASC값 중 $50\text{m}^2/\text{nmi}^2$ 미만은 44%, $100\text{m}^2/\text{nmi}^2$ 미만은 13%, $500\text{m}^2/\text{nmi}^2$ 미만은 19%, $1000\text{m}^2/\text{nmi}^2$ 미만은 8%, $2000\text{m}^2/\text{nmi}^2$ 미만은 8%, $2000\text{m}^2/\text{nmi}^2$ 이상은 8%로 나타났다. 대부분의 어류 밀도는 44%를 차지한 $50\text{m}^2/\text{nmi}^2$ 미만 이었다.

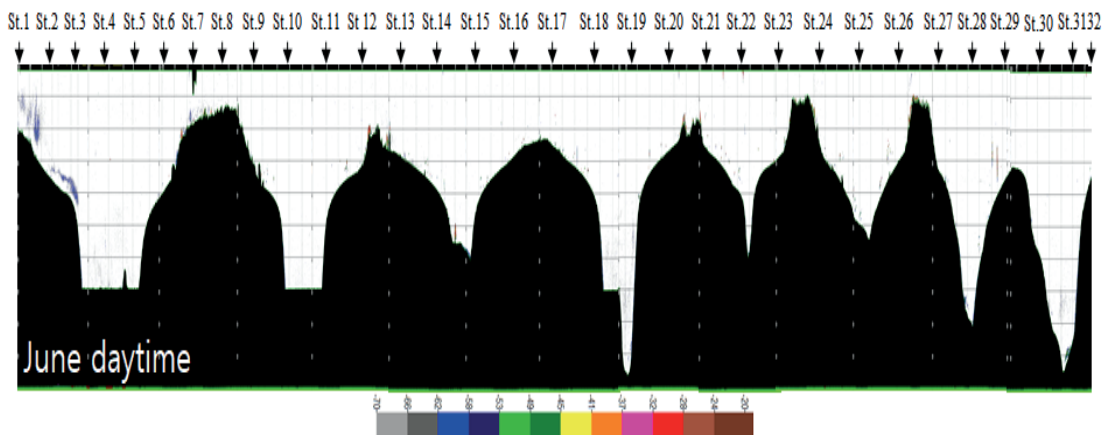


Fig. 5. Vertical distribution of fish during the daytime of June 16, 2023.

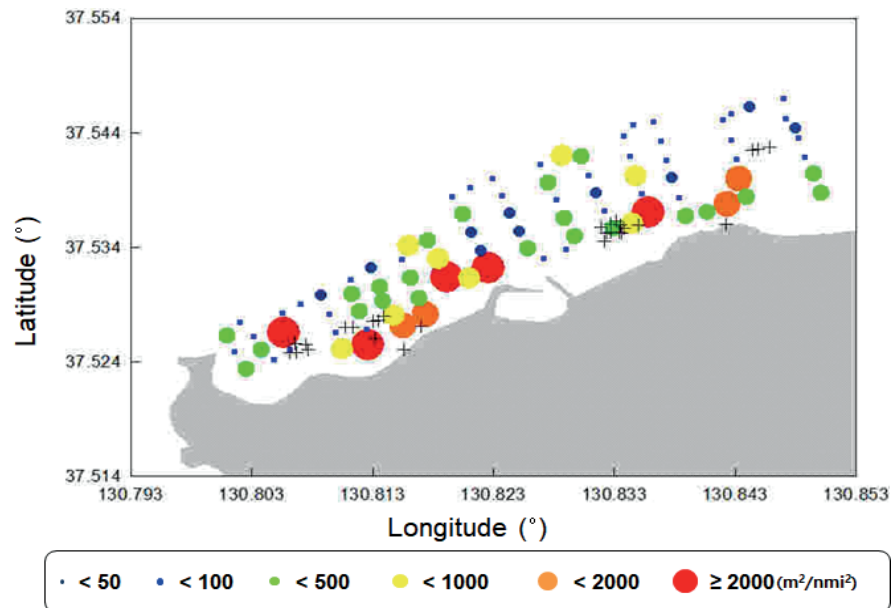


Fig. 6. Spatiotemporal patterns of fish distribution during the daytime on June 16.

3) 2023년 06월 16일 주간(2)에 어류의 수직분포

울릉도 섬의 특성상 조사해역의 접근도 쉽지 않고 동해 먼 바다의 특성상 너울이 높은 해역이고 조사 다음날인 17일은 해상 날씨가 좋지 않아 2023년 06월 16일은 주간 조사를 2회 실시 하였다. 주간(2) 조사한 어류의 수직 분포를 Fig. 7과 같이 나타내었다. St. 1에서 중층가까이 중형 어군이 관측되었고, St. 7~8까지에서 저층에서 강한 어군이 탐지되었고, St. 10~12, St. 18~19, St. 21, St. 24~26, St. 28~29 정점에서 중·소형 어군이 나타났다. 조사해역의 저층에서 정착성 어군이 탐지되었다.

4) 2023년 06월 16일 주간(2)에 어류의 시·공간적 분포

주간(2)의 시·공간적 분포는 Fig. 8에 나타내었으며 인공어초 주변에서 강한 어군이 나타났다, 주로 연안 쪽에서 강한 반응을 보였다. 전체 NASC값 중 50 m^2/nmi^2 미만은 37%, 100 m^2/nmi^2 미만은 22% , 500 m^2/nmi^2 미만은 21%, 1000 m^2/nmi^2 미만은 6%, 2000 m^2/nmi^2 미만은 6%, 2000 m^2/nmi^2 이상은 10%로 나타났다. 대부분의 어류 밀도는 37%를 차지한 50 m^2/nmi^2 미만 이었다.

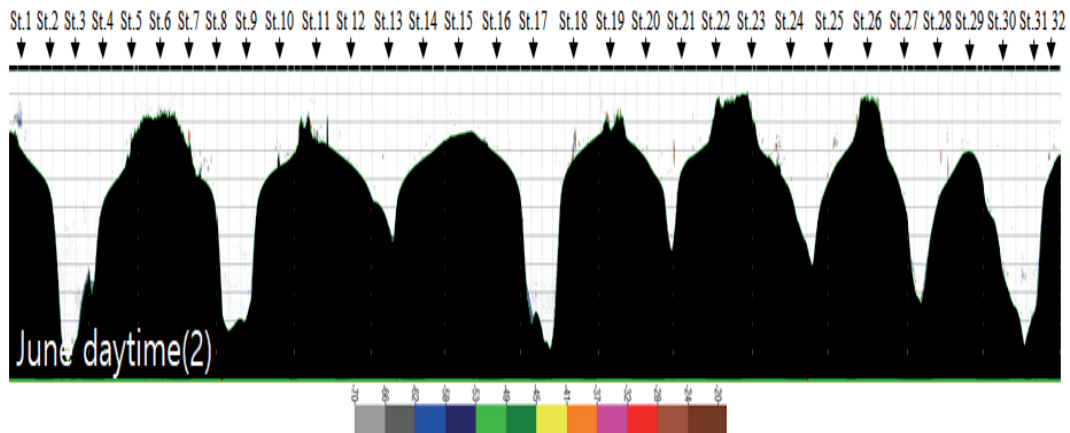


Fig. 7. Vertical distribution of fish during the daytime (2) of June 16, 2023.

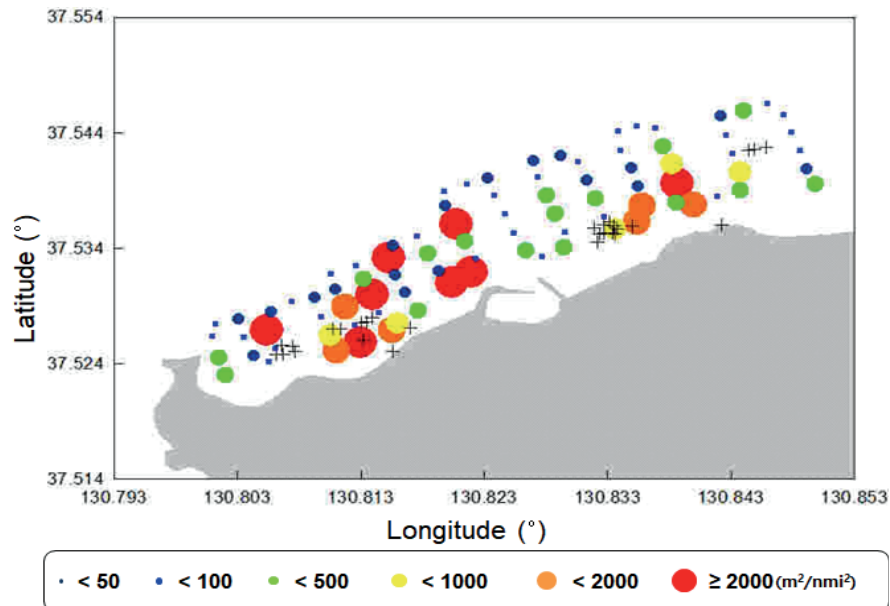


Fig. 8. Spatiotemporal patterns of fish distribution during the daytime (2) on June 16.

5) 2023년 08월 30일 주간 어류의 수직 분포

주간에 조사한 어류의 수직 분포를 Fig. 9와 같이 나타내었다. 전 중층에서 각 개별 어류의 분포를 나타내었고, St. 3~4 에서는 강한 중형 어군이 나타났으며, 각 개체어별로 중·저층에 넓게 퍼져 분포하였다. 그리고 해당해역에서 정점 조사 중 바다 위로 방어 때가 수면위로 움직이는 것이 관측되었기에 에코그램에 표시된 St. 3~4에 나타난 강한 어군은 방어 어군으로 추정된다.

6) 2023년 08월 30일 주간 어류의 시·공간적 분포

주간의 시·공간적 분포는 Fig. 10에 나타내었으며, 대부분의 어군이 조사해역 연안에서 어류가 나타났고, 전체 해역에서 각 개체어로 분포하였다. 전체 NASC값 중 50 m²/nmi²미

만은 55%, 100 m^2/nmi^2 미만은 17% , 500 m^2/nmi^2 미만은 12%, 1000 m^2/nmi^2 미만은 6%, 2000 m^2/nmi^2 미만은 3%, 2000 m^2/nmi^2 이상은 7%로 나타났다. 대부분의 어류 밀도는 17%를 차지한 50 m^2/nmi^2 미만이었다.

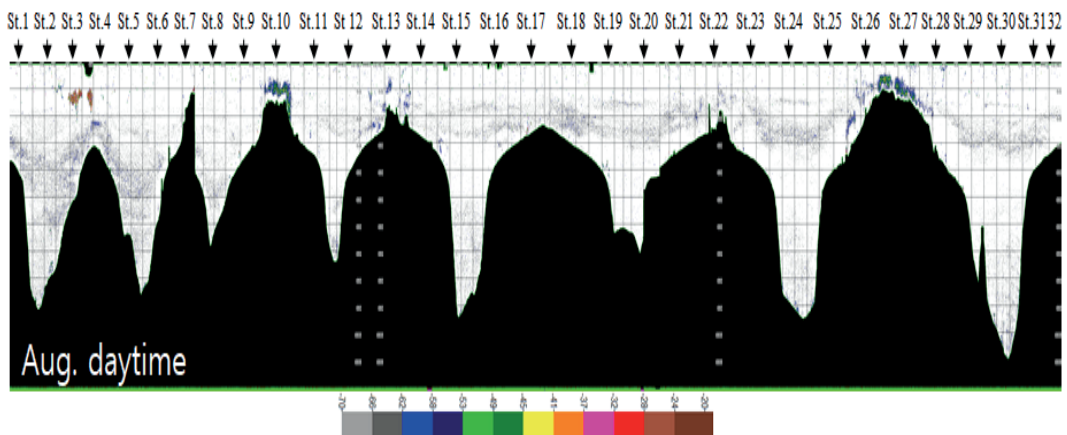


Fig. 9. Vertical distribution of fish during the daytime of August 30, 2023.

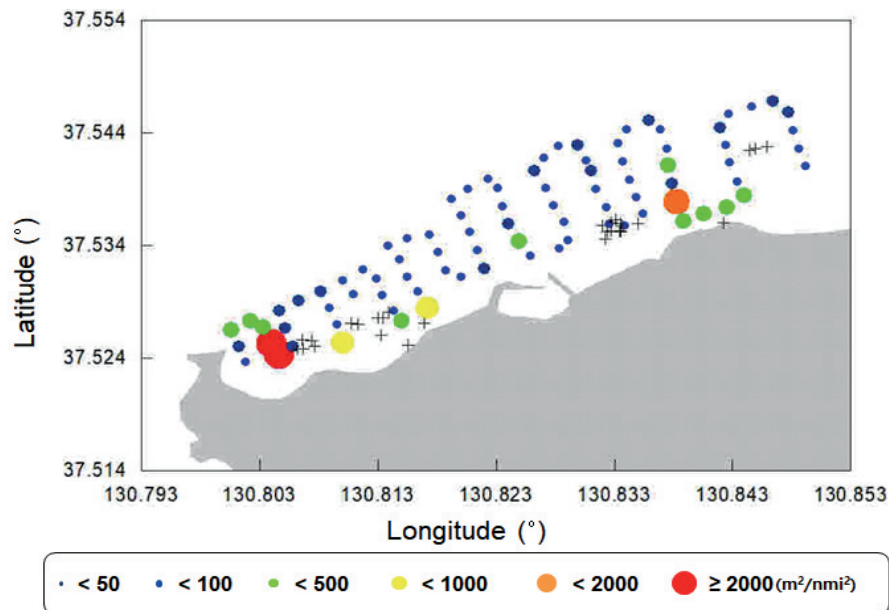


Fig. 10. Spatiotemporal patterns of fish distribution during the daytime on August 30.

7) 2023년 08월 30일 야간에 어류의 수직분포

야간에 조사한 어류의 수직 분포를 Fig. 11과 같이 나타내었다. 조사해역의 중층에서 어군이 분포하였고, St. 6~7, St. 12~13, St. 17~18 정점에서 강한 어군의 분포가 나타났고, 조사해역 중·저층에서 각 개체 별로 어류가 분포하였다.

8) 2023년 08월 30일 야간에 어류의 시·공간적 분포

야간의 시·공간적 분포는 Fig. 12에 나타내었으며, 조사해역 연안에서 주로 강한 어군이 분포하였으며, 주로 인공어초 주변에서 강한 반응이 나타났다. 전체 NASC값 중 50 m^2/nmi^2 미만은 23%, 100 m^2/nmi^2 미만은 38%, 500 m^2/nmi^2 미만은 31%, 1000 m^2/nmi^2 미만은 2%, 2000 m^2/nmi^2 미만은 3%, 2000 m^2/nmi^2 이상은 3%로 나타났다. 대부분의 어류 밀도는 38%를 차지한 100 m^2/nmi^2 미만 이었다.

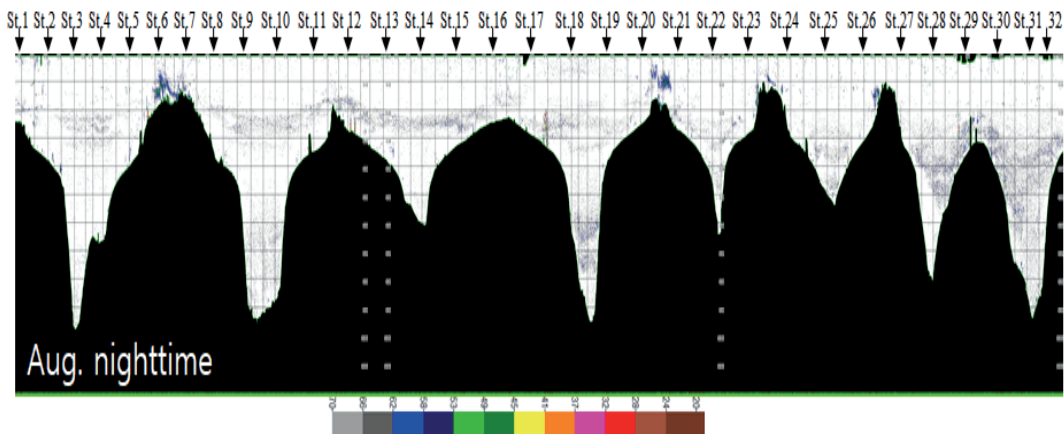


Fig. 11. Vertical distribution of fish during the nighttime of August 30, 2023.

9) 2023년 10월 26일 주간에 어류의 수직분포

주간에 조사한 어류의 수직 분포를 Fig. 13에 나타내었다. 조사해역의 표층에서 저층까지 넓게 각 개체별로 어류가 분포 하고 있으며, St. 5~7, St. 11, St. 14, St. 21 St. 27~28 정점에서 소형 어군들이 저층에 분포하고 있다.

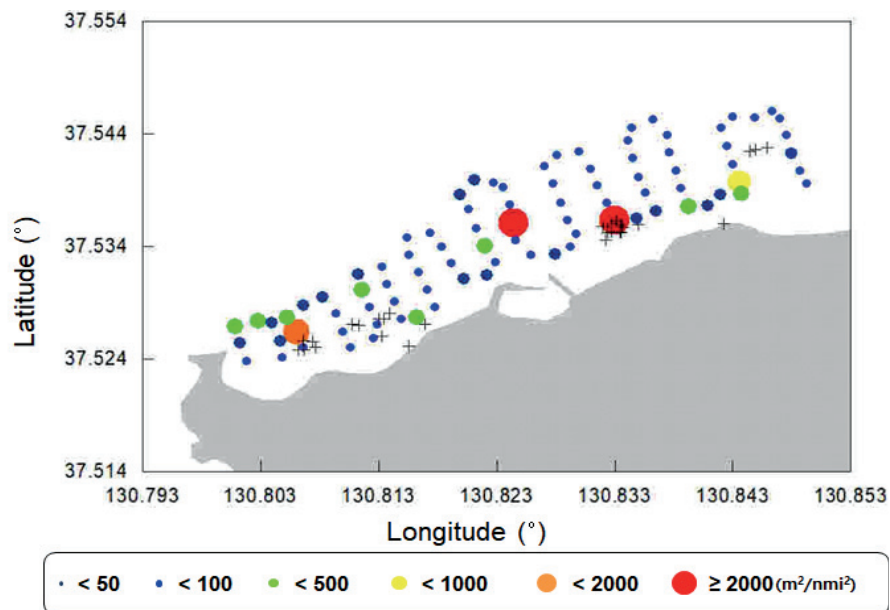


Fig. 12. Spatiotemporal patterns of fish distribution during the nighttime on August 30.

10) 2023년 10월 26일 주간 어류의 시·공간적 분포

주간의 시·공간적 분포는 Fig. 14에 나타내었으며, 조사해역의 표·중층에서 각 개체별 어류로 분포 되었고, 조사해역 연안으로 강한 어군으로 탐지되었다. 전체 해역에서 전체 NASC값 중 50 m^2/nmi^2 미만은 12%, 100 m^2/nmi^2 미만은 9%, 500 m^2/nmi^2 미만은 57%, 1000 m^2/nmi^2 미만은 8%, 2000 m^2/nmi^2 미만은 4%, 2000 m^2/nmi^2 이상은 10%로 나타났다. 대부분의 어류 밀도는 57%를 차지한 500 m^2/nmi^2 미만 이었다.

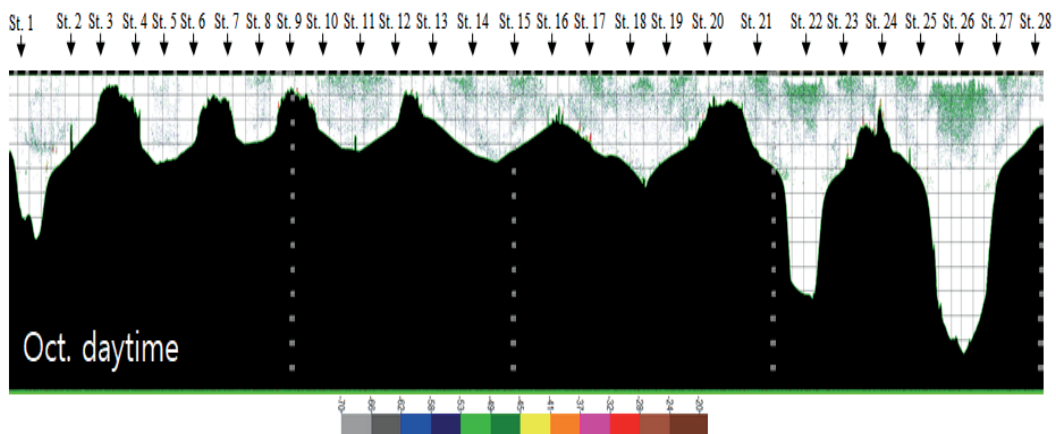


Fig. 13. Vertical distribution of fish during the daytime of October 26, 2023.

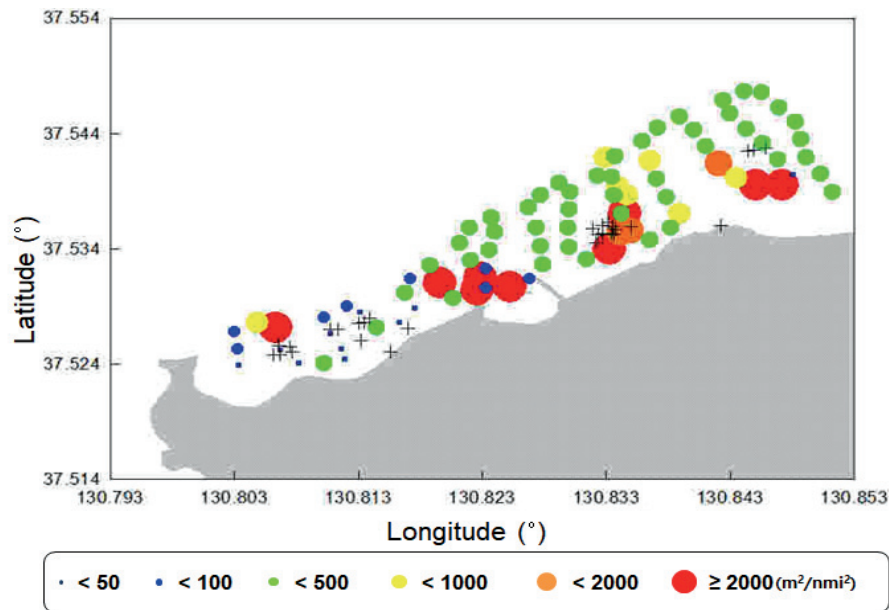


Fig. 14. Spatiotemporal patterns of fish distribution during the daytime on October 26, 2023.

11) 2023년 10월 26일 야간에 어류의 수직분포

야간에 조사한 어류의 수직 분포를 Fig. 15와 같이 나타내었다. 조사해역 St. 2~3, St. 4~5, St. 10~11, St. 21~24, 저층에서 소형 어군이 분포하는 것이 보였고, 그 외 해역에는 수심 40 m에서 긴 띠를 이루며 어류가 각 개체별로 분포하였다.

12) 2023년 10월 26일 야간에 어류의 시·공간적 분포

야간의 시·공간적 분포는 Fig. 16에 나타내었으며, 조사해역에서 연안에서 어류의 강도가 강하게 나타났고, 소형 어군의 형태로 분포하였다. 전체 NASC값 중 50 m^2/nmi^2 미만은 4%, 100 m^2/nmi^2 미만은 4%, 500 m^2/nmi^2 미만은 49%, 1000 m^2/nmi^2 미만은 24%, 2000 m^2/nmi^2 미만은 10%, 2000 m^2/nmi^2 이상은 9%로 대부분의 어류 밀도는 49%를 차지한 500 m^2/nmi^2 미만 이었다.

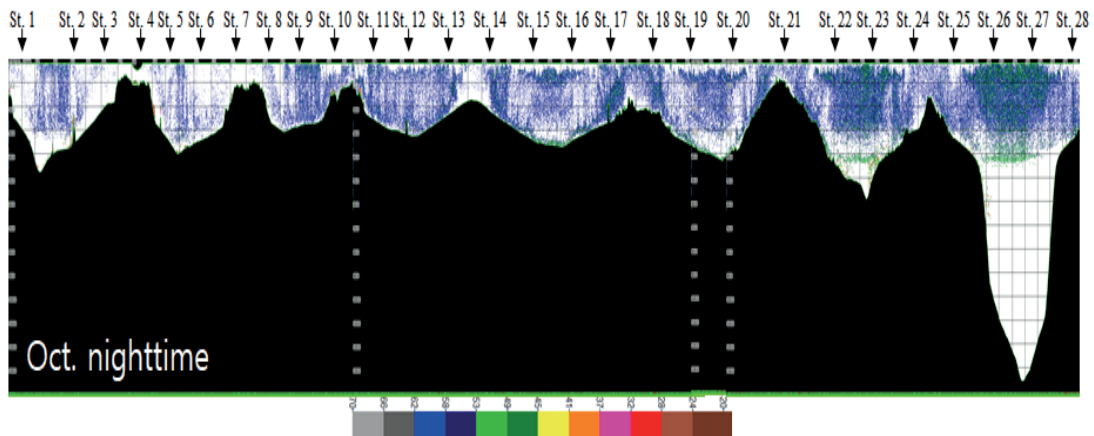


Fig. 15. Vertical distribution of fish during the nighttime of October 26, 2023.

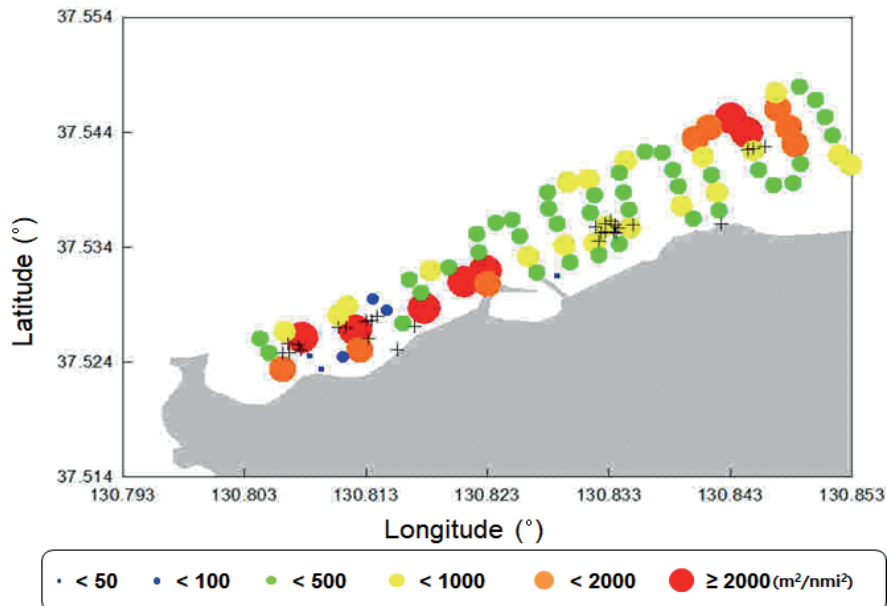


Fig. 14. Spatiotemporal patterns of fish distribution during the nighttime on October 26, 2023.

2. 어구를 이용한 어획조사 결과

어구를 이용하여 조사해역에 서식하는 어류의 현존량을 평가하기 위해서는 그 해역에서 서식하는 어종의 구성비, 체장-체중 정보 등 어종의 생물학적 정보가 필요하다. 본 해역에서 어획조사는 한국수산자원관리공단에서 통발, 자망을 이용하여 어획하였다. 울릉도 해역의 어획 조사는 2023년 6월, 8월, 10월에 이루어졌다.

6월에 어획된 어류의 어종별 구성비를 Fig. 17과 같이 나타내었다. 어획된 종은 흑돔, 참돔, 전갱이, 자리돔, 용치놀래기, 삼세기, 볼락, 베도라치, 밀복, 미역치, 문어, 말쥐치, 돌돔, 도다리, 능성어, 광어 등이 었으며, 우점 어류로는 음향으로 탐지가 어려운 저서어류를 제외하고 조피볼락, 말쥐치, 쥐노래미로 나타내었다.

8월에 어획된 어류의 구성비는 Fig. 18과 같이 나타내었다. 어획된 어류는 황어, 쥐치, 쥐노래미, 조피볼락, 성대, 방어, 문치가자미, 망상어, 말쥐치, 넙치, 등이 어획되었으며, 음향으로 탐지가 어려운 저서어류를 제외하고 조피볼락, 망상어, 방어로 나타내었다.

10월의 어획된 어종별 구성비는 Fig. 19와 같다. 어획된 종의 정보는 쥐노래미, 조피볼락, 성대, 방어, 망상어, 말쥐치, 돌돔, 노래미, 넙치 등이 어획되었으며, 음향으로 탐지가 어려운 저서어류를 제외하고 망상어, 말쥐치, 쥐노래미로 나타내었다.

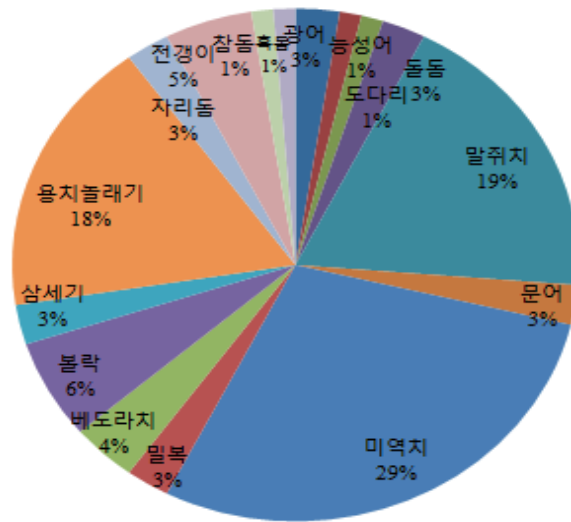


Fig. 17. Proportional composition of fish species caught by traps and gillnets at Ulleung marine ranching area in June 2023.

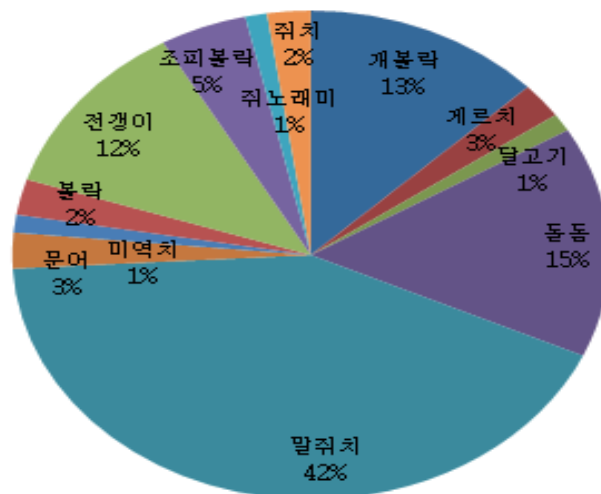


Fig. 18. Proportional composition of fish species caught by traps and gillnets at Ulleung marine ranching area in August 2023.

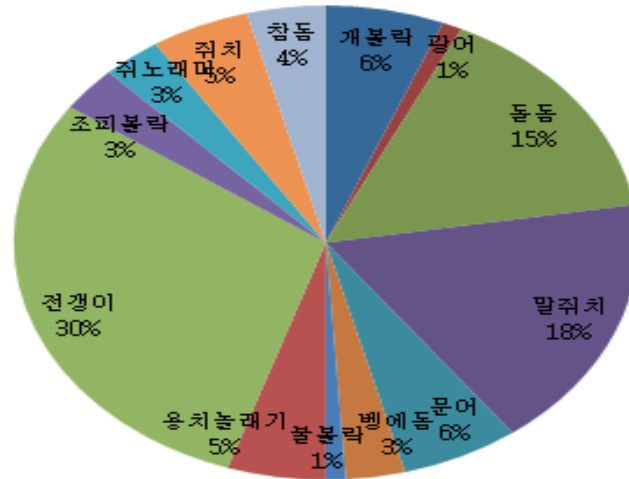


Fig. 19. Proportional composition of fish species caught by traps and gillnets at Ulleung marine ranching area in October 2023.

6월에 우점종인 말쥐치, 미역치, 용치놀래기의 체장-체중 관계식 및 체장 체중의 분포를 각각 Fig. 20, 21 및 22에 나타내었다. 말쥐치의 체장-체중 관계식은 $w = 0.002L^{3.5985}$ ($R^2 = 0.9418$) 평균체장은 26.0 cm 평균체중은 261.3 kg이었다. 미역치의 체장-체중 관계식은 $w = 0.033L^{2.593}$ ($R^2 = 0.8573$) 평균체장은 8.3cm 평균체중은 8.2 kg이었다.

용치놀래기의 체장-체중 관계식은 $w = 0.0345L^{2.6756}$ ($R^2 = 0.8966$) 평균체장은 17.0 cm 평균체중은 74.7 kg로 나타났다.

8월에 우점종인 개불락, 돌돔, 말쥐치의 체장-체중 관계식 및 체장-체중의 분포를 Fig. 23, 24 및 25에 나타내었다. 개불락의 체장-체중 관계식은 $w = 0.1423L^{2.3364}$ ($R^2 = 0.7785$) 평균체장은 19.1 cm 평균체중은 143.3 kg이었다.

돌돔의 체장-체중 관계식은 $w = 0.2012L^{2.3311}$ ($R^2 = 0.6969$) 평균체장은 20.4 cm 평균체중은 241.9 kg이었다.

말쥐치의 체장-체중 관계식은 $w = 0.0096L^{3.1043}$ ($R^2 = 0.7034$) 평균체장은 21.8 cm 평균체중은 142.1 kg로 나타났다.

10월에 우점종인 돌돔, 말쥐치, 전갱이의 체장-체중 관계식 및 체장-체중의 분포를 그림 26, 27, 28에 나타내었다. 돌돔의 체장-체중 관계식은 $w = 0.0206L^{3.0743}$ ($R^2 = 0.8476$) 평균체장은 20.4 cm 평균체중은 235.4 kg이었다. 말쥐치의 체장-체중 관계식은 $w = 0.0114L^{3.0123}$ ($R^2 = 0.9297$) 평균체장은 22.3 cm 평균체중은 137.5 kg이었다.

전갱이의 체장-체중 관계식은 $w = 0.01L^{3.0763}$ ($R^2 = 0.9484$) 평균체장은 21.3 cm 평균체중은 127.3 kg로 나타났다.

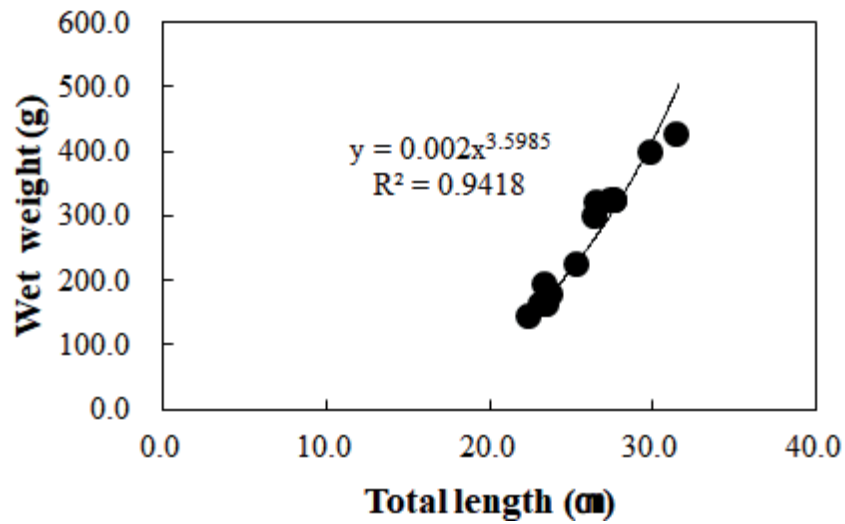


Fig. 20. Length-weight relationship of the black scraper (*Thamnaconus modestus*) in June 2023.

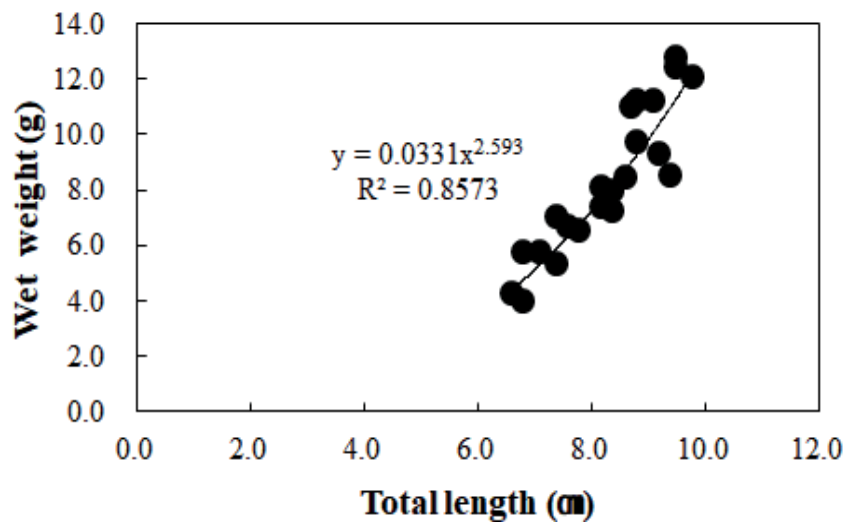


Fig. 21. Length-weight relationship of the redfin velvetfish (*Hypodytes rubripinnis*) in June 2023.

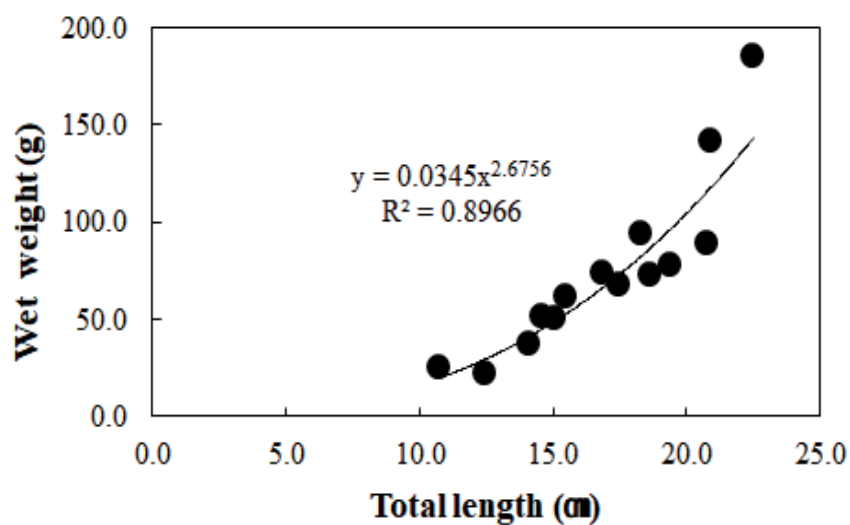


Fig. 22. Length-weight relationship of the parajulis (*Halichoeres poecilepterus*) in June 2023.

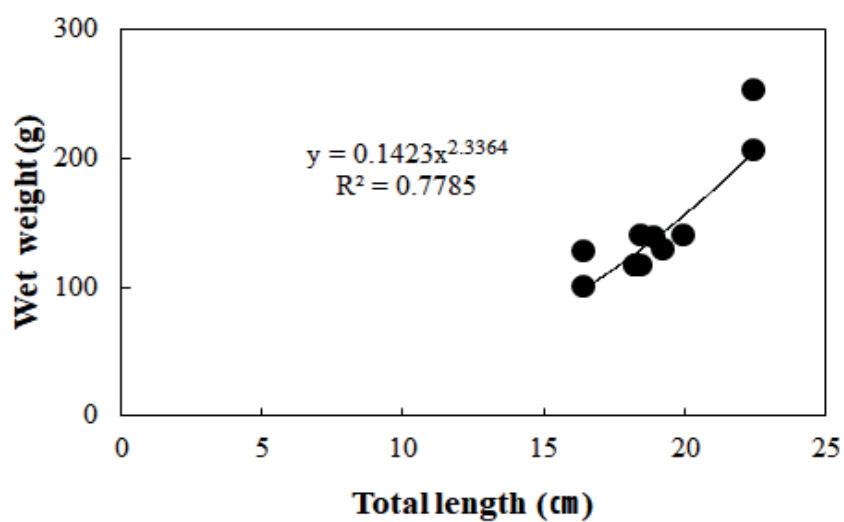


Fig. 23. Length-weight relationship of the spotbelly rockfish (*Sebastes pachycephalus*) in August 2023.

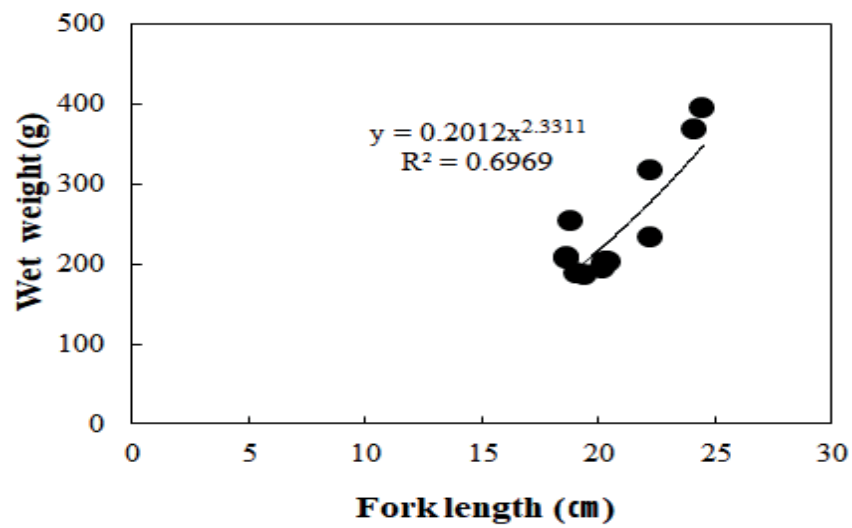


Fig. 24. Length-weight relationship of the rock bream (*Oplegnathus fasciatus*) in August 2023.

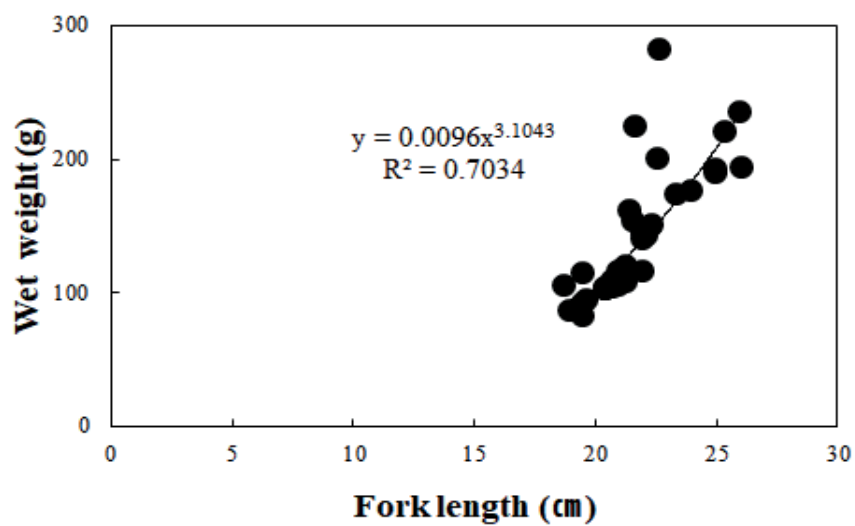


Fig. 25. Length-weight relationship of the black scraper (*Thamnaconus modestus*) in August 2023.

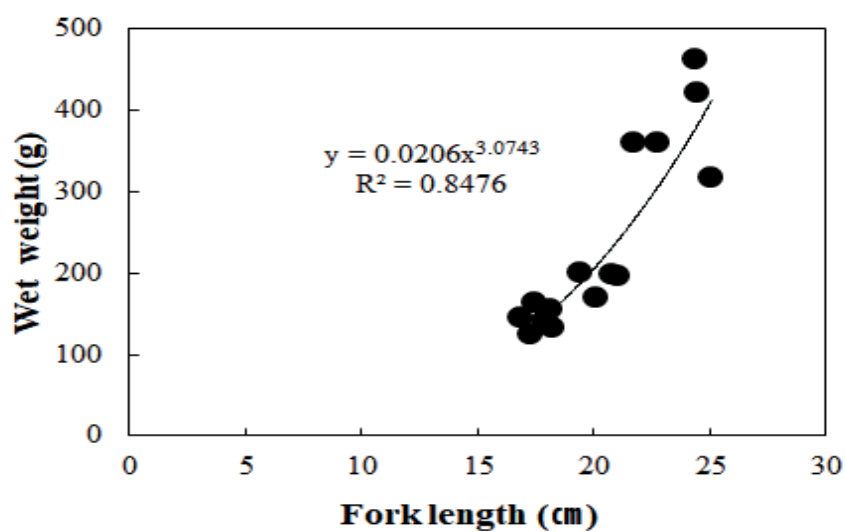


Fig. 26. Length-weight relationship of the rock bream (*Oplegnathus fasciatus*) in October 2023.

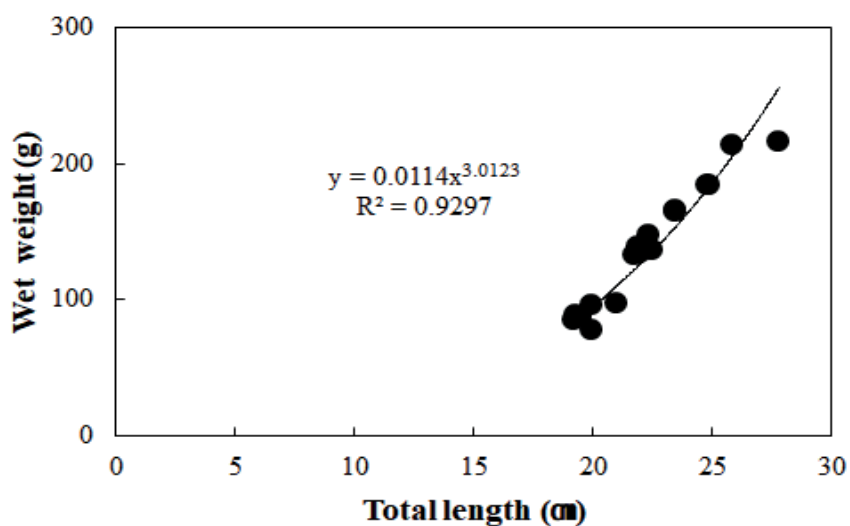


Fig. 27. Length-weight relationship of the black scraper (*Thamnaconus modestus*) in October 2023.

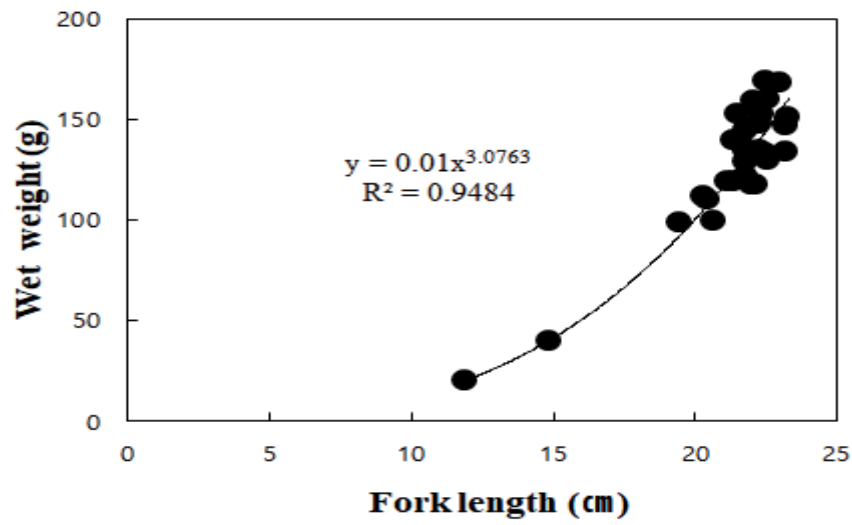


Fig. 28. Length-weight relationship of the Japanese jack mackerel (*Trachurus japonicus*) in October 2023.

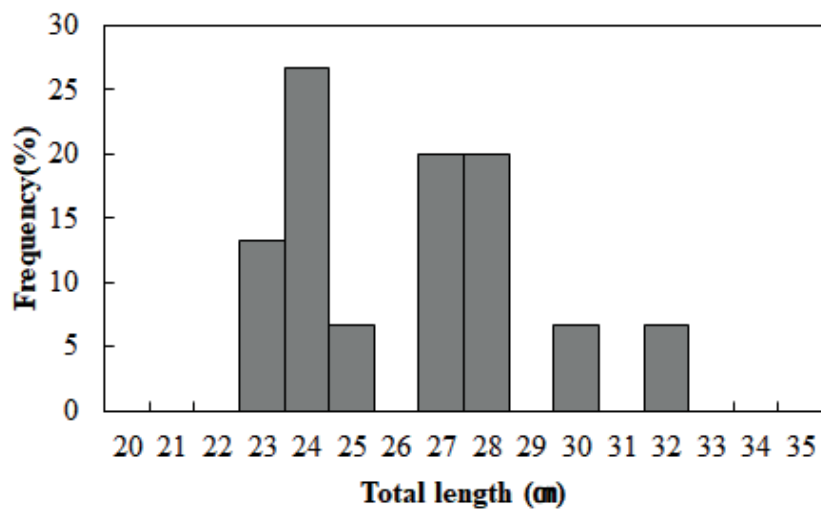


Fig. 29. Body length-frequency distribution of the spotbelly rockfish (*Sebastes pachycephalus*) in June 2023.

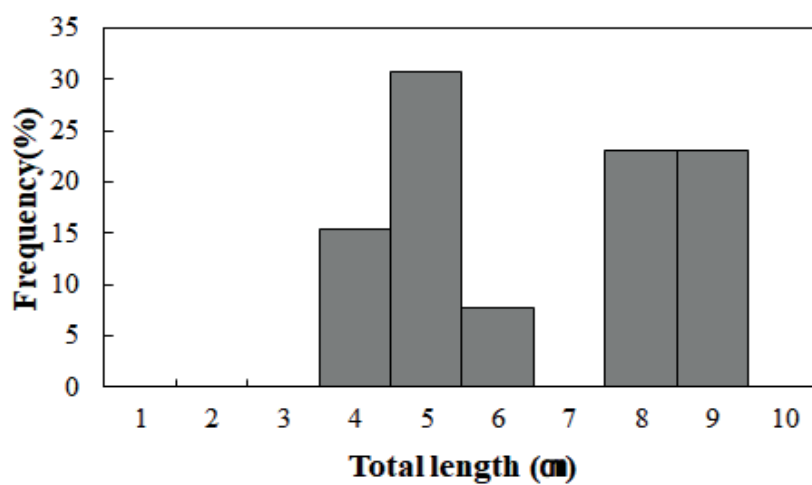


Fig. 30. Body length-frequency distribution of the redfin velvetfish (*Hypodytes rubripinnis*) in June 2023.

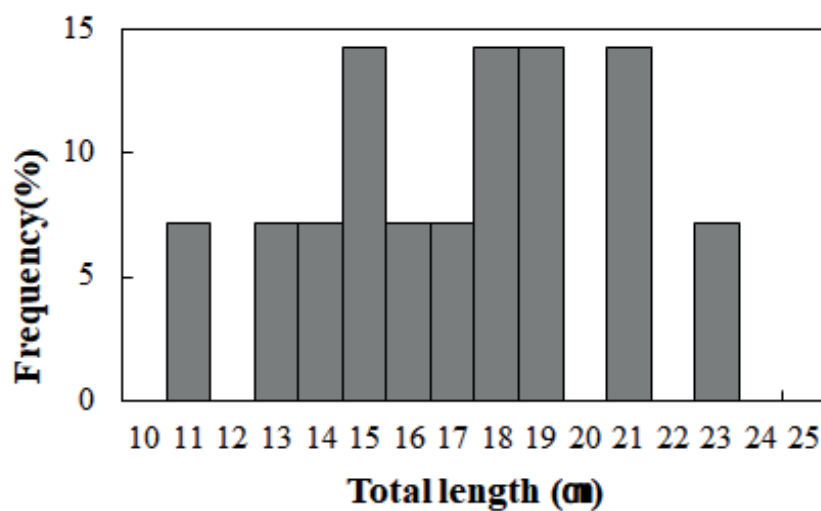


Fig. 31. Body length-frequency distribution of the parajulis (*Halichoeres poecilepterus*) in August 2023. .

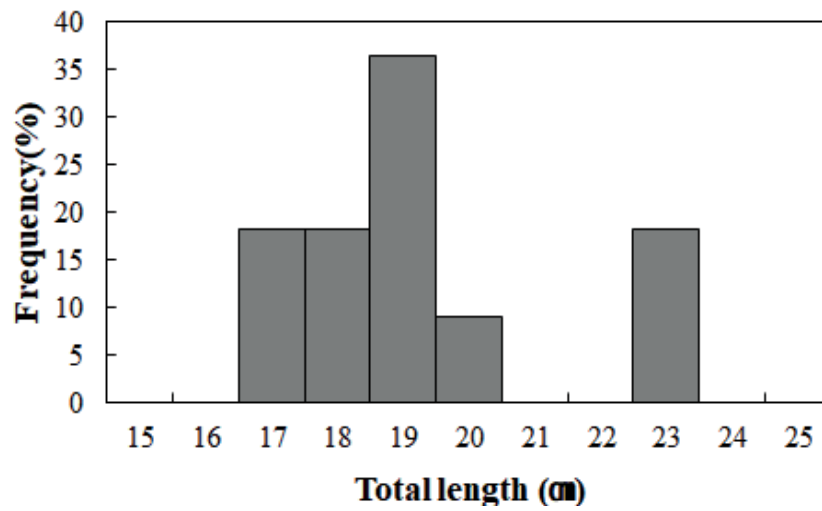


Fig. 32. Body length-frequency distribution of the spotbelly rockfish (*Sebastes pachycephalus*) in August 2023.

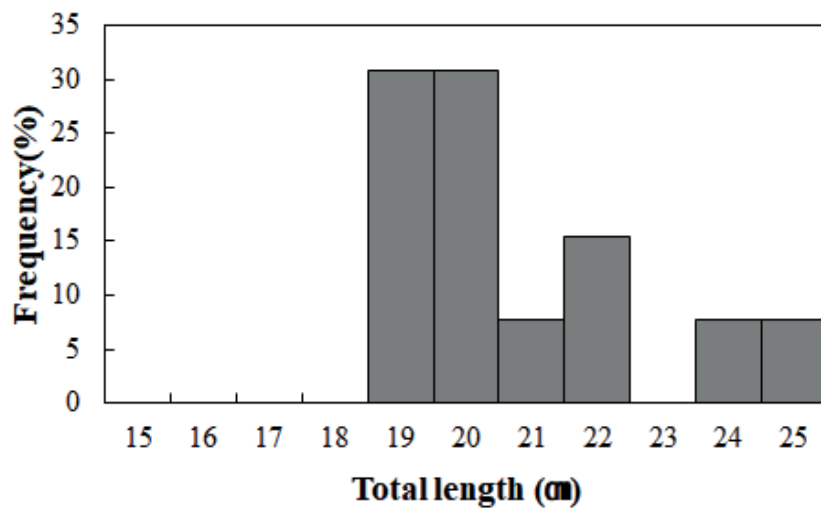


Fig. 33. Body length-frequency distribution of the rock bream (*Oplegnathus fasciatus*) in August 2023.

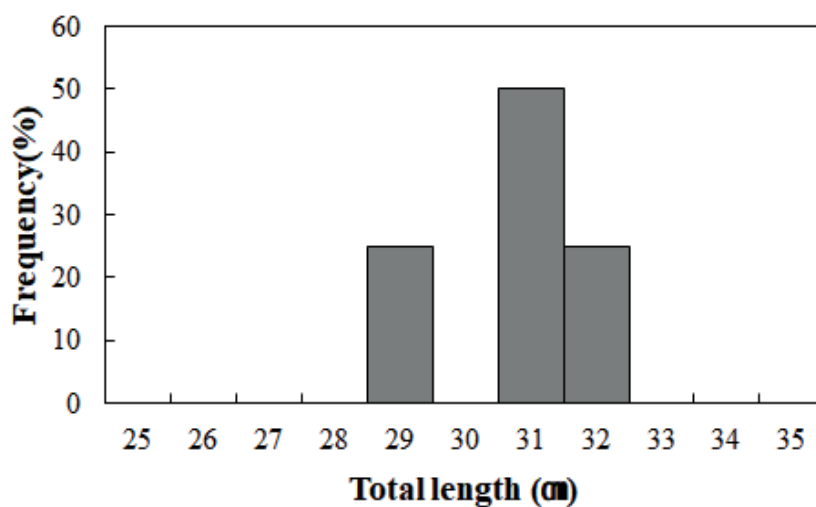


Fig. 34. Body length-frequency distribution of the black scraper (*Thamnaconus modestus*) in August 2023.

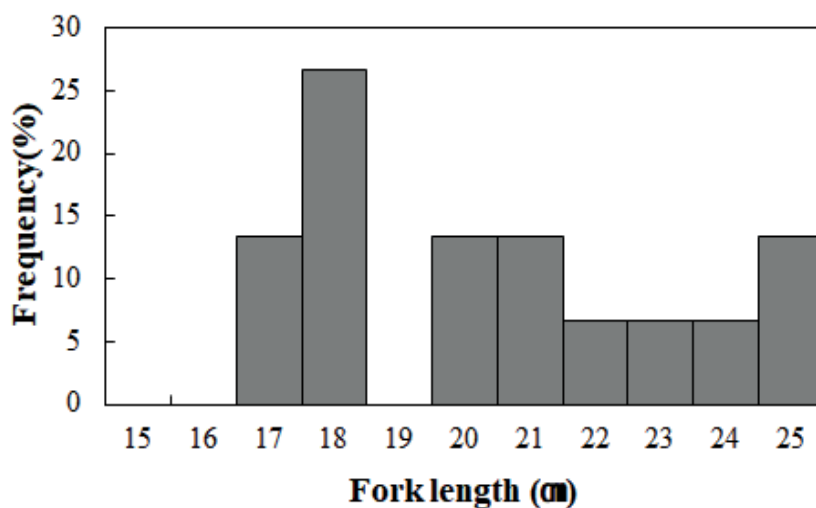


Fig. 35. Body length-frequency distribution of the rock bream (*Oplegnathus fasciatus*) in October 2023.

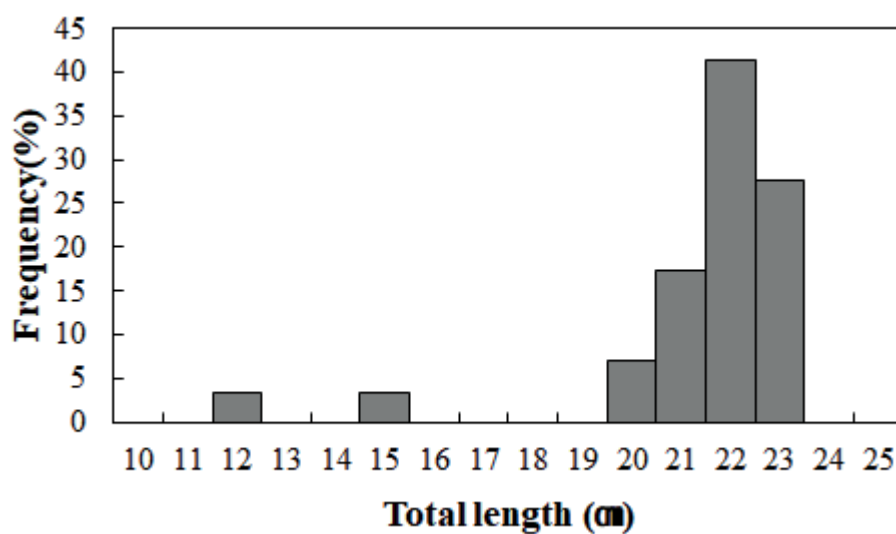


Fig. 36. Body length-frequency distribution of the Japanese jack mackerel (*Trachurus japonicus*) in October 2023.

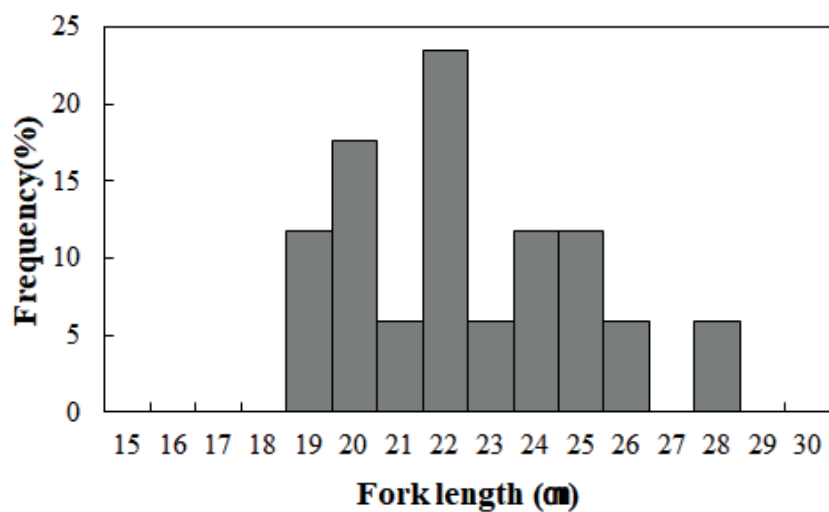


Fig. 37. Body length-frequency distribution of the black scraper (*Thamnaconus modestus*) in October 2023.

3. 울릉도 바다목장해역 우점 어류의 음향산란 특성

수산자원 현존량을 추정하기 위해서는 어종의 음향산란강도 (Target strength TS)가 꼭 필요한 요건 중 하나이다. 음향산란강도에 대한 연구가 많이 진행되고 있지만 아직 상당히 부족한 편이다. 본 연구에서는 선행된 연구를 인용하여 결과 분석을 실시하였다. 울릉도 바다목장해역에서 어획된 우점어종의 음향산란강도를 표 1과 같이 나타내었다. 음향산란강도의 선행 연구 결과가 없는 울릉도 바다목장해역의 우점어종인 말퀴치, 용치놀래기 미역치는 일반 경골어류의 120kHz 값을 적용하였고, 돌돔 또한 선행 연구결과가 없어 비슷한 체형을 가진 참돔의 연구결과를 인용하였다.

Table 1. Target strength of dominant species at Ulleung marine ranching area.

Species (Scientific name)		Target strength (TS)	References
June	black scraper (<i>Thamnaconus modestus</i>)	20 log (L)-72.0	Lee et al., 2014
	redfin velvetfish (<i>Hypodytes rubripinnis</i>)	20 log (L)-72.0	Lee et al., 2014
	parajulis (<i>Halichoeres poecilopterus</i>)	20 log (L)-72.0	Lee et al., 2014
Aug.	spotbelly rockfish(<i>Sebastes pachycephalus</i>)	20 log (L)-66.9	Mun et al., 2005
	rock bream (<i>Oplegnathus fasciatus</i>)	20 log (L)-73.9	Kang et al., 2001
	black scraper (<i>Thamnaconus modestus</i>)	20 log (L)-72.0	Lee et al., 2014
Oct.	rock bream (<i>Oplegnathus fasciatus</i>)	20 log (L)-73.9	Kang et al., 2001
	Japanese jack mackerel (<i>Trachurus japonicus</i>)	20 log (L)-66.7	Hwang et al., 2012
	black scraper (<i>Thamnaconus modestus</i>)	20 log (L)-72.0	Lee et al., 2014

4. 울릉도 바다목장해역에서 어류의 현존량

음향데이터를 이용하여 울릉도 바다목장해역의 현존량 추정한 결과는 표 2와 같다. 울릉도바다목장 조사해역의 면적은 $4 \times 10^{10} \text{ m}^2$ 이었다. 6월 주간예 Transect 6에서 $5.7 \text{ n}^2/\text{nm}^2$ 으로 가장 낮았고, Transect 5에서 $2426.2 \text{ n}^2/\text{nm}^2$ 으로 가장 높았다. 6월 야간에 Transect 2에서 $50.2 \text{ n}^2/\text{nm}^2$ 으로 가장 낮았고, Transect 5에서 $942.5 \text{ n}^2/\text{nm}^2$ 으로 가장 높았다. 8월 주간예 Transect 14에서 $21.9 \text{ n}^2/\text{nm}^2$ 으로 가장 낮았고, Transect 16에서 $2725.5 \text{ n}^2/\text{nm}^2$ 으로 가장 높았다. 8월 야간에 Transect 4에서 $58.1 \text{ n}^2/\text{nm}^2$ 으로 가장 낮았고, Transect 3에서 $1584.4 \text{ n}^2/\text{nm}^2$ 으로 가장 높았다. 10월 주간예 Transect 15에서 $77.9 \text{ n}^2/\text{nm}^2$ 으로 가장 낮았고, Transect 13에서 $3435.2 \text{ n}^2/\text{nm}^2$ 으로 가장 높았다. 10월 야간에 Transect 4에서 $172.8 \text{ n}^2/\text{nm}^2$ 으로 가장 낮았고, Transect 5에서 $1737.2 \text{ n}^2/\text{nm}^2$ 으로 가장 높았다.

음향산란강도를 이용하여 우점어류의 평균 밀도 및 현존량을 표 3에 나타내었다. 6월 주간에 평균 밀도는 말쥐치 34.3 g/m², 미역치 9.1 g/m², 용치놀래기 21.5 g/m²이었다. 6월 야간에 평균 밀도는 말쥐치 30.7 g/m², 미역치 8.2 g/m², 용치놀래기 19.2 g/m²이었다. 8월 주간에 평균 밀도는 개불락 8.6 g/m², 돌돔 63.6 g/m², 말쥐치 30.8 g/m²이었다. 8월 야간에 평균 밀도는 개불락 5.0 g/m², 돌돔 37.3 g/m², 말쥐치 18.1 g/m²이었다. 10월 주간에 평균 밀도는 돌돔 111.6 g/m², 전갱이 35.5 g/m², 말쥐치 10.5 g/m²이었다. 10월 야간에 평균 밀도는 돌돔 93.8 g/m², 전갱이 29.8 g/m², 말쥐치 8.8 g/m²이었다.

6월의 현존량은 주간에 말쥐치 306.6 ton, 미역치 0.4 ton, 용치놀래기 21.9 ton이었고 야간의 현존량은 말쥐치 274.4 ton, 미역치 0.3 ton, 용치놀래기 19.6 ton이었다. 총합은 주간에 916 ton, 야간에 297.3 ton 이었다. 8월의 현존량은 주간에 개불락 18.6 ton, 돌돔 320.5 ton, 말쥐치 86.7 ton이었고 야간의 현존량은 개불락 10.9 ton, 돌돔 187.8 ton, 말쥐치 50.8 ton이었다. 총합은 주간에 425.8 ton 야간에 249.5 ton이었다. 10월의 현존량은 주간에 돌돔 132.2 ton, 전갱이 52.7 ton, 말쥐치 77.1 ton이었고 야간의 현존량은 돌돔 111.1 ton, 전갱이 44.2 ton, 말쥐치 64.8 ton이었다. 총합은 주간에 262.6 ton 야간에 220.1 ton이었다.

본 조사는 울릉도 연안바다목장이 조성된 해역에서 수중 음향을 이용하여 6월, 8월, 10월 주·야간 어류의 시공간 분포 및 현존량을 추정하였다. 음향 조사 결과의 에코그램을 보면 표층, 중층에 주로 어군이 분포하였다. 그러나 어획자료는 주로 저서 어종이 분포하는 것을 알 수 있었다. 우점어종은 용치놀래기, 미역치 등 저층어류였고 중층 어류이고 무리를 이루는 전갱이의 경우 어획량이 많지 않았다. 이는 중층 어류의 분포를 명확하게 알 수 없는 것을 보였다. 전 수층의 어류를 파악할 수 있는 어구의 개량이 필요하다. 그리고 어류의 현존량을 추정하는 것에 대한 중요한 요건 중 하나인 어류의 음향산란강도 역시 더 많은 연구가 병행되어야 할 것으로 판단된다.

Table 2. Assessment of fish biomass in the Ulleung-do marine ranching area.

Transect	Station	June				August				October			
		daytime		nighttime		daytime		nighttime		daytime		nighttime	
		ni	NASC	ni	NASC	ni	NASC	ni	NASC	ni	NASC	ni	NASC
1	1~2	3	111.5	4	149.9	3	301.3	3	122.1	3	187.1	3	735.1
2	3~4	4	36.0	4	50.2	4	60.3	4	158.5	4	304.9	4	886.9
3	5~6	3	30.0	3	842.4	3	73.1	3	1574.4	5	340.7	5	1521.8
4	7~8	5	576.3	5	569.7	5	2019.9	5	58.1	3	2591.6	3	172.8
5	9~10	5	2426.2	58	942.5	2	215.1	5	200.2	4	2252.2	3	1737.2
6	11~12	5	5.7	6	1407.0	5	25.9	5	145.4	3	262.8	3	1242.3
7	13~14	5	1166.8	5	757.8	5	49.1	5	83.7	5	437.5	4	1270.5
8	15~16	4	78.1	4	741.1	5	65.4	5	261.1	6	540.7	5	392.6
9	17~18	5	3059	6	1417.2	5	49.2	6	130.2	6	1334.6	6	374.7
10	19~20	7	69.2	7	73.7	7	169.3	6	804.8	7	711.5	7	526.8
11	21~22	6	80.2	6	109.6	6	30.5	7	63.9	7	198.1	6	448.8
12	23~24	6	1348.6	6	221.4	8	272.2	6	71.0	5	808.3	6	435.8
13	25~26	6	697.4	6	581.3	7	949.3	7	109.0	7	3435.2	5	745.2
14	27~28	7	317.6	7	7641.1	8	21.9	7	275.1	6	723.1	6	1241.7
15	29~30	7	1419.0	6	175.9	7	143.5	7	914.6	8	77.9	6	754.5
16	31~32	9	611.0	7	69.5	7	2725.5	7	84.9	7	585.2	6	447.9
$\sum_{i=1}^N n_i$		87		87		87		88		86		78	
Survey area (A , m ²)		4×10 ⁷		4×10 ⁷		4×10 ⁷		4×10 ⁷		4×10 ⁷		4×10 ⁷	
Estimated Biomass (B , ton)		328.9		294.3		1206.1		249.5		262.0		220.1	
Coefficient of variation (CV , %)		11.5		5.4		8.0		1.4		21.0		7	

Table 3. Biomass and mean density of dominant species estimated by Target strength at Ulleung marine ranching area.

Fish species	Conversion factor	NASC partitioning	Mean density ($\bar{\rho}$, g/m ²)		Biomass(ton)	
			Day	Night	Day	Night
<i>Thamnaconus modestus</i>	0.137235464	0.93657421	34.3	30.7	306.6	274.4
<i>Hypodytes rubripinnis</i>	0.036671659	0.004386729	9.1	8.2	0.4	0.3
<i>Halichoeres poecilopterus</i>	0.086162000	0.101955850	21.5	19.2	21.9	19.6
<i>Sebastes pachycephalus</i>	0.043499927	0.215787242	8.6	5.0	18.6	10.9
<i>Oplegnathus fasciatus</i>	0.319855705	0.155181000	63.6	37.3	320.5	187.8
<i>Thamnaconus modestus</i>	0.155181000	0.280711915	30.8	18.1	86.7	50.8
<i>Oplegnathus fasciatus</i>	0.307707695	0.118420976	111.6	93.8	132.2	111.1
<i>Trachurus japonicus</i>	0.097878000	0.148508666	35.5	29.8	52.7	44.2
<i>Thamnaconus modestus</i>	0.028988000	0.733070358	10.5	8.8	77.1	64.8

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콘크리트 방형구를 이용한 조하대 해조천이에 관한 연구

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A Study on Subtidal Seaweed Succession Using Concrete quadrats

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This study on the marine algal succession process of three areas (Yeongunri, Pildo-island, Mangchiri), southern sea of Korea, was monitored March 2021 to May 2022. A total of 28 marine algal species were identified during the survey period, with 3 species as Chlorophyta (10.7%), 8 species as Ochrophyta (28.6%), and 17 species as Rhodophyta (60.7%). In Yeongun-ri, a total of 20 marine algal species were identified, with 3 species as Chlorophyta (15.0%), 6 species as Ochrophyta (30.0%), and 11 species as Rhodophyta (55.0%). In Pildo-island, a total of 18 marine algal species were identified, with 3 species as Chlorophyta (16.7%), 5 species as Ochrophyta (27.8%), and 10 species as Rhodophyta (55.6%). In Mangchi-ri, a total of 11 marine algal species were identified, with 2 species as Chlorophyta (18.2%), 3 species as Ochrophyta (27.3%), and 6 species as Rhodophyta (54.5%). The (R+C)/P values for Yeongun-ri, Pildo, and Mangchiri were 2.00, 1.83 and 2.00, respectively, indicating the marine algal flora of cold temperature to temperate. During the survey period, the dominant and subdominant species by study areas were *Ulva australis* and *Colpomenia sinuosa* in Yeongun-ri, *Gracilaria textorii* and *Sargassum honeri* in Pildo-island, and *S. honeri* and *U. australis* in Mangchi-ri. In each study areas, coarsely branched form (36.4-55.6%) showed the highest proportion, and the filamentous form and crustose form (5.0%-9.1%)

showed the lowest proportion. In all study areas, the marine algal succession process began with the establishment of annual algae species such as *U. australis* and *C. sinuosa* during the early succession. As the water temperature increased from July, melobesioidean algae started to cover the substrate. In late succession, young plants of perennial large brown algae started to establishment, showed typical successional patterns.

Key words: Concrete quadrats, Subtidal Seaweed, Succession

Running title: 콘크리트 방형구를 이용한 해조천이 연구

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서 론

바다숲은 다양한 해양생물의 산란장, 생육장, 먹이장 등 중요한 역할을 한다 (Watanuki and Yamamoto, 1990). 또한, 수산자원 생태계의 중요 환경자원으로서 직접적으로 우리 인간에게 식용, 의약용등으로 이용되며, 최근에 들어와서는 유어 낚시나 스킨 스쿠버 등 해양레저 활동과 체험하는 해양교육 활동의 장소로 제공되어 해양 체험관광 및 교육 수요의 확산에도 크게 일조한 것으로 평가받고 있다(Kang, 2018).

그러나, 우리나라에서는 1980년대 이후 제주도와 남해안 일부 해역에서 갯녹음 현상이 발생하기 시작하여 1990년대에는 동해 연안으로 확산되었고, 현재까지도 갯녹음은 확산 추세에 있으며, 이로 인하여 많은 면적의 바다숲이 사라지고 있다. 갯녹음이란 해조류의 일부 또는 전부가 탈락, 고사, 유실, 소멸하고 그 공간과 기질을 산호조류가 피복, 점유함으로써 암반이 백색, 황백색 또는 분홍색을 나타내는 현상이다. 이러한 갯녹음 현상은 과도한 섭식압, 연안개발, 수온상승 등 다양한 원인으로 인해 발생하고 있으며, 갯녹음이 발생하면서 바다숲을 서식처나 산란장으로 이용하는 모든 수중생물의 자원 또한 감소하게 되어 결국 어업생산이 현저하게 저하되는 결과를 초래함으로써 해양생태학적으로나 수산업적으로 심각한 문제가 된다고 보고하였다(Sohn et al., 2001; Kim, 2003; FIRA, 2019).

1970년대부터 인공어초 시설 사업과 수산 종자 매입방류 사업 위주로 시행하였지만, 갯녹음 발생 이후 이를 방지하기 위해 바다숲 조성 사업과 연안 바다목장 조성

사업 등 해양수산부 산하 연구기관이나 지자체에서 다양한 노력이 전개되고 있으며, 1971년부터 2021년까지 지난 50년 동안 인공어초는 대략 231,645 ha 가 시설되었다(FIRA, 2019; 2021).

자연 기질은 형성 시기와 위치, 경사도, 방위, 환경요인 등 연구자 임의로 조절하기 힘들기 때문에 자연 기질의 특성에 따른 저서생물의 분포변화 양식을 파악하는데 많은 제약과 어려움이 따른다. 이러한 점에서 인공기질은 연구자가 의도하는 바에 따라 생리적 또는 생물적 특성이나 환경을 단순화시킬 수 있으므로, 자연 상태에서 파악하기 어려운 군집 형성이나 천이과정을 용이하게 관찰할 수 있다. 또한, 자연 상태에서 반복 실험이 가능하고, 서식처에서 비연속적으로 분리 시설이 가능하므로 생태적 섬으로 정의된다. 이러한 점에서 인공기질은 저서생물 생태연구에 다양한 유용성을 제공한다(Borowitzka, 1978; Osman, 1982; Kim, 1987).

Cho et al. (2008), Choi et al. (2019), Lee and Choi (2019), Jung and Choi (2020) 등에 의해 인공기질을 활용한 해조 천이에 관한 연구가 제주, 문동리, 양양, 포항에서 진행되어왔지만, 남해안 연안에서 인공기질을 활용한 조하대 해조 천이에 관한 연구는 전무한 실정이다.

해양수산부 산하 연구기관이나 지자체 사업들이 효율적인 성과를 거두기 위해서는 많은 정점에서 해조군집에 관한 연구가 이루어짐으로써 해조천이 및 해조상의 변동이 상세하게 파악되어야 하며, 이를 바탕으로 과학적인 대책이 필요하다(Woo, 2022).

따라서, 이번 연구는 조하대에서 콘크리트 방형구 시설 이후 진행되는 해조 천이 패턴을 모니터링 하고, 천이 단계에 있어 군집구조와 우점종을 파악하여 인공기질을 활용한 바다숲 조성과 같은 연구에 필요한 기초자료를 제공하고자 하였다.

재료 및 방법

이번 연구의 조사 해역은 남해안 동부에 위치한 통영시 평립동 무인도인 필도, 산양읍 영운리 연안, 거제시 일운면 망치리 연안에서 2021년 1월부터 2022년 5월까지 격월로 실시되었다(Fig. 1). 조사 해역에서 천이패턴을 모니터링하기 위하여 각 해역의 조하대에서 SCUBA diving을 통하여 10×10 cm의 소방형구 25개로 구획된 50×50 cm 크기의 콘크리트 방형구 4개를 설치하였다(Fig. 2). 수중 디지털카메라(Sony RX100 M5)를 사용하여 콘크리트 방형구내에 천이된 해조류를 스틸사진 및 동영상

을 촬영하였고, 피도값 산출은 Saito and Atobe (1970)의 방형구법을 따랐다. 콘크리트 방형구 회수 이전까지는 촬영 결과물과 주변 암반부에 서식하는 해조류를 채집 동정한 결과를 바탕으로 자료를 확보하였다. 이러한 방법은 방형구내에 해조 천이 과정을 자연 상태 그대로를 모니터링하기 위함이며, 종 동정이 어려울 것으로 판단되는 해조류는 콘크리트 방형구내에서 소량 채집하여 종 동정에 참고하였다. 조사가 종료되는 시점인 5월에는 시설된 콘크리트 방형구를 모두 회수하여, 천이된 해조류를 전량 채집하였으며, 채집된 시료는 쿨러에 보관하여 실험실로 운반하였다 (Fig. 3). 동정 및 분류는 광학현미경(Olympus CH30), 입체현미경(Leica EZ4)을 사용하였고, 한국동식물도감(Kang, 1968), 제주의 바닷말(Lee, 2008), 한국산 해조류의 목록(Lee and Kang, 2001)을 참고하였다.

이번 연구에서 우점종 파악을 위한 중요도 계산은 출현 종의 빈도와 피도를 기초로 하여 다음과 같은 수식을 이용하였다(Saito and Atobe, 1970).

중요도 계산 수식

$$\text{빈도}(F) = \frac{qn}{25} \times 100 = 4 \cdot qn$$

· qn : 종이 출현한 10×10 cm 범위의 방형구 수

해조류의 피도를 기록하기 위해 다음의 수로 우점 또는 피도의 정도를 나타내었다.

5 : 기질표면의 1/2-1을 덮고 있는 경우(75%)

4 : 기질표면의 1/4-1/2을 덮고 있는 경우(37.5%)

3 : 기질표면의 1/8-1/4을 덮고 있는 경우(18.75%)

2 : 기질표면의 1/16-1/8을 덮고 있는 경우(9.375%)

1 : 기질표면의 1/16보다 적게 덮여 있을 경우(4.6875%)

$$\text{피도}(C) = \frac{C_1}{25} + \frac{C_2}{25} + \dots + \frac{C_{qn}}{25}$$

$C_1, C_2, \dots, C_{qn}$: 각 피도의 백분율 중간 값

상대피도(RC) = (X종의 피도 합/전체 종의 피도 합) × 100

상대빈도(RF) = (X종의 빈도 합/전체 종의 빈도 합) × 100

중요도(IV) = (RC+RF)/2

위도별 해조상의 특성을 분석하기 위하여 출현 종수를 이용, Segawa (1956)의 대롱편모조류에 대한 녹조류의 비(C/P)와 Feldmann (1937)의 대롱편모조류에 대한 홍조류의 비(R/P) 및 Cheney (1977)의 대롱편모조류에 대한 홍조류와 녹조류를 합한 값의 비율인(R+C)/P값을 사용하여 구하였다. 해조군집의 천이단계에서 생태적 특징 변화를 비교하기 위해 Littler and Littler (1984)의 기능형군에 따라 출현 종을 엽상형(sheet form), 사상형(filamentous form), 성긴분기형(msely branched form), 다육질형(thick leathery form), 유절산호말형(jointed calcareous form), 각상형(crustose form)의 6개 그룹으로 분류하였다. 각 해역의 해조군집의 차이를 파악하기 위해 출현한 해조류의 종 수를 기준으로 PRIMER statistical package (version 5.0)를 사용하여 유사도를 산출하였다.

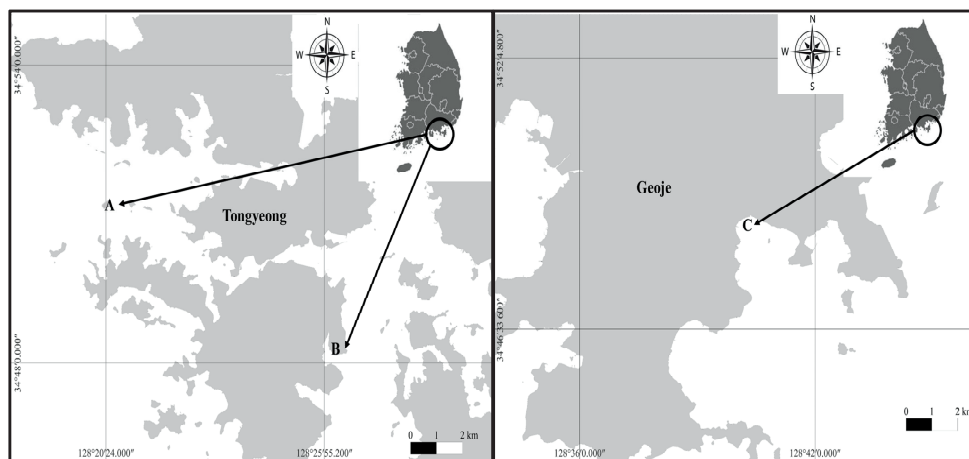


Fig. 1. A map showing the study areas in the coastal waters off Tongyeong and Geoje, southern sea, Korea. A, Pildo-island; B, Yeongun-ri; C, Mangchi-ri.

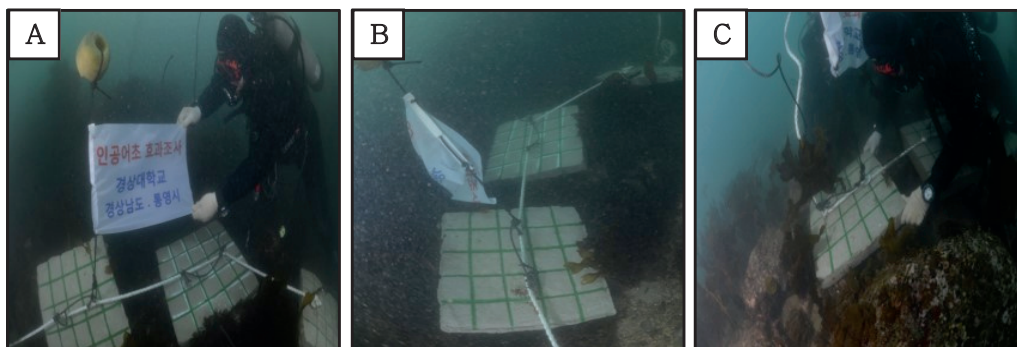


Fig. 2. Concrete quadrats installation process in the coastal waters off Tongyeong and Geoje, the South sea, Korea. A, Yeongun-ri; B, Pildo-island; C, Mangchi-ri.



Fig. 3. Concrete quadrats withdrawn from the coastal waters off Tongyeong and Geoje, southern sea, Korea. A, Yeongun-ri; B, Pildo-island; C, Mangchi-ri.

결 과

1. 출현종

조사 기간 동안 콘크리트 방형구내에 출현한 해조류 목록은 Table 1, 분류군별 출현 종 수는 Fig. 4, 분류군별 구성비는 Fig. 5와 같다. 조사기간 동안 모든 조사 해역에서 녹조류 3종(10.7%), 대롱편모조류 8종(28.6%), 홍조류 17종(60.7%)으로 총 28종이 출현하였다. 영운리에서 녹조류 3종(15.0%), 대롱편모조류 6종(30.0%), 홍조류 11종(55.0%)으로 총 20종이 출현하였고, 조사 해역 중 가장 많은 해조류의 종 수가 출현하였다. 필도는 녹조류 3종(16.7%), 대롱편모조류 5종(27.8%), 홍조류 10종(55.6%)으로 총 18종이 출현하였다. 또한, 망치리에서 녹조류 2종(16.7%), 대롱편모조류 3종(25.0%), 홍조류 6종(58.3%)으로 총 11종이 출현하였는데, 조사 해역 중에서 가장 낮은 종수가 출현하였다. 모든 조사 해역은 콘크리트 방형구 설치 초기인 2021년도 춘계를 제외하면 추계부터 다음 해 춘계까지 출현 종수가 비교적 높게 나타났으며, 하계에는 출현 종수가 낮게 나타나는 것을 확인할 수 있었다. 영운리와 망치리에서 구멍갈파래(*Ulva australis*)와 팽생이모자반(*Sargassum honeri*)이 가장 많이 출현하였고, 필도에서 팽생이모자반(*S. honeri*)과 잎꼬시래기(*Gracilaria textorii*)가 가장 많이 출현하였다. 또한, 조사해역 세곳 모두 구멍갈파래(*U. australis*), 창자파래(*U. intestinalis*), 팽생이모자반(*S. honeri*), 톱니모자반(*S. serratifolium*), 돌가사리(*Chondracanthus tenellus*)가 출현하였다.

Table 1. A list of marine algae occurred in the coastal waters off Tongyeong and Geoje, southern sea, Korea.

Month	Mar.			May			July			Sept.			Nov.			Jan.			Mar.			May		
	Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma			
Study areas																								
Species																								
Chlorophyta																								
<i>Codium fragile</i>																								
<i>Ulva australis</i>	+			+		+	+	+																
<i>U. intestinalis</i>	+			+		+						+	+	+										
Ochrophyta																								
<i>Colpomenia sinuosa</i>	+			+		+																		
<i>Dictyota dichotoma</i>											+									+				
<i>Myagropsis myagroides</i>										+														
<i>Sargassum fuvellum</i>																								
<i>S. horneri</i>						+																		
<i>S. serratifolium</i>																								
<i>Scytosiphon lomentaria</i>	+																							
<i>Undaria pinnatifida</i>																								
Rhodophyta																								
<i>Champia recta</i>																								
<i>Chondracanthus tenellus</i>						+																		
<i>Chondrus ocellatus</i>																			+					
<i>Crustose algae</i>																								
<i>Gelidium elegans</i>																								
<i>Gracilaria textorii</i>																								
<i>G. vermiculophylla</i>																								
<i>Grateloupia chiangii</i>																								
<i>G. elata</i>																								
<i>G. elliptica</i>																								
<i>G. turuturu</i>																								
<i>Hypnea asiatica</i>																								
<i>Laurencia pinnata</i>																								

*Abbreviations: Ye, Yeongun-ri; Pi, Pildo-island; Ma, Mangchi-ri



Table 1. (Continueud)

Species	Month	Study areas			Mar.			May			July			Sept.			Nov.			Jan.			Mar.			May		
		Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma	Ye	Pi	Ma			
<i>Lomentaria catenata</i>																												
<i>Martensia elegans</i>																												
<i>Plocamium telfairiae</i>																												
<i>Pterocladiaella capillacea</i>																												



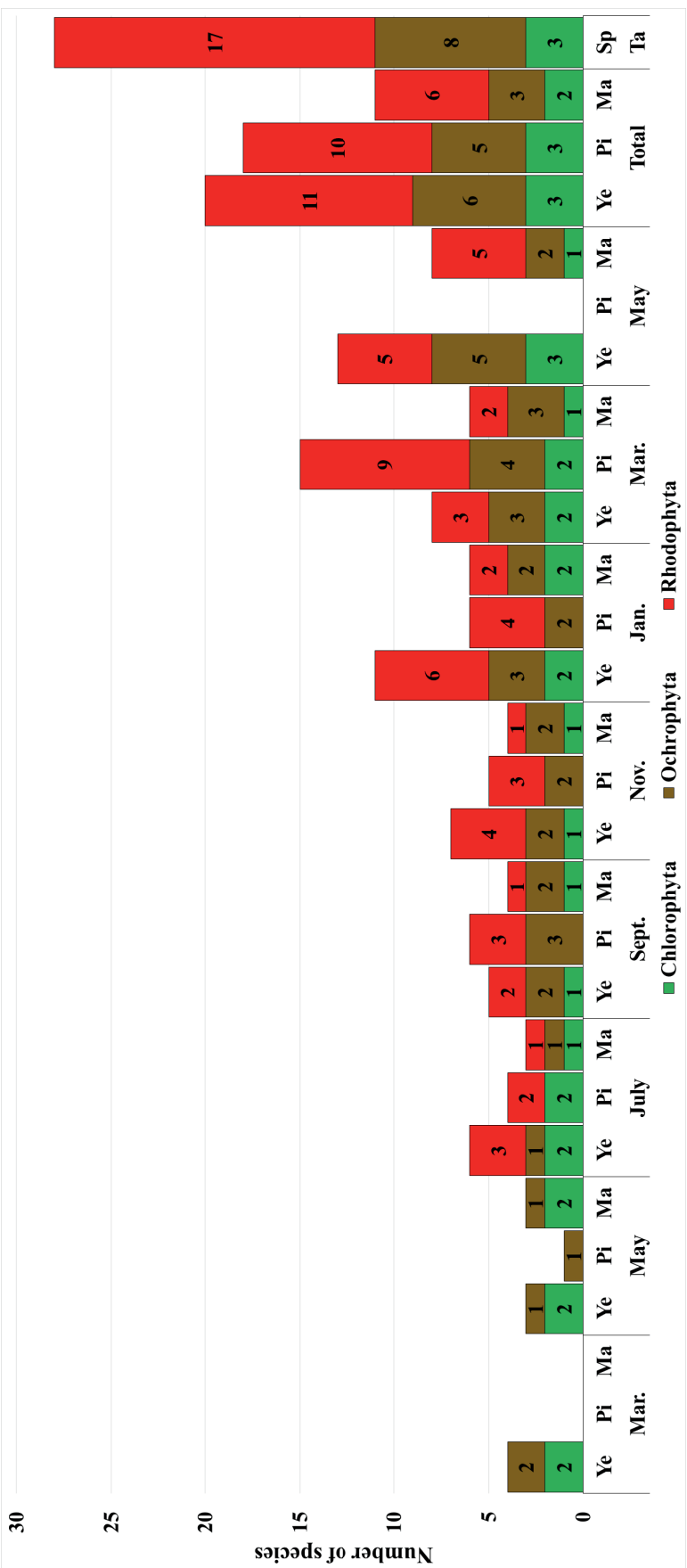


Fig. 4. The number of species by taxa occurred on concrete quadrats in the coastal waters off Tongyeong and Geoje, southern sea, Korea.
*Abbreviations: Ye, Yeongun-ri; Pi, Pildo-island; Ma, Mangchi-ri; Sp, Study periods; Ta, Total of all areas.



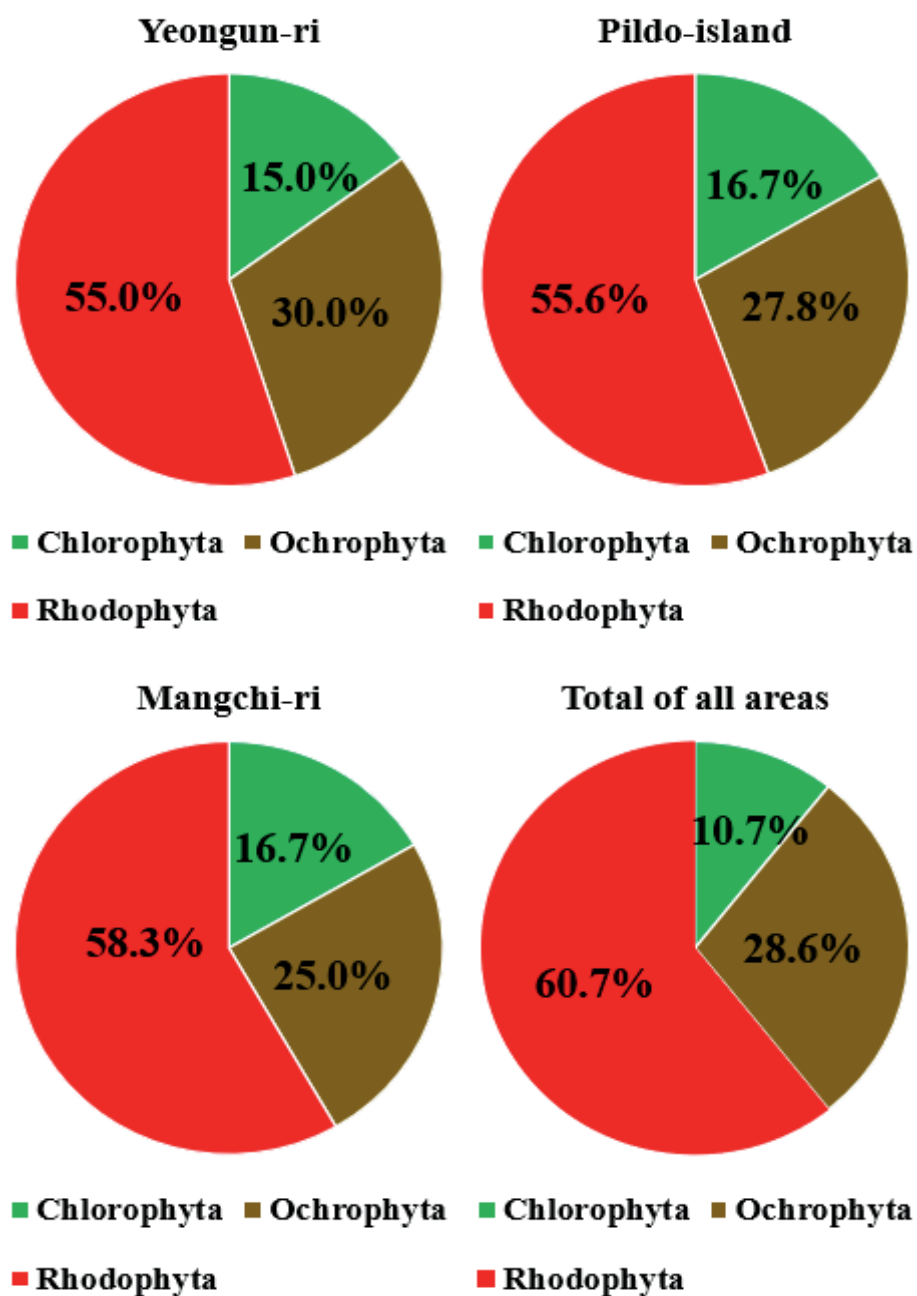


Fig. 5. The proportion by the taxa of marine algae occurred on concrete quadrats in the coastal waters off Tongyeong and Geoje, southern sea, Korea.

2. C/P, R/P, (R+C)/P 값

영운리, 필도, 망치리에서 출현한 해조류의 분류군별 종수는 영운리에서 녹조류 3종, 대룡편모조류 6종, 홍조류 11종, 필도에서 녹조류 3종, 대룡편모조류 5종, 홍조류 10종, 망치리에서 녹조류 2종, 대룡편모조류 3종, 홍조류 6종이 출현하였다 (Fig. 4). 이를 C/P 값으로 나타내면 영운리는 0.60, 필도는 0.50, 망치리는 0.67로 나타났으며, R/P 값은 각각 2.00, 1.83, 2.00이었고, (R+C)/P 값은 각각 2.60, 2.33, 2.67로 나타났다. 이 결과를 토대로 영운리, 필도, 망치리의 해조상은 한대에서 온대계의 해조상으로 판단된다(Table 2).

Table 2. Comparison of R/P, C/P and (R+C)/P value of marine algae occurred in the coastal waters off Tongyeong and Geoje, southern sea, Korea.

Values Study areas	C/P	R/P	(R+C)/P
Yeongun-ri	0.60	2.00	2.60
Pildo-island	0.50	1.83	2.33
Mangchi-ri	0.67	2.00	2.67

3. 중요도 값

방형구내에 출현한 해조류의 중요도 값 상위 2종을 우점종, 아우점종으로 나타냈고, 3월부터 다음 해 5월까지 해역별 우점종은 Table 3과 같다. 영운리에서 3월 잘록이고리매(*Scytosiphon lomentaria*) 50.04, 불레기말 25.01, 5월 불레기말 86.31, 창자파래 7.38, 7월 구멍갈파래 72.31, 팽생이모자반 12.06, 9월 모자반(*S. fulvellum*) 63.69, 돌가사리 13.07, 11월 구멍갈파래 58.26, 우뚝가사리(*Gelidium elegans*) 13.70, 1월 구멍갈파래 53.23, 톱니모자반 11.40, 2022년 3월 불레기말 64.13, 구멍갈파래 12.50, 2022년 5월 불레기말 71.02, 톱니모자반 5.38의 값을 보이며 우점종, 아우점종으로 나타났다. 필도는 2021년 5월에는 불레기말 1종만이 출현하면서 중요도 값 100으로 우점하였고, 7월 가시우무(*Hypnea asiatica*) 68.60, 구멍갈파래 28.58, 9월 외톨개모자반(*Myagropsis myagroides*) 34.84, 앞꼬시래기 30.70, 11월 앞꼬시래기 73.25, 팽생이모자반 20.75, 1월 앞꼬시래기 77.67, 팽생이모자반 15.22, 3월 앞꼬시래기 50.49, 구멍갈파래 16.35의 값을 보이며 우점종, 아우점종으로 나타났다. 망치리의 우점종은 5월 팽생이모자반 86.53, 구멍갈파래 8.16, 7월 팽생이모자반 64.48, 구멍갈파래 35.52, 9월 팽생이모자반 95.53, 톱니모자반 3.92, 11월 팽생이모자반 87.03 창자파래 7.35, 2022년 1월 구멍갈파래 51.36, 팽생이모자반 31.34, 3월 구멍갈파래 61.76, 팽생이모자반 28.73, 5월 구멍갈파래 51.18, 팽생이모자반 35.77의 값을 보이며 우점종, 아우점종으로 나타났다.

Table 3. Bimonthly important value (IV) of dominant species on concrete quadrats in the coastal waters off Tongyeong and Geoje, southern sea, Korea.

Study areas		Ye			Pi			Ma		
Values		RC	RF	IV	RC	RF	IV	RC	RF	IV
Month	Species									
Mar.	<i>Scytosiphon lomentaria</i>	58.41	41.67	50.04						
	<i>Colpomenia sinuosa</i>	19.47	30.56	25.01						
	<i>Sargassum horneri</i>									
	<i>Ulva australis</i>									
May	<i>Colpomenia sinuosa</i>	93.62	79.00	86.31	100.00	100.00	100.00			
	<i>Ulva intestinalis</i>	2.77	12.00	7.38						
	<i>Sargassum horneri</i>							95.38	77.68	86.53
	<i>Ulva australis</i>							2.93	13.39	8.16
July	<i>Ulva australis</i>	84.91	59.70	72.31	18.92	38.24	28.58	31.43	39.60	35.52
	<i>Sargassum horneri</i>	6.21	17.91	12.06				68.57	60.40	64.48
	<i>Hypnea asiatica</i>				78.38	58.82	68.60			
Sept.	<i>Sargassum fulvellum</i>	73.68	53.70	63.69						
	<i>Chondracanthus tenellus</i>	9.47	16.67	13.07						
	<i>Myagropsis myagroides</i>				47.04	22.64	34.84			
	<i>Gracilaria textorii</i>				25.56	35.85	30.70			
	<i>Sargassum horneri</i>							98.83	92.23	95.53
	<i>Sargassum serratifolium</i>							1.05	6.80	3.92
Nov.	<i>Ulva australis</i>	56.52	60.00	58.26						
	<i>Gelidium elegans</i>	17.39	10.00	13.70						
	<i>Gracilaria textorii</i>				73.17	73.33	73.25			
	<i>Sargassum horneri</i>				23.17	18.33	20.75	91.30	82.76	87.03
	<i>Ulva intestinalis</i>							4.35	10.34	7.35
Jan,	<i>Ulva australis</i>	47.76	58.70	53.23				55.94	46.79	51.36
	<i>Sargassum serratifolium</i>	11.94	10.87	11.40						
	<i>Gracilaria textorii</i>				77.92	77.42	77.67			
	<i>Sargassum horneri</i>				17.53	12.90	15.22	28.73	33.94	31.34
Mar.	<i>Colpomenia sinuosa</i>	84.79	43.48	64.13						
	<i>Ulva australis</i>	12.50	43.48	27.99	13.08	19.61	16.35	71.11	52.41	61.76
	<i>Gracilaria textorii</i>				59.81	41.18	50.49			
	<i>Sargassum horneri</i>							21.32	36.14	28.73
May	<i>Colpomenia sinuosa</i>	84.90	57.14	71.02						
	<i>Sargassum serratifolium</i>	4.27	6.49	5.38						
	<i>Ulva australis</i>							56.21	46.15	51.18
	<i>Sargassum horneri</i>							31.36	40.17	35.77

*Abbreviations: Ye, Yeongun-ri; Pi, Pildo-island; Ma, Mangchi-ri; RC, Relative coverage; RF Relative frequency; IV, Important value

4. 기능형군

해조류의 기능형 군별 구성비는 Table 4와 같다. 모든 조사 해역에서 출현한 해조류의 기능형 군별 구성비는 성긴분기형은 53.6% 다육질형 및 엽상형은 17.9%, 사상형은 7.1%, 각상형 3.6% 순으로 나타났다. 영운리는 성긴분기형 55.0%, 다육질형 20.0%, 엽상형 15.0%, 사상형, 각상형 5.0% 순으로 나타났으며, 필도는 성긴분기형 55.6%, 다육질형, 엽상형이 16.7%, 사상형, 각상형이 5.6% 순으로 나타났고, 망치리는 성긴분기형 36.4%, 엽상형 27.3%, 다육질형 18.2%, 사상형 및 각상형 9.1% 순으로 나타났다. 모든 조사해역에서 유절산호말형 해조류는 출현하지 않았으며, 성긴분기형이 가장 높은 비율을 나타냈고, 각상형이 가장 낮은 비율을 나타냈다.

Table 4. Composition proportion (%) of marine algal functional form group observed on concrete quadrats in the coastal waters off Tongyeong and Geoje, southern sea, Korea.

F-form	Study areas	Ye	Pi	Ma	Total of all areas
S		15.0	16.7	27.3	17.9
F		5.0	5.6	9.1	7.1
CB		55.0	55.6	36.4	53.6
TL		20.0	16.7	18.2	17.9
JC		0.0	0.0	0.0	0.0
C		5.0	5.6	9.1	3.6

* Abbreviations: Ye, Yeongun-ri; Pi, Pildo-island; Ma, Mangchi-ri; S, Sheet form; F, Filamentous form; CB, Coarsely form; TL, Thick leathery form; JC, Jointed calcareous; C, Crustose form

5. 천이과정

영운리의 천이과정은 Fig. 6과 같다. 2021년 3월과 5월에 일년생 해조류인 구멍갈파래, 불레기말, 잘룩이고리매, 창자파래가 입식 되었다. 구멍갈파래는 연중 관찰되었고, 창자파래는 7월과 9월을 제외한 모든 시기에 관찰되었으며, 불레기말은 7, 9, 11월을 제외한 모든 시기에 관찰되었다. 수온이 높아지는 7월은 각상 산호조류 (Crustose algae)가 방형구를 피복하기 시작하였고, 일년생 대형 대룡편모조류인 팽생이모자반 유엽과 홍조류인 돌가사리와 우뚝가사리 유엽이 입식 되었다. 팽생이모자반은 7월부터 조사가 끝날 때까지 관찰되었으며, 돌가사리는 7월과 11월에 관찰되었고, 우뚝가사리는 7월부터 2022년 3월까지 관찰되었다. 9월은 각상 산호조류가 방형구를 1/2가량 피복하였고, 다년생 대형 대룡편모조류인 모자반이 입식 되었다. 11월은 각상 산호조류가 방형구를 완전히 피복하였고, 모자반이 탈락하고, 다년생 대룡편모조류인 톱니모자반과 소형홍조류인 개우무(*Pterocladia capillacea*)의 유엽이

입식되었다. 톱니모자반은 2022년 5월까지 관찰되었고, 개우무는 2022년 1월까지 관찰되었다. 1월은 미끌도박(*Grateloupia turuturu*), 앞꼬시래기, 참곱슬이(*Plocamium telfairiae*)가 입식 되었고, 참곱슬이는 3월까지 관찰되었다. 3월은 불레기말이 번무하였고, 5월은 꼬시래기(*G. vermiculophylla*), 마디잘록이(*Lomentaria catenata*), 미역(*Undaria pinnatifida*), 참도박(*G. elliptica*), 청각(*Codium fragile*)이 입식 되면서 종 다양성이 가장 높게 나타났다.

필도의 천이과정은 Fig. 7과 같다. 2021년 5월에 불레기말이 입식 되었으며, 9월과 2022년 3월에 관찰되었다. 7월은 각상 산호조류가 피복하기 시작하였으며, 가시우무, 구멍갈파래, 창자파래가 입식 되었고, 구멍갈파래는 7월, 2022년 5월에 관찰되었다. 9월부터 조사가 끝날 때까지 각상 산호조류가 방형구를 1/2가량 피복하였으며, 팽생이모자반, 돌가사리, 외톨개모자반, 우뚝가사리, 앞꼬시래기, 톱니모자반 유엽이 입식 되었다. 또한, 팽생이모자반, 앞꼬시래기, 톱니모자반은 조사가 끝날 때까지 관찰되었다. 11월은 돌가사리가 입식 되었고, 9월에 입식 되었던 미야베모자반과 우뚝가사리가 탈락하였다. 22년 1월은 미끌도박이 입식되어 3월까지 관찰되었고, 우뚝가사리가 재 입식 되었다. 3월은 가지까막살(*G. chiangii*), 개우무, 그물마탕말(*Dictyota dichotoma*), 마디잘록이, 진두발(*Chondrus ocellatus*), 청각(*Codium fragile*)이 입식 되면서 조사기간 중 종 다양성이 가장 높게 나타났다.

망치리의 천이과정은 Fig. 8과 같다. 5월에 팽생이모자반 유엽, 구멍갈파래, 창자파래가 입식되었고, 팽생이모자반은 조사가 끝날 때까지 관찰되었다. 또한, 구멍갈파래는 11월을 제외한 나머지 기간에 모두 관찰되었고, 창자파래는 5월과 11월, 2022년 1월에만 관찰되었다. 7월부터는 각상 산호조류가 피복하기 시작하였고, 새로 입식된 종은 관찰되지 않았다. 9월부터 조사가 끝날 때까지 각상 산호조류가 방형구의 1/2가량 피복하고 있었고, 톱니모자반 유엽이 입식되기 시작하여 조사가 끝날 때까지 관찰되었다. 11월에도 추가로 입식된 종은 없었고, 2022년 1월은 비단망사(*Martensia elegans*)가 입식되었고, 3월에 탈락하였다. 3월에는 불레기말, 돌가사리가 입식되었고, 돌가사리는 5월까지 관찰되었다. 2022년 5월은 홍조류인 긴까막살(*G. elata*), 깃꼴서실(*Laurencia pinnata*), 사슬풀(*Champia recta*)이 입식 되면서 조사기간중 해조류 다양성이 가장 높게 나타났다.

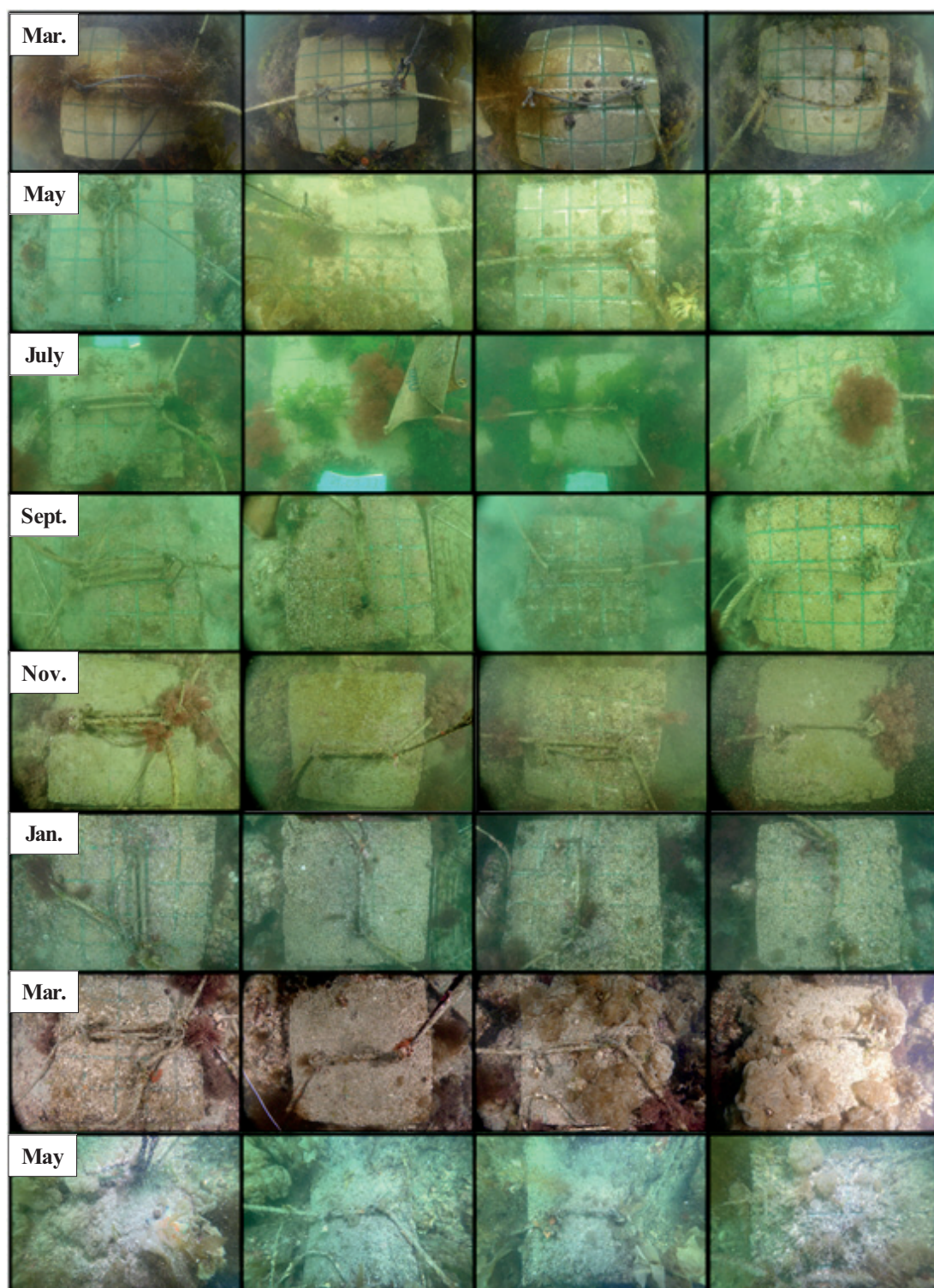


Fig. 6. Succession of marine algae settled on concrete quadrats in Yeongun-ri.

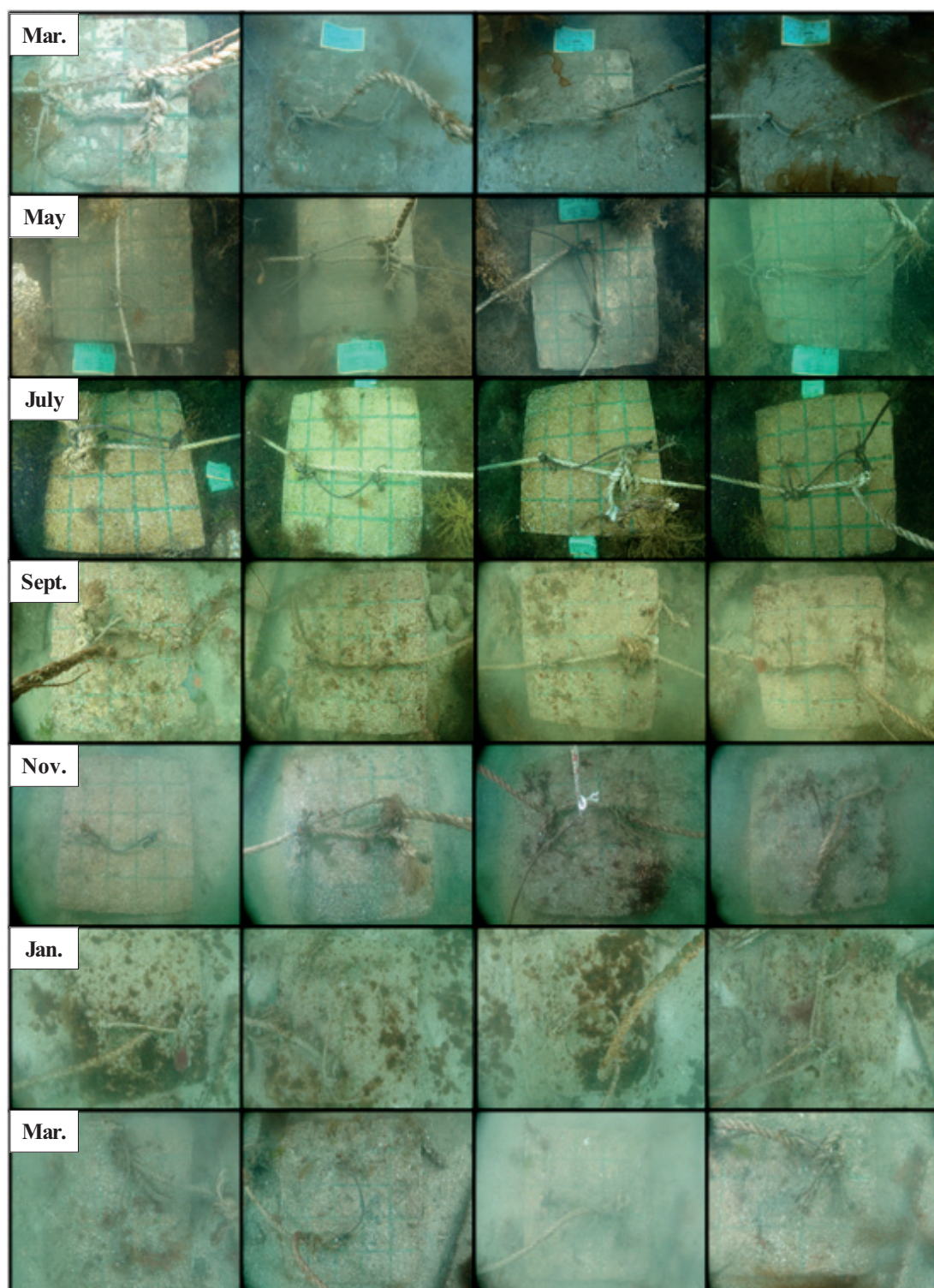


Fig. 7. Succession of marine algae settled on concrete quadrats in Pildo-island.

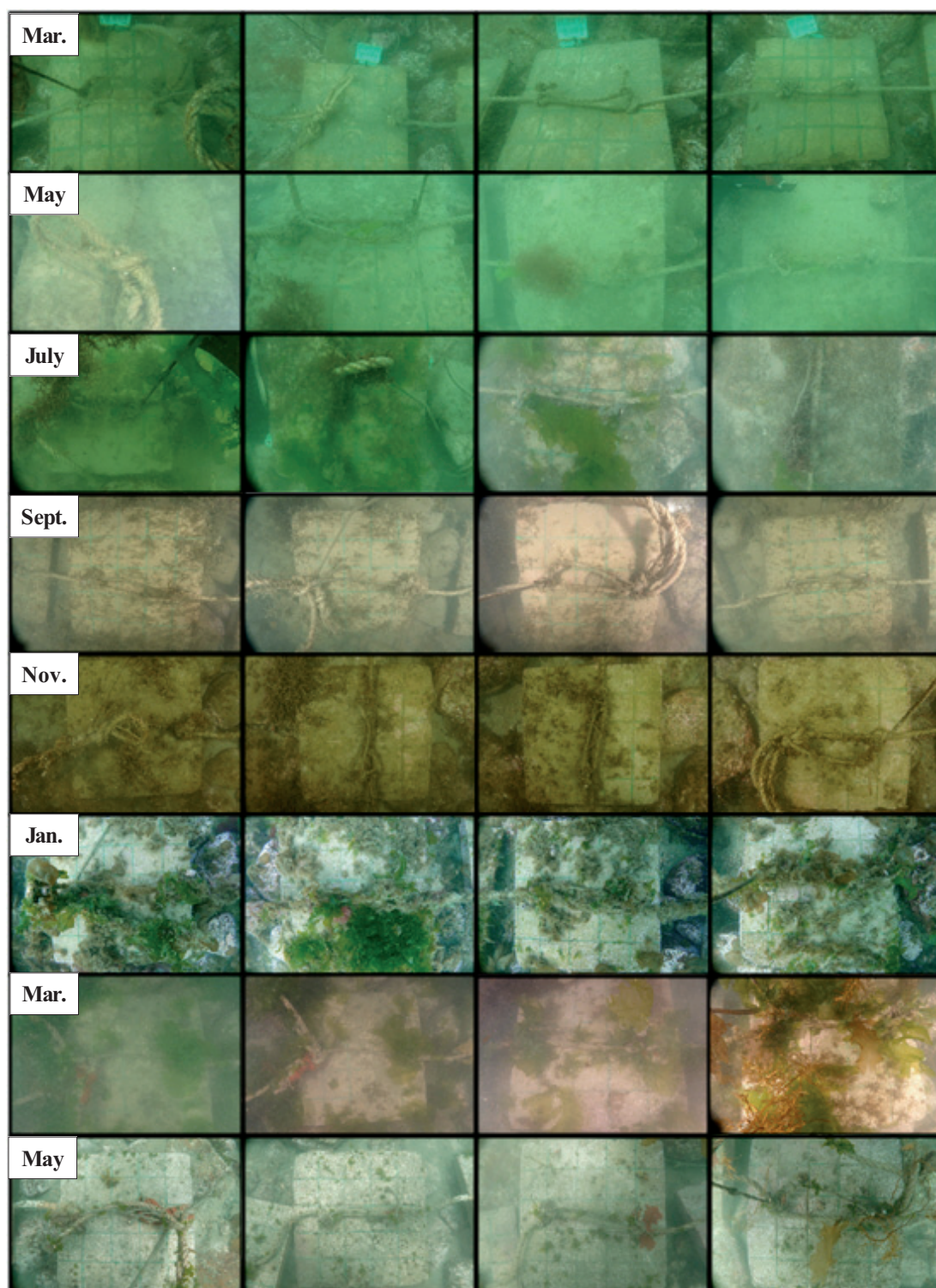


Fig. 8. Succession of marine algae settled on concrete quadrats in Mangchi-ri.

6. 유사도

이번 연구의 정점 간 유사도를 산출하였을 때, 크게 그룹 A(필도,영운리)와 그룹 B(망치)로 나누었으며, 그룹 A와 B간의 유사도는 39%를 나타냈으며, 필도와 영운리는 65%로 가장 높은 유사도를 나타냈다(Fig. 9).

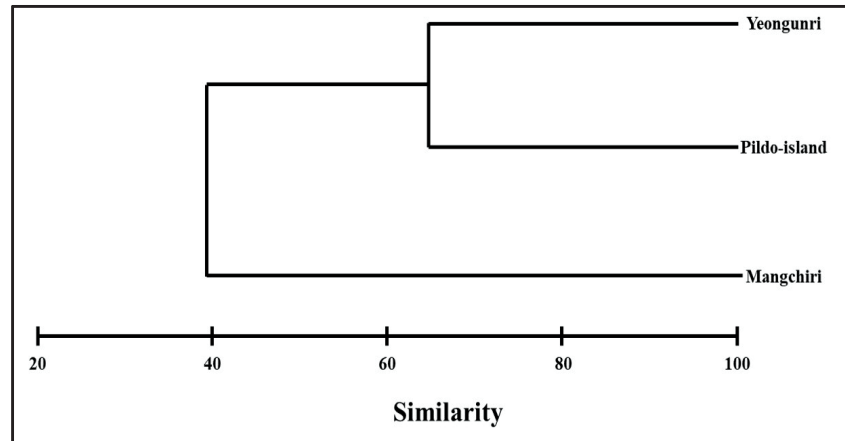


Fig. 9. Dendrogram of the similarity of marine algae occurred in the coastal waters off Tongyeong and Geoje, southern sea, Korea.

고 찰

이번 연구 결과 모든 조사 해역에서 녹조류 3종(10.7%), 대롱편모조류 8종(28.6%), 홍조류 17종(60.7%)으로 총 28종이 출현하였다. 남해안 연안에서 수행된 선행연구들의 보고에 따르면 Kim (1991)의 충무 연안 해조상 연구의 분류군별 종 수 및 구성비는 녹조류 9종(13%), 대롱편모조류 19종(27.5%), 홍조류 41종(59.4%), 통영 욕지도에서 수행된 Choi et al. (2008)의 해조류 생물량의 연간 변동양상 연구에서 녹조류 13종(11%), 대롱편모조류 34종(28.8%), 홍조류 71종(60.2%)이 보고되었다. 또한, Choi (2008)의 한려해상국립공원 해조상 연구에 의하면 녹조류 10종(11.2%), 대롱편모조류 30종(33.7%), 홍조류 49종(55.1%)이 보고되었으며, 위도별 해조상의 특징을 특정하는 지표인 C/P, R/P, (R+C)/P 값은 Kim (1991)의 연구에서 R/P 2.1, Choi (2008)의 연구에서 (R+C)/P 2.65이 보고되면서 분류군별 구성비와 C/P, R/P, (R+C)/P 값은 유사한 결과를 나타냈지만, 출현 종 수에서 많은 차이가 있던 것으로 추정된다. 이러한 결과는 앞선 선행연구에서는 조간대와 조하대가 동시에 조사되었고, 기존에 군락을 형성하고 있던 암반에서 조사가 수행되었다. 하지만, 이번 연구는 조하대에서만 실시되었으며, 방형구에 착생한 해조류의 천이과정을 모니터링하는 것이 추가되

고, 부수적으로 출현 종수를 파악할 목적으로 연구가 이루어 졌기에 나타난 결과로 판단된다.

해역별 우점종, 아우점종은 영운리 연안에서 구멍갈파래, 불레기말 필도 무인섬에서 잎꼬시래기, 갯생이모자반, 망치리 연안에서 갯생이모자반, 구멍갈파래로 나타났다. 이번연구 해역과 같은 해역인 영운리 연안에서 수행된 Lee (2013)의 연구에서 구멍갈파래가 연중 우점종으로 보고되었고, 국립환경과학원의 전국 무인도서 자연환경조사(2006)에서 필도와 주변 무인도인 태도의 우점종으로는 갯생이모자반과 잎꼬시래기가 보고되었다. 또한, 이번 연구해역인 망치연안과 가까운 거제 지세포 연안에서 수행된 Choi (2009)의 연구에서는 구멍갈파래, 미역, 갯생이모자반이 우점종, 불레기말이 아우점종으로 보고되었다. 모니터링 위주로 수행된 이번연구는 선행연구와 조사 방법에서 많은 차이가 있었지만, 지리적 위치 및 해역환경이 유사한곳에서 수행됨으로써 선행연구에서 밝혀진 우점종과 이번연구를 통해 밝혀진 우점종이 유사하게 나타난 것으로 판단된다.

Choi (2008)의 연구에서 기능형군 별 구성비는 성긴 분기형, 사상형, 엽상형, 다육질형, 유절산호말형, 각상형이 높은 순으로 보고되었고, 필도에서 가까운 곳에 위치한 사랑도에서 수행된 Kim (1988)의 연구에서도 성긴 분기형이 가장 많이 출현 하였다. 또한, Jang (2015)의 연구에 따르면 성긴 분기형, 엽상형, 사상형, 다육질형, 유절산호말형, 각상형이 높은 순으로 보고되었다. Sohn (1987)의 연구에 의하면 남해안의 기능형 군별 구성비는 성긴 분기형 해조류가 다른 기능형군의 구성비율에 비해 높게 보고되었다. 이번 연구 또한 성긴 분기형 해조의 구성비가 높게 나타나 남해안에서 보고된 전형적인 기능형군별 구성비를 보임으로서 남해안에서 이루어진 선행연구 결과인 성긴 분기형 해조 우점현상과 일맥상통하는 결과를 보였다. 선행연구의 천이 패턴은 일년생의 기회성 해조류가 천이 초기에 우점하고 시간이 지남에 따라 다년생 대형 대룡편모조류 위주로 우점한다고 보고하였다(Choi, 2006; Choi et al., 2019; Jung and Choi 2022). 또한, Jung and Choi (2019)의 포항 구룡포 연안에서 수행된 연구에서 천이단계를 Early stage, Competition, Late succession stage로 구분하였는데, 이번 연구에서도 선행연구를 참고하여 천이단계를 구분하였다. Early stage에서 일년생 해조류인 불레기말과 구멍갈파래가 입식 되었고, Competition 단계에서는 다년생 소형 홍조류와 대룡편모조류 유엽이 입식 되었다가 탈락하는 때도 있었다. 이러한 요인은 조무래기따개비(*Chthamalus challenger*)가 방형구 내에 대량 번식하는 과정에서 발생한 중간 착생 기질 경쟁에 의한 스트레스 및 조업 등에 의한 인위적 교란에 의한 것으로 판단된다. Late succession stage에서는 다년생 대룡편

모조류인 톱니모자반이 입식 되어 조사가 끝날 때까지 관찰되었다. 이번연구와 선행연구는 같은 재료를 사용하였지만, 그 면적과 해역환경에서 많은 차이가 있었기에 천이단계에서 출현 종, 해조류의 성장상태 등은 상이한 결과를 나타냈다. 그러나, 초기에 일년생해조와 기회성해조가 입식되고 후기에 다년생 대형 갈조가 입식된다는 점에서 천이패턴은 유사하게 나타났다. 선행연구에 의하면, 이러한 일련의 결과는 일반적으로 인공어초에서 진행되는 해조상의 전형적인 천이 단계로 인식되고 있다. 또한, 해중립을 유지하는 데 있어 기질의 안정성은 매우 중요하며, 다년생 대룡편모조류에 의해 바다숲이 안정화되어 해조숲이 극상에 이르는 과정까지 오랜 기간이 소요된다고 보고하였다(Watanuki and Yamamoto, 1990; Lee and Choi 2019).

그러므로 이러한 천이 패턴을 고려할 때 바다숲 조성은 안정성이 높은 기질을 활용하여 장기적인 모니터링을 통해 해조군집의 변동 양상을 추적하고, 지속적으로 천이과정을 모니터링하여 대상해역 바다숲의 생태적 안정성을 확보할 필요성이 있다.

요 약

이번 연구는 2021년 3월부터 2022년 5월까지 남해안 동부의 통영시 평림동 무인도인 필도, 산양읍 영운리 연안, 거제시 일운면 망치리 연안에서 해조 천이과정을 모니터링 하였다. 이번 연구의 출현종 수는 총 28종으로 녹조류 3종(10.7%), 대룡편모조류 8종(28.6%), 홍조류 17종(60.7%)이 출현하였다. 영운리에서 녹조류 3종(15.0%), 대룡편모조류 6종(30.0%), 홍조류 11종(55.0%)으로 총 20종, 필도에서 녹조류 3종(16.7%), 대룡편모조류 5종(27.8%), 홍조류 10종(55.6%) 총 18종, 망치리에서 녹조류 2종(18.2%), 대룡편모조류 3종(27.3%), 홍조류 6종(54.5%)으로 총 11종이 출현하였다. (R+C)/P 값은 영운리, 필도, 망치리 각각 2.00, 1.83, 2.00로 나타나면서 한대에서 온대계의 해조상으로 나타났다. 조사기간 동안 해역별 우점종, 아우점종은 영운리에서 구멍갈파래(*Ulva australis*), 불레기말(*Colpomenia sinuosa*) 필도에서 잎꼬시래기(*Gracilaria textorii*), 팽생이모자반(*Sargassum honeri*), 망치리에서 팽생이모자반과 구멍갈파래로 나타났다. 각 해역마다 기능형 군별 구성비는 성긴 분기형(36.4-55.6%)이 가장 높게 나타났으며, 각상형 및 사상형(5.0%-9.1%)이 가장 낮은 비율을 나타냈다. 모든 조사해역의 천이 과정은 천이 초기 단계에서 일년생 해조류인 구멍갈파래와 불레기말이 입식 되었고, 수온이 높아지는 7월부터는 무절산호조류가 피복하기 시작하였다. 천이 후기 단계로 갈수록 모든 방형구에서 다년생 대형 대룡편모조류의 유엽이 입식되어 일반적인 천이패턴을 나타냈다.

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[Review] Issue-I

중국의 “남해 1호”와 수중 침몰선 전체 발굴-I

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Underwater Excavation of "Nanhai No.1" in China and Total Excavations of the Sunken Shipwrecks-I

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Underwater archaeology in Korea began with the attempt to explore the naval relics of Admiral Yi Sun-Sin in 1973, followed by the excavation of Anapji in 1975–1976 and the underwater investigation off Sinan from 1976 to 1984. Since then, more than ten underwater excavations have been carried out, mainly under the initiative of government and military authorities. In some cases, however, private parties undertook such projects, often pursuing material and commercial interests rather than archaeological value. At present, it is necessary to review the achievements to date and to consider the future development of the field. Underwater archaeology requires close collaboration across various disciplines and technologies, along with active investment from the nation and interested institutions and organizations.

Key words: China, Nanhai No.1, Sunken Shipwrecks, Underwater Excavation

Running title: 중국 수중 침몰선 전체 발굴

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서 언

우리나라의 수중 선체 발굴조사와 인양은, 유물과 선체 파손 조각 등을 먼저 조사·인양하고 주 선체를 분해 인양한 경우가 대부분이었다. 최근에 이루어진 중국의 “남해 1호(Nanhai No.1; South China Sea No.1)” 수중 발굴은 유구(feature) 전체를 육상 보관 수조로 옮긴 사례로서 인양 기법, 운송, 박물관(장기적 발굴과 보존 포함) 등이 인상적이었으며, 더욱이 중국을 다시금 생각하게 되었다. 물론, 가 물막이(Cofferdam, 김도현 2006, pp.56-57)¹⁾를 이용한

전체 발굴 사례와 바사호(Vasa, 김도현 2006), 메리로즈호(Mary Rose, 김도현 2006)와 헨리호(H.L. Hunley) 등과 같이 침몰 주 선체를 분해하지 않고 전체를 동시에 인양한 경우도 있었다. 이러한 침몰선 전체 인양 사례들을 살펴보면, 우리나라 수중고고학의 현 위상과 앞날을 생각하여 본다.

Table 1. Summary of the underwater excavations to be introduced.

사 례	시 기		내 용	보존·전시	비 고
	침몰	조사·발굴*1			
남해 1호(Nanhai 1) 중국, 30 msw	1127 ~ 1279	1987~2007	유구 전체 인양. Steel box 이용.	전용 박물관 (2009. 12.)	
바사호(Vasa) 스웨덴, 32 msw	1628	1956~1961	조석·부력과 유압 견인기(Hydraulic jacks)를 이용하여 18회 이동 후 인양. Lifting frame & wire 이용.	전용 박물관 (1990. 06.)	김도현(2006) p. 67-69 당시 생활상을 알 수 있는 값진 자료.
메리로즈호 (Mary Rose) 영국, 36~50 fsw	1545	1966~1982	Lifting frame with wire, & cradle 이용.	박물관(2012. 가을) 2016년 - 보존처리 완료 예정	김도현(2006) p. 57-66
헨리호(H.L. Hunley) 미국, 8 msw	1864	1970~2000	Lifting frame, wire & band 이용.	Conservation Laboratory 2011.06. 바로세움.	
*1 발견, 인양 등 주요 년대이다. 모든 조사, 발굴과 보존 처리는 장기간에 걸쳐 수행된다.					

“남해 1호”

“남해 1호(Nanhai No.1; South China Sea No.1)”는 남송 시대(1127~1279년)에 중국 남부 해안 - 양장(陽江, Yangjiang)시의 해릉도(海陵島, Hailing Island)로부터 20마일 떨어진 곳, 수심 30m에 침몰한 중국 상선이다. 이 침몰선은, 중국의 해난구조 기관과 영국의 해난구조 회사(Maritime Exploration & Recoveries PLC of Southampton UK)가 공동으로 18세기 동인도 회사 선박 린스버그(Rhynsburg)호를 찾던 중(Wikipedia)²⁾, 200점 가량의 자기류가 침몰선에서 우연히 발견됨으로써 1987년에 세상에 알려지게 되었다. 이는 길이 30.4m, 폭 9.8m, 높이 3.5m(돛대 제외)로써, 당시까지 발견된 같은 종류의 배들 중 가장 큰 것이었다. 또한 “바다의 실크로드(Marine Silk Road, Fig. 1)”와 연관되어 처음으로 발견된 오래된 선박이다. 발굴 책임자에 따르면, 이 배는 외국과의 교역을 위하여 남 중국의 어느 항구를 출발한 후, 아마도 폭풍우를 만나 침몰한 것으로 추정되며, 빠른 시간 이내에 침니(silt; 김도현 2006, Fig. 2-3 참조)³⁾로 덮여지게 되었다.

1) 한컴사전. 토목] (일시적으로 물을 막는) 방죽; 잠함(潛函)

2) China.org.cn“while they were searching for abandoned Dutch shipwreck of the 17th century.”

3) 해양과학용어사전, 2005.

‘모래와 점토 사이 정도 크기에 해당하는 세립입자의 퇴적물. 입도 범위가 1/16~1/256mm 사이’



Fig. 1 Nanhai No.1 and Marine Silk Road (wikipedia).

a) In the recent years, several ancient shipwrecks full of porcelain vases, plates, cups and iron pots and copper plates were discovered in the South China Sea and East China Sea. The most important shipwrecks found there are:

- Nanhai No. 1 and Huaguangjiao No. 1: Sank some 800 years ago during the Southern Song Dynasty (1127-1279)
- Nan'ao No. 1: Previously known as Nahai No. 2, sank some 400 years ago during the Ming Dynasty (1368-1644)
- Wanjiao No. 1: Sank some 300 years ago during the Qing Dynasty (1644-1911).

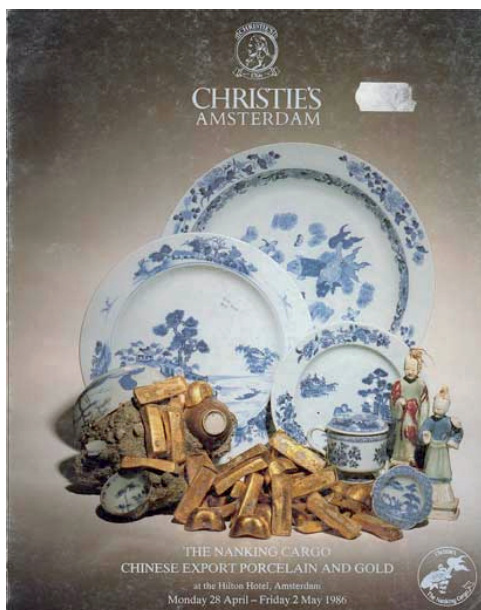
b) The marine silk road, like its overland counterpart, had its origins during the Han Dynasty (202 BC-220 AD). The maritime routes opened by Emperor Han Wudi (reigned 140-87 BC) provided access to the Roman Empire via India, marking the first oceanic route as well as the earliest marine trading route in the world. This enabled China to actively seek out overseas markets and establish foreign trade relations, and laid the foundation for the development of the maritime Silk Road.

1. “남해 1호”와 중국의 수중고고학

과거 중국의 수중고고학은 사상, 재원과 인력 등의 문제로 낙후되었다 (Fig. 2). 하지만 “남해 1호”의 발굴을 계기로 중국은 세계적 수준에 달했다고 자부하고, 심지어 한국과 일본을 앞섰다고 표현하였다.⁴⁾ 이는 우리나라의 신안선 발굴을 염두에 둔 표현으로 생각된다.

4) china.org.cn (China.org.cn by Chen Lin, August 31, 2007).

'The Chinese underwater technology and equipment has already reached world development level, even better than that of South Korea and Japan. It was not easy for China to reach this level in only 20 years.'



Mike Hatcher, the man who compelled China's underwater archaeology to develop

The formation and development of Chinese underwater archaeology should acknowledge a controversial person named Mike Hatcher. He is a world famous salvage diver, an adventurous explorer and world-renowned treasure hunter known to many foreign governments. To the field of Chinese underwater archaeology his name equates with disaster. Mike Hatcher discovered the wreck of *Geldermalsen* (or the Nanking cargo) in May 1985 in South China Sea. *Geldermalsen*, built in 1746, was a vessel belonging to the Dutch East India Company (VOC). It traveled the usual tea trade route between China's Guangdong and the Netherlands. Besides a cargo of valuable tea the ship also held a cargo of gold and a large cargo of porcelain stored in the lower decks as ballast. In January 1752 it sank into the sea.

Mike Hatcher eventually brought up an amazing haul consisting of much of the gold and over 150,000 pieces of porcelain. The ceramics originated from the Jingdezhen region, often termed the "Porcelain Capital of China" because of the area's high-quality porcelain productions. The Chinese government was shocked to learn of these treasures being auctioned at Christies in Amsterdam in April 1986. The Chinese government researched many laws:

After the heavy blow dealt by Mike Hatcher, the Chinese government decided to found a Chinese underwater archaeology team. After establishing this team, Zhang Wei started competing with all the greedy robbers salvaging Chinese marine treasures.

"Although we all aimed to discover ancient relics, there is an essential difference between archaeologists and 'treasure seekers': archaeologists seek to recover the history and protect all the ancient heritage as well but treasure hunters just want to maximize their profits," Zhang explained.

Sadly, the tragedy of *Tek Sing* (also called True Star) proved Zhang Wei indeed to be correct.

Fig. 2 Mike Hatcher and China underwater archaeology (china.org.cn).

In 1999 Hatcher spent a great deal of money to hire several archaeology experts. They started to study the Dutch East India Company Archives. He suddenly found the record of the *Tek Sing*. The junk *Tek Sing* was en route from Amoy off the mainland of China to Java in 1822 when the ship hit a reef in the South China Sea. The vessel quickly sank; more lives were lost on this shipwreck than the Titanic. Hence, the *Tek Sing* is also called the "Oriental Titanic."

The record stated: the boat was 50 meters long, 10 meters wide and when it sank into the sea it carried more than one thousand tons of cargo: more than one million pieces of porcelain. The pottery was made in Jingdezhen and included bowls, dishes, pouring vessels, storage jars, stoves, opium containers and even urinals.

They searched for months. When the *Tek Sing* shipwreck was located they retrieved millions pieces of porcelain.

The quantity and quality of the *Tek Sing* cargo is unusual. Most of the Tek Sing cargo was blue and white porcelain, produced by painting the decoration onto white porcelain just before the final firing that applied cobalt oxide. This method has been in use in China from the 12th century to the present day.

Besides those treasures from the Jingdezhen, many other types of porcelain from some other famous kilns during Emperor Kangxi's reign (1662~1722) were located. All these antiques were well protected under the sea.

The great amount: one million pieces of porcelain, shocked everybody, but they were more shocked by Hatcher when he commanded them to smash more than 600,000 pieces and only keep 365,000. Hatcher knew better than anyone else that in the world culture relics collection market, the rare things sell higher. After a nine day auction, Hatcher pocketed more than US\$30 million.

“남해 1호” 발굴의 주요 인물인 장위(張威, Zhang Wei)는 초대 중국수중고고학센터장(director of the Underwater Archaeology Center of China)으로서 발굴을 지휘하였다. 이 센터는 1987년에 설립되었다. 그는 1982년 북경(Peking)대 고고학과를 졸업하였으며, 이 센터의 설립 전에 잠수를 배우기 위하여 네덜란드로 파견되었다. 또한 1989년에는 미국에 건너가 비록 짧은 기간이지만 바스(George F. Bass) 박사의 지도를 받았다.



There wasn't enough time to recruit additional team members when the "Nanhai No.1" appeared unexpectedly in August 1987. The Guangzhou Salvage Bureau under the Ministry of Communications and a British salvage company discovered an ancient wooden sunken ship off the coast near the Shangchuan and Xiachuan islands while they were searching for abandoned Dutch shipwreck of the 17th century.

They used grab buckets to dredge up more than 200 pieces of porcelain and metal wares, but all the porcelain was accidentally destroyed. The British sailors were excited and wanted to continue exploring. After receiving the report, the State Administration of Cultural Heritage ordered the British side to cease their operations.

Fig. 3 Zhang Wei

When pieces of porcelain were shown to Zhang Wei, he guessed that the vessel was traveling on the "Marine Silk Road." At that time China had not yet the means to undertake exploring such a huge shipwreck. In 1988 Zhang Wei organized the first underwater training and established an underwater archaeology team. He went to the USA for some short-term training under George Bass, the father of underwater archaeology, in 1989.

Salvage on the sunken ship started in November 1989. The ship was dubbed the "Nanhai No.1" (South China Sea No.1). Due to his simple equipment, he only reached one part of the ship and retrieved a piece of porcelain from it.

Research was suspended for ten years due to a money and labor shortage. But the Nanhai No.1 lived on in Zhang Wei's heart. In 2001 his team expanded into 40 members. Wei received HK\$1.2 million from the Hong Kong Underwater Archaeology Association as a supporting grant. He also bought a map drawn by a British sailor who attended the 1987 salvage of the "Nanhai No.1".

When they located the ship, they first drew an outline of the ship. They didn't enter the ship until March 2003. They opened a window and entered a little cabin of the ship. More than 4,000 delicate porcelains were found in a cupboard.

There are many precious porcelain wares in the ship, but to Zhang Wei, the ship itself is far more important than the porcelain it carried. There's few record of the shipbuilding technology 800 years ago in China. It's also rare in the world.

2. “남해 1호” 발굴 과정

2000년에, 중국국립박물관(National Museum of China) 산하의 이 센터는, 광동문화유산고고학연구소(Guangdong Cultural Relics Archaeological Research Institute)와 함께 12명의 전문 요

원으로 연구진을 결성하였다. 2002년의 두 번째 수중 탐사를 통하여, 4,000점 이상의 금, 은, 도자기류 유물과 약 6,000점의 동전 등을 인양하였다. 이후, 2004년 6월까지 네 차례의 발굴 조사를 통하여 약 4,500점의 문화적 유물과 10,000점에 달하는 동전 등 값진 유물들을 수집하였다(Fig. 4). 2004년 광둥개발·개량위원회(Guangdong Development and Reform Commission)는 양장(陽江, Yangjiang)의 해릉도(海陵島, Hailing Island) 해변에 바다의 실크로드 박물관(Marine Silk Road Museum) 건립을 결정하고, 공사에 착수하였다. 4년에 걸쳐 약 2억 위안(USD29 million)을 들여 12,200m²의 박물관을 2009년 11월에 준공하고, 12월 24일에 개관하였다(Fig. 6, 7 & 8). 2007년 1월 16일, 고고학 팀은 침몰선 전체 인양에 앞서 최종 수중 조사를 실시하였다.



Fig. 4 Exploration of the "Nanhai No.1" (english.cntv.cn).

From March 2002 to June 2004, the Nanhai No. 1 archeological team conducted four large scale surveys and excavations of the sunken ship, collecting plenty of valuable objects including 4500 cultural artifacts and coins nearly 10,000 in number.

3. “남해 1호” 선체 인양

2007년 1월, 인양 사업 본부가 결성되고, 재무부로부터 3,000만 위안(USD4.3 million)의 예산이 책정되었다. 5월부터 밀이 터진 대형 철제 상자(길이 35.7m, 폭 14.4m, 높이 12m, 무게 530톤, 농구장 넓이의 3층 건물 크기로 표현함)를 제작하면서 선체를 통째로 인양하는 작업에 착수하여, 2007년 12월 21~22일에 인양한 뒤, 박물관의 수정 궁전("Crystal Palace")이라 이름지은 해수 수조(길이 64m, 폭 40m, 높이 23m, 수심 12m)로 이송, 보관하였다.

밀이 터진 대형 철제 상자를 침몰선 전체 위에 씌어 누른 뒤, 잠수사들이 상자 아래 36개의 철제 가로 들보(steel beam)를 설치하였다. 첫 번째 들보는 2007년 9월 4일에 설치하였으며, 굳은 빨 속으로 어렵게 설치하여 11월 13일에 모두 완료하였다. 이어 각 들보간의 틈은 12mm 두께의 긴 철판 37개로 막았다.

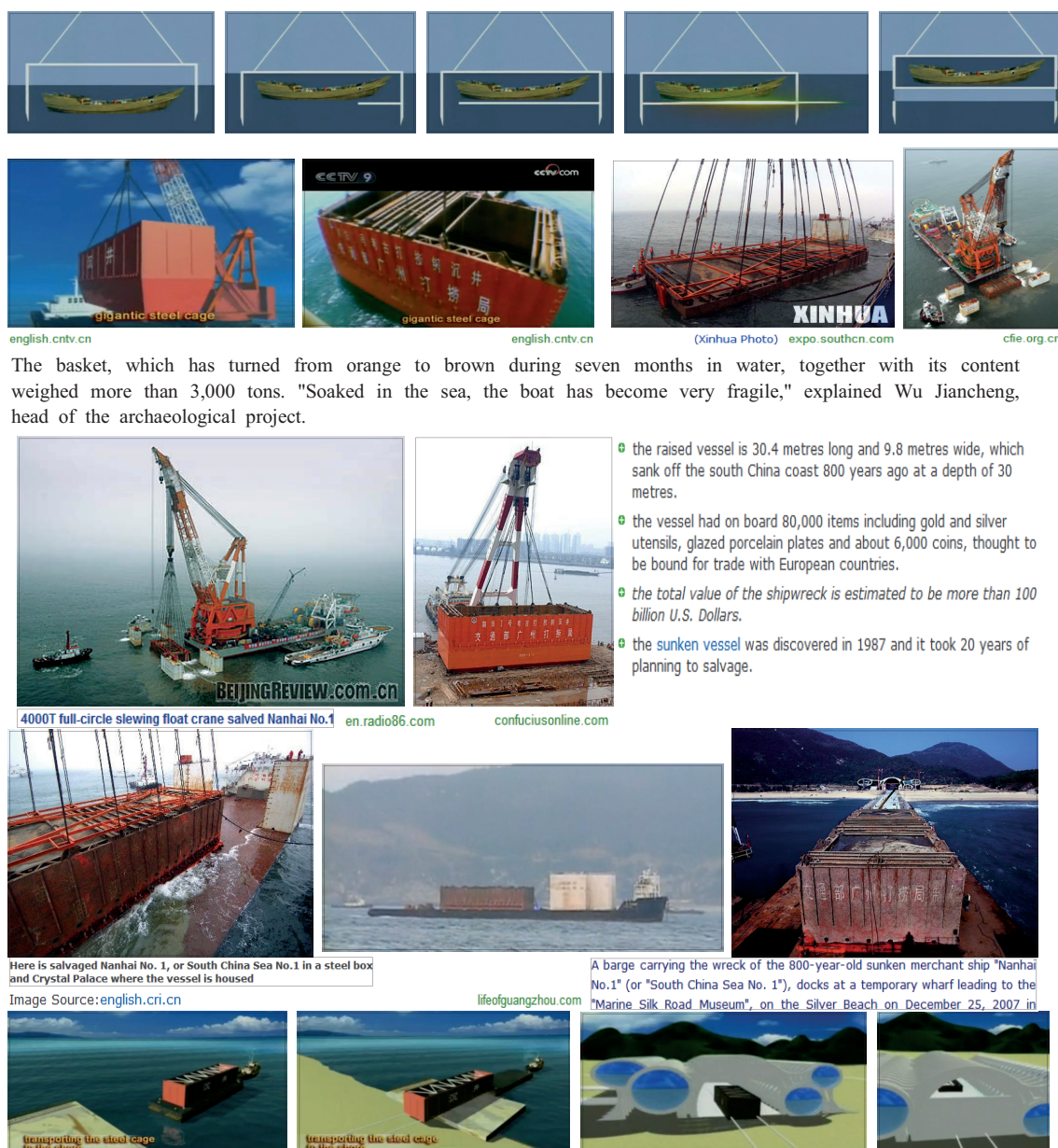


Fig. 5. Salvage of the "Nanhai No.1" (english.cntv.cn; confuciusonline.com).

Work Begins to Bring Ancient Ship Back to Port By nimeitu on 10/1/2010



Workers placed the first steel beam under the ancient sunken ship Nanhai No.1 on Tuesday, paving the way for the ship to be hoisted out of water in mid-October, officials said.

Another 34 beams, each stretching 15 meters and weighing more than five tons, would be placed under the ship at a pace of one beam for each day afterwards, said Wang Renyi, an official with the Guangzhou Salvage Bureau in charge of the salvage of the ship.

The beams were made airtight and hollow to be buoyant, Wang said. Two floating bags are tied on each end of one beam and start inflation when the beam goes under water to generate more buoyant force.

Salvage operations on the ship Nanhai No.1, produced during the Southern Song Dynasty (1127-1279), started in May as a specially designed steel structure was lowered into the sea near Yangjiang, in south China's Guangdong Province.

The rectangular structure was pulled by a 900-ton tug to a position just above the ill-fated ship.

According to the salvage plan, the upper part of the steel structure will be brought out of the seawater together with the sunken ship, while the lower part will stay on the seabed forever.

Experts spent three years planning the salvage, considered a world first for underwater archaeology. Archaeologists normally excavate the relics on the sunken boat first and then salvage the boat.

The salvage workers had planned to start placing beams under the ship on August 3. The job, however, was delayed by typhoons Pabuk, Sepat, and Wutip.

Workers have cleared away 25 tons of silt around the sunken ship and have brought out of the seawater 390 cultural relics. They include green glazed porcelain plates, tin pots, and shadowy blue porcelain objects.

4. “남해 1호” 와 바다의 실크로드 박물관(Maritime Silk Route Museum)

“남해 1호” 발굴을 계기로 새로운 박물관을 지었으며 2009년 12월 24일 대중에게 공개되었다. 대형 철제 상자 속에 든 채로 인양된 “남해 1호”를 수조(glass pool) 속에 보존함으로써, 발견된 당시의 수중 환경 - 수온, 수압, 기타 환경 조건 등과, 가능한 비슷하게 유지할 수 있다. 관람객들은 수중에서 행하여지는 발굴조사 등의 작업 과정들을 지켜 볼 수 있다. 이 수조로 된 전시관이 박물관의 핵심 부분이며, 이 같은 시설은 아시아에서 유일한 것이다. 박물관은 세(3) 곳의 주요 전시 공간과 여덟(8) 곳의 전시실로 구성되어 있다.

이 수조에서 2009년 8월 18일 ~ 9월 27일 동안, 선체 중간 부분에서 각 4m² 넓이의 네(4) 곳에 대한 첫 시굴이 실시되었다. 이 후 이(2)차 발굴은 2011년 3월까지 진행되었다.



Fig. 6 "Nanhai No.1" moving to its final residence "Crystal Palace" (wikipedia).

Maritime Silk Route Museum is the name of a museum on Hailing Island, Yangjiang, Guangdong Province, China. Work on the museum started in late 2004 and the museum opened to the public on 24 December 2009. The museum was built to hold 300,000 artifacts as well as having the facilities necessary to house pieces of shipwrecks in water tanks. The main exhibition is the Nanhai 1 shipwreck, a wooden vessel which sank just off Hailing Island. The Nanhai 1 is housed in the Crystal Palace in a water tank, one of main features for the museum which is the only museum in Asia with these facilities for underwater display. The museum also has 200 artifacts on display from the wreck.

*"Nanhai No.1" in China
and Total Excavations of the Sunken Shipwrecks-I*

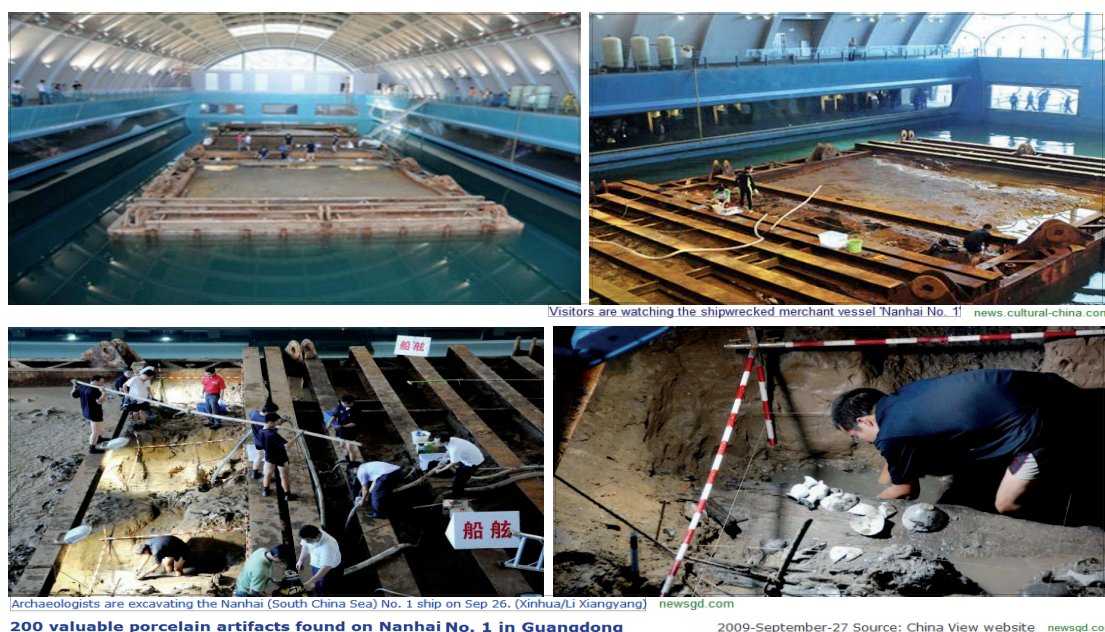


Fig. 7 Excavation in the glass pool of Maritime Silk Route Museum.

Chinese archaeologists have discovered more than 200 precious porcelain artifacts on an 800-year-old merchant ship in the southern province of Guangdong. The 40-day trial excavation ended Saturday (Sep 26) and a massive excavation would start next year, said Wei Jun, an archaeologist leading the excavation. The Nanhai (South China Sea) No. 1 ship from the Song Dynasty (960-1279) was loaded with an estimated 60,000 to 80,000 pieces of relics. Archaeologists have also found well-preserved cabin, board and deck in the trial excavation. They had recovered more than 4,000 artifacts of gold, silver and porcelain, and about 6,000 copper coins on the merchant ship while it was still on the seabed. Discovered in mid-1987 off the coast near Yangjiang City, the 5,000-tonne Nanhai No. 1 was recognized as one of the oldest and biggest merchant boats sunk in Chinese waters. Experts said the well-preserved vessel has offered more evidence for the existence of an ancient maritime trade route linking China and the West. The ship, 30.4 meters long and 9.8 meters wide, was salvaged off the coast of Guangdong and moved to its purpose-built "Crystal Palace" at the Marine Silk Road Museum in Yangjiang in December 2007. The glass pool features a water temperature, pressure and other environmental conditions that were the same as where the ship had rested on the sea floor for centuries.

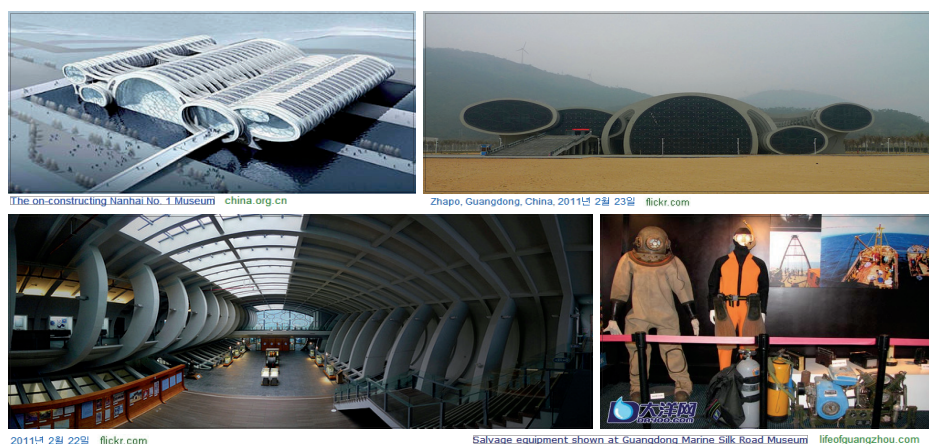
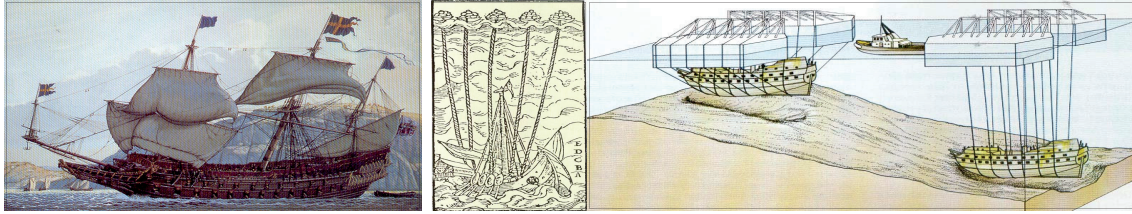
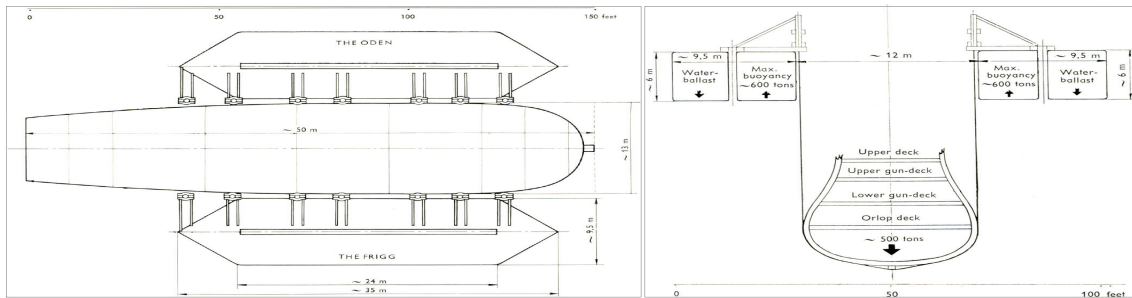


Fig. 8 Maritime Silk Route Museum.

바사호(Vasa)

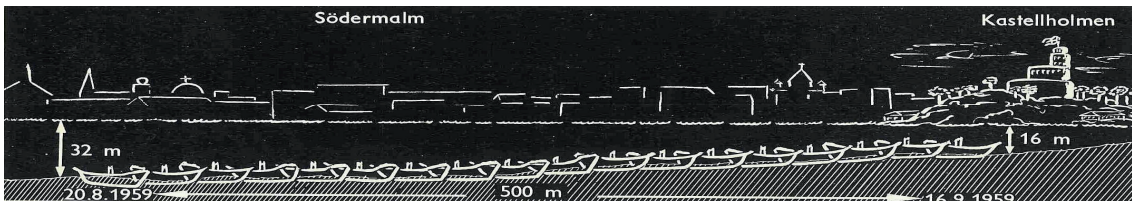


a) Drawing by Bjoern Landstroem (Matz,1991) b) Ohrelius (1963). c) An artist's illustration of the lifting (Wenk, 1977).



d) Plan showing the lifting with seven hydraulic jacks.

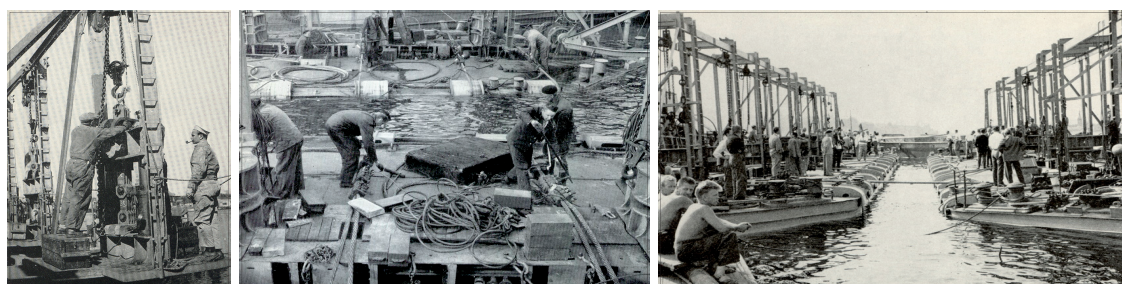
e) Cross-section showing the lifting of the *Vasa*.



f) Lifting and shifting sequence.

Fig. 9 Lifting and shifting sequence (Franzen 1974).

a) *Vasa* lay at a depth of 32 meters. The navy's heavy divers were able to cut six tunnels through the clay under the ship with special water jets. Steel cables were drawn through the tunnels and taken to two lifting pontoons on the surface, which would pull the ship free of the harbour bottom's grip. In August 1959, it was time for the first lift. There was great uncertainty - would the old wooden ship hold together? Yes! *Vasa* held. She was lifted in 18 stages to shallower water, where she could be patched and reinforced in preparation for the final lift, to the surface! b) Early days salvage technique. The Italian Gerlamo Cardano, like the Swede Olaus Magnus, demonstrated how ships could be salvaged in the mid-16c. The technique used in salvaging the *Vasa* in 1961 was basically the same. c)~e) The *Vasa* leaving her 331-year old grave. Though each of the six tunnels two wire ropes were passed which were locked together across the decks of the Neptune Company's salvage pontoons, the *Oden* and the *Frigg*, floating with their decks near the surface. Next the pontoons were emptied thus raising the ship a few feet. Since the pumping of the pontoons was carried out gradually there was no trouble with the suction effect of the clay. The wreck of the *Vasa* weighed about 700 tons under water which gave a maximum load of only 30 tons on each of the wire ropes. The ship now resumed her voyage which was interrupted in 1628. f) With the *Vasa* suspended just over the bottom, the pontoons were towed towards shallow water until the wreck came aground. g) Artist's sketch of the 18 lifts that carried the *Vasa* about 600 meters. The *Vasa* was moved under water in 18 stages from a depth of 100 feet to 50 feet of water to a point just off the island of Kastellholmen in the center of the harbour. The course followed by the by the *Vasa* in her journey towards the daylight was far more complicated and less direct than is indicated by the diagram above. Sometimes the wreck slide back into the position where it had rested before the last lift and on occasions it sank so deeply into the mud that it was as far from the surface as it had been before the previous lift. It was sometimes necessary to turn the *Vasa* round completely and tow her stern foremost.



a) (Ohrelius 1963). b) Tightening the lifting wires. c) Waiting for the wires began to take the weight.

Fig. 10 Raising the *Vasa* with lifting pontoons with hydraulic jacks (Franzen 1974).

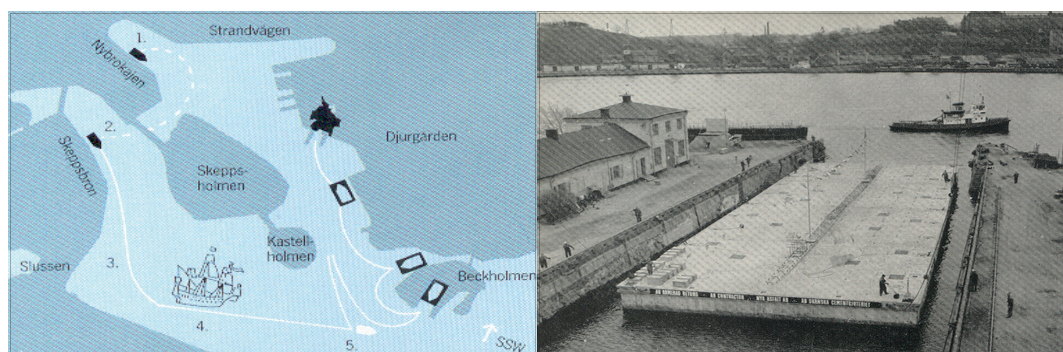
a) The chains being fixed on the hydraulic jacks on the pontoon. b) The pontoons are now low with their decks near the surface and the lifting wires are being hauled tight and locked across the decks with huge wire clips weighing over 100 pounds each. c) The pontoons were flooded with water until their decks were almost on the surface. The wires were hauled tight and locked across the decks with huge trebled, wire clips. The pumping then began and the salvors could only hope that the ship would be able to bear the strain down there in the dark water as the wires began to take the weight.



a) After 333 years, The *Vasa* broke the surface on the morning of 24 April 1961. b) (Ohrelius 1963).

Fig. 11 Arrival at the surface (Matz 1991; Ohrelius 1963).

a) The press, radio and TV from the whole world followed this unique event. b) *Vasa* looking long and slender as she lies between the two pontoons, *Oden* and *Frigg*. Her stern is nearest the camera. The hydraulic jacks are on the small platforms on the side of the pontoon turned towards *Vasa*. The staging in the middle is where they were originally mounted. The midships shaft is now covered over.

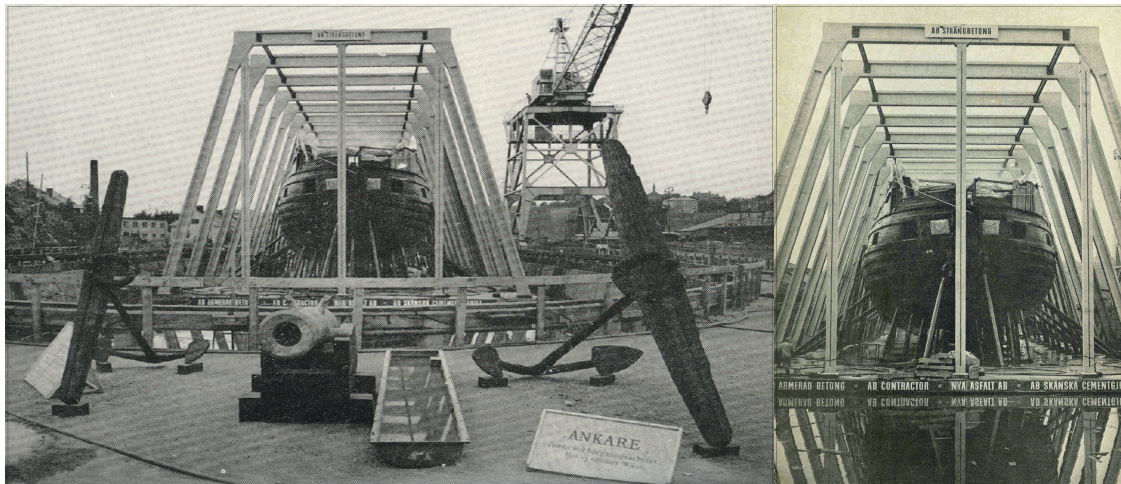


a) Voyage of the *Vasa* (Matz 1991).

b) The big *Vasa* pontoon being docked at Beckholmen.

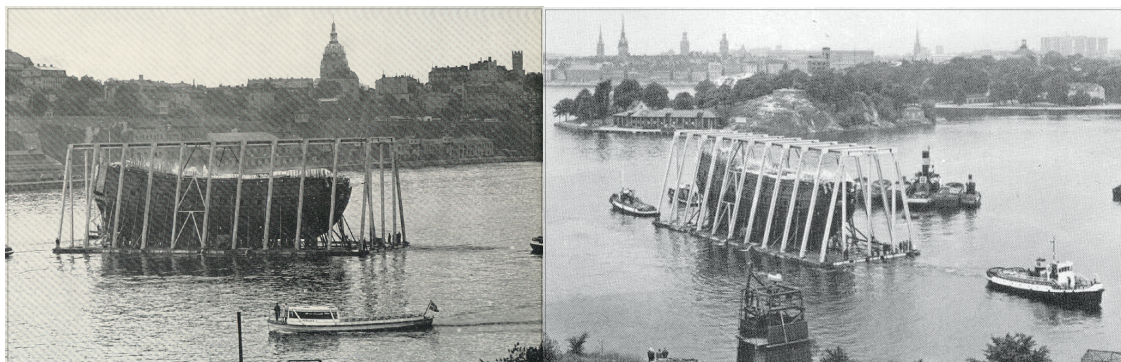
Fig. 12 Moving into the dry dock at Beckholmen (Matz 1991; Ohrelius 1963).

- a) 1. Where the *Vasa* was built. 2. In the early of summer 1628, the *Vasa* was moved to the quay below the Royal Castle. There, guns ballast and equipment were taken onboard. 3. On Aug. 10 1628, the *Vasa* was kedged to Tranbodarna(Slussen), and set sail. 4. The *Vasa's* route. 5. After 1,300 meters, at Tegelviken, the wind increased and the *Vasa* capsized and sank 100 meters off the island of Beckholmen.
- b) The *Vasa* will be rested on this concrete pontoon for the following works (ref. **Fig. 13**).



a) *Vasa* cleared for taking out.

b) *Vasa* on the concrete pontoon.



c) Out of the dock once more.

d) Brief journey to a provisional site (Franzen 1974).

Fig. 13 Leaving the dry dock going to the provisional site (Ohrelius 1963; Franzen 1974).

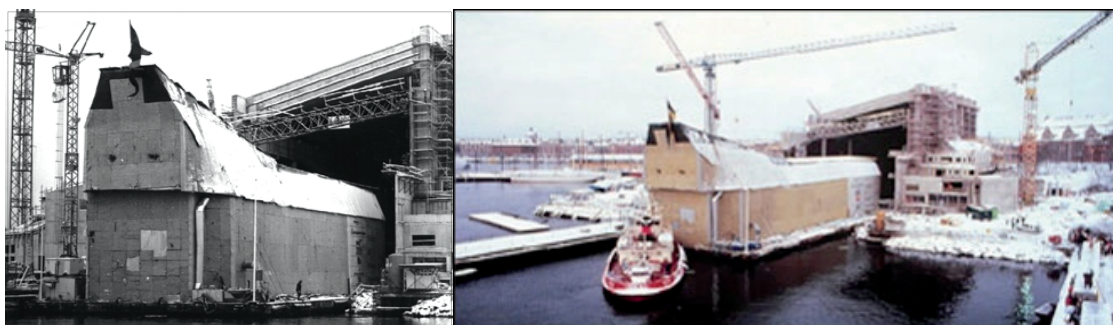
- a) In the foreground is a cannon, removed on 6 June 1961, along with 2 of the nearly 30 anchors found in her.
- b) *Vasa* positioned on the concrete pontoon (ref. **Fig. 12 b**).
- c) & d) From the dry dock at nearby Beckholmen, The *Vasa* being towed across Stockholm harbor on a concrete pontoon after having been lifted in 1961. In July *Vasa* was towed out for further archaeological excavation. Even while being towed, the sprinklers were kept going to prevent her drying out.
- Once the *Vasa* was properly set up on her concrete pontoon she made a brief journey to a provisional site, where a temporary building was being constructed to receive her.



a) During the autumn of 1961. b) On a misty morning in November 1961.

Fig. 14 Preparation works for the temporary museum (Saunders 1962).

- a) The old ship gradually disappears behind a growing cocoon of tubular steel scaffolding as a prelude to the building of the aluminium house that will protect the *Vasa* for the next decade.
- b) The *Vasa*, now completely housed, is towed at a speed of two knots from Beckholmen to the museum site. The house and pontoon together weighed 3,900 tons.



a) The temporary protection encasement. b) Towing out the temporary protection encasement containing *Vasa*.

Fig. 15 Moving into the permanent museum (Hafors 1997; The *Vasa* Museum).

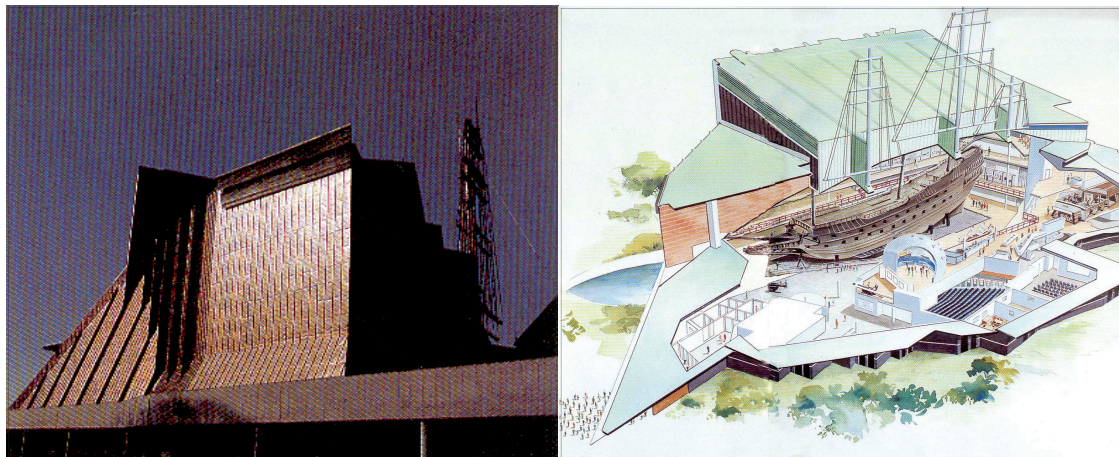
- a) The temporary protection encasement containing the *Vasa* ship on its way into the *Vasa* museum.

Because the new *Vasa* museum was constructed with the main part of an old drydock inside the building it was possible to move the whole floating pontoon with the *Vasa* hull inside the temporary protection encasement into the museum. This was a risky business although the distance between the position of the old museum and the building site was as short as some 500 meters. The encasement made a huge surface exposed to the wind and the day of transport had to be chosen carefully with the help of meteorologists to have as low velocity of wind as to provide a safe journey. The chosen day was the perfect for the task and on the 6th of December 1988 an assembly of invited people witnessed two tow-boats skillfully manouvering the precious parcel of the *Vasa* hull on the pontoon into the new museum. The freeboard on each side of the pontoon to the dock sides was 40 centimetres.

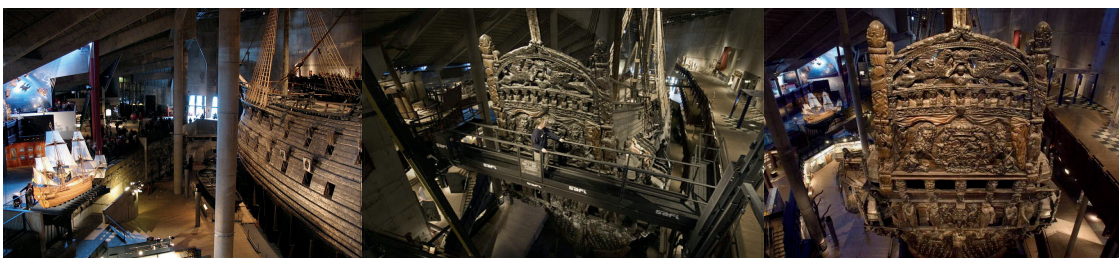
After the pontoon had been brought into the museum the drydock was emptied and sealed off from the surrounding water. The pontoon was carefully placed on plinths that were distributed on the bottom of the dock in order to give adequate support. The pontoon then became a permanent part of the new museum building.



a) Exterior of The *Vasa* Museum, was officially opened on June 15, 1990 by King Carl XVI Gustav.



b) & c) The warship *Vasa* now has her own museum in the middle of Stockholm (Matz 1991).



d) The main hall with a model of *Vasa*. e) Stern platform.

f) (UNESCO).

Fig. 16 The *Vasa* Museum (vasamuseet.se).

e) The *Vasa* Museum has installed a 9 metre wide and 25 metre high platform to help the curators to reach the stern sculptures on the ship which were previously inaccessible. The platform is permanent and has an advanced construction which is to provide for the needs and demands of the museum while harmonising with a sensitive environment.

Sulphur precipitates were discovered after the summer of the year 2000, and intensive research work has been ongoing ever since to find the best way to treat the *Vasa*'s wood. The sculptures are the parts that are most

sensitive to surface changes. The sculptures have been surveyed over the years with the help of a sky lift, but this is both a complicated and tedious job. The new permanent platform will facilitate this work and the sculptures will receive a thorough overhaul.

f) © Swedish Maritime Museum, The *Vasa* Museum, Stockholm, Sweden. After the raising of the *Vasa* the public could visit the wreck in a temporary museum. The new *Vasa* museum was then opened in 1990 and attracts in between 730,000 and 1.2 million visitors every year. Only 25% of these are Swedish. The *Vasa* museum is therefore one of most visited museums in Sweden, and an enormous economic asset for the Stockholm region and Sweden in general. This success as a national icon is partly due to strong narratives, an excellent visitor service and a successful long-term marketing strategy. Despite the high numbers of visitors, the *Vasa* museum has though never been, and will never be, a financial success. The recovery of a shipwreck as complex as the *Vasa* could not possibly happen today in Sweden. It would most probably be regarded too costly in relation to the scientific and cultural benefits and too big a risk when it comes to conservation and developing a successful museum.

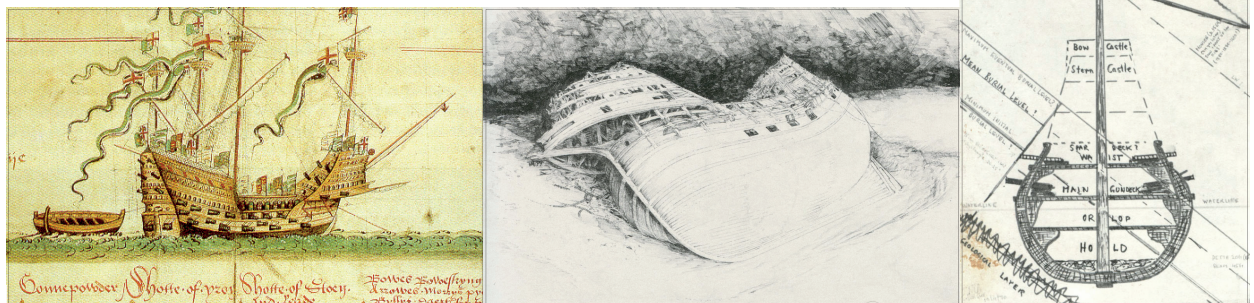
메리 로즈호(Mary Rose)



a) The Cowdray engraving of the battle of the Solent, 1545. 1788, James Basire (1730-1803).

The main and foremasts of the recently sunken Mary Rose are in the middle; bodies, debris and rigging float in the water and men are clinging to the fighting tops.

It was on the 10th May 1966 that Alexander McKee and John Towse went to the Hydrographic Office in London and found the 1841 Admiralty chart that marked the last known position of the *Mary Rose*. At last they had found a more accurate clue to the site of the wreck and John transferred the position to his latest chart of the 'Approaches to Portsmouth'. This chart was used on the first dive to relocate the wreck site and on many subsequent occasions. It would be another four years before the survival of the wreck under the mud could be confirmed and even longer to positively identify it as the *Mary Rose*. Having established the position of the *Mary Rose*, Alexander McKee and John Towse did the first dive on the site of the *Mary Rose* on the 14th May 1966.



b) Contemporary illustration of *Mary Rose*.

c) At the beginning of the 17th century.

d) (McKee 1982).

Fig. 17 The *Mary Rose* (maryrose.org).

b) The only contemporary illustration of *Mary Rose*, which comes from the Anthony Roll, a list of King Henry VIII's vessels completed in 1546 (Magdalene College, Cambridge). c) An artist's impression of what the ship may have looked like at the beginning of the 17th century. When the *Mary Rose* sank the momentum carried the hull through the light upper sediments and the keel settled on the intractable geological clay. Immediately the silt-laden currents carried fine sediments into the hull through the open gunports and settlement occurred within the calm waters inside the hull. At the same time currents hit the exposed upper hull, vortexing and eddying around the protecting superstructure, and scouring away a moat or scourpits in the seabed on the port side of the hull. A shallow scourpits was also found beneath the sterncastle on the starboard side of the ship but this quickly filled with fine sediments which smothered and killed the developing young oysters on the outside of the hull. After several decades of tidal attack, the exposed hull structure became weakened by the attrition of the silt-laden tides and it collapsed into the scourpits around the ship. Once this obstruction was removed the currents could flow freely across the relatively flat site and although minor scourpits were found from time to time around individual deck beams or frames, the site remained stable until archaeological excavation began in 1971. (Rule 1982).

d) The author's interpretation of the 'pinger' graphs obtained by Professor Edgerton in 1968 (**Fig. 18 e & f**): a ship heeled over, with one side largely preserved, the other missing. He expected the ship to be cut off on the line marked 'Mean Burial Level', all timbers above this line being eaten and eroded. This rough drawing, made in 1970, was for the benefit of divers on the boat at Spithead. It proved to be basically correct.

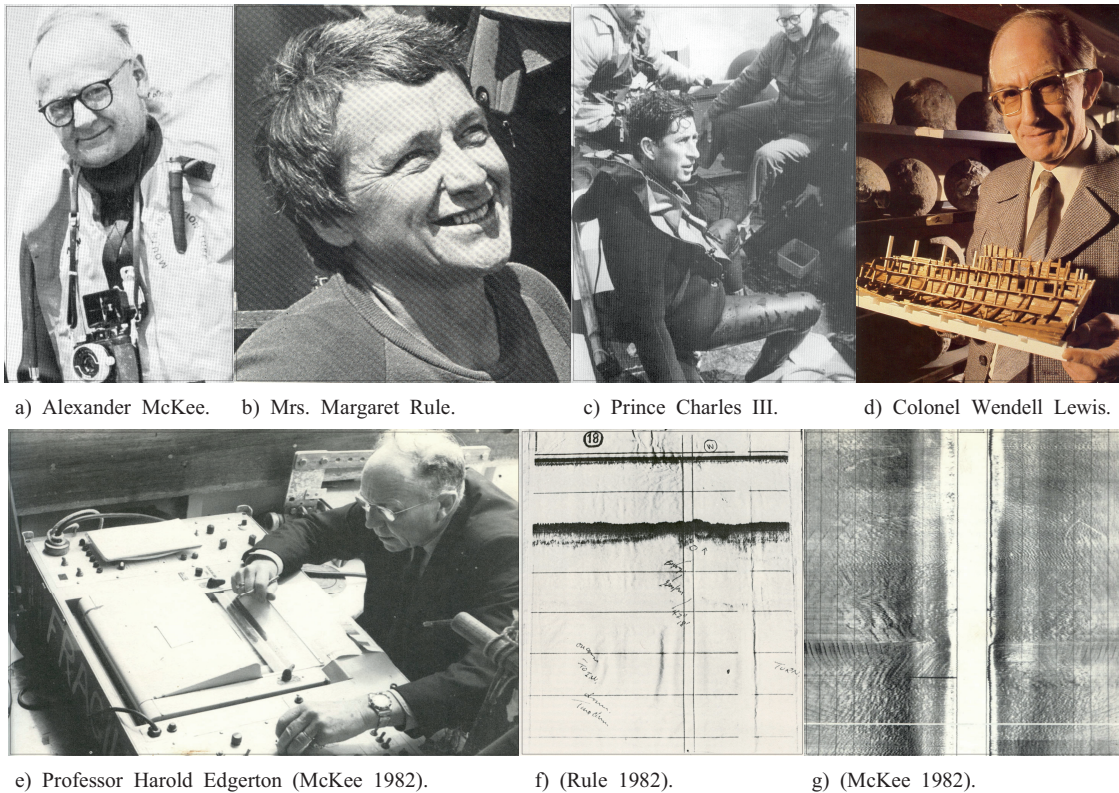


Fig. 18 Important personnel and sonar records (Bradford 1982; Lampton 1988; McKee 1982; Rule 1982).

- a) Alexander McKee, a journalist and amateur diver, who found the site of the wreck of the *Mary Rose* and so opened the way for her excavation and recovery. He died in 1992, aged 74, 10 years after the wreck was raised.
- b) Mrs. Margaret Rule, who leads the team of archaeologists and volunteers who are excavating the *Mary Rose*.
- c) Prince Charles rests after his dive to see the wreck of the *Mary Rose* (Lampton 1988).
- d) Colonel Wendell Lewis, Director of recovery, holds a model reconstruction of the remains (Bradford 1982).
- e) Professor Harold Edgerton of MIT operating one of his special 'pingers' at Spithead in July 1968.
- f) Photograph of a sonar trace over the site of the *Mary Rose* using sub-bottom sonar operating at 5 k/c. The profiler revealed a W-shaped anomaly beneath the surface of the seabed and above the anomaly, a slight mound. On the basis of this evidence
- g) Sidescan graph of a half-mile of seabed at Spithead in October 1967.

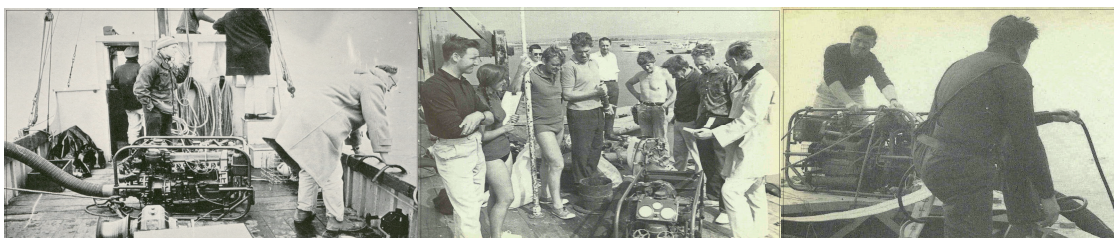
Top left: a distinct anomaly is shown among the natural ripple patterns. It proved to be two long mounds which the author interpreted as the scour mark left by the *Mary Rose* before all trace of the hull vanished from the seabed surface.

*"Nanhai No.1" in China
and Total Excavations of the Sunken Shipwrecks-I*



a) *Julie-Anne*, pitching in a heavy swell.

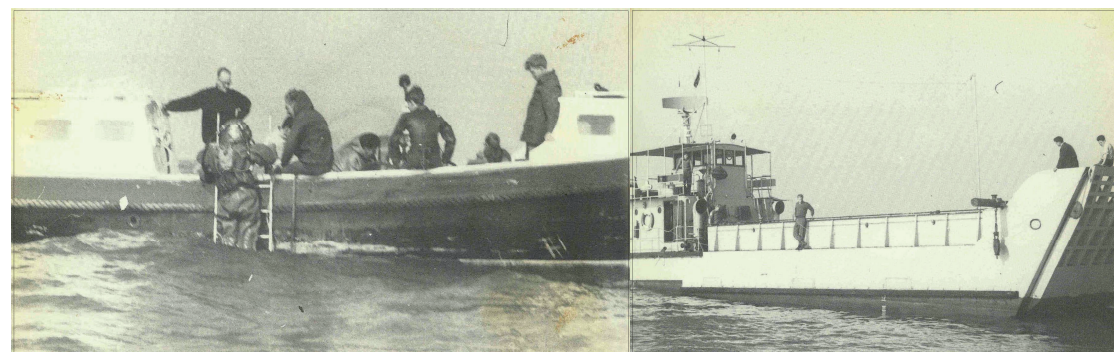
b) Tony Glover's *Julie-Anne* (Bradford 1982).



c) 'Fire Brigade' team 1968 (Rule 1982).

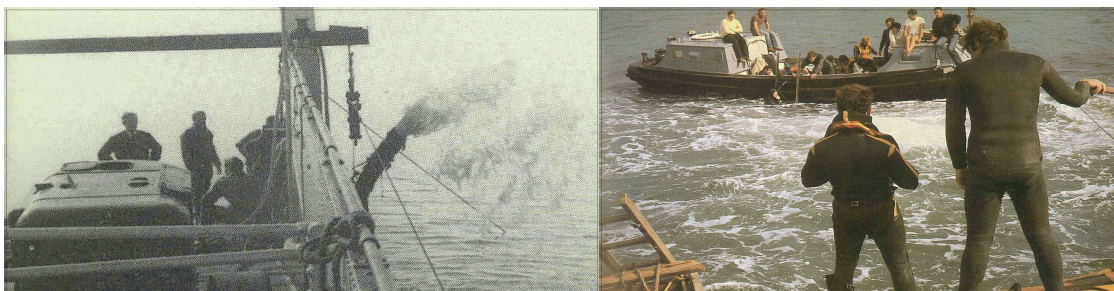
d) Pierhead briefing in 1969.

e) Ted Peam and Tom Smith.



f) Mr. S.J. Utley, a Portsmouth Dockyard diver in 1969.

g) The Royal Engineers arrive in 1969.



h) Compressor for 8-inch airlift.

i) The surface eddy caused by the airlifting.

Fig. 19 Early day works and equipments (McKee 1982; Bradford 1982; Rule 1982).

a) One of our early diving boats, Tony Glover's *Julie-Anne*, pitching in a heavy swell.

b) In the early days Alexander McKee and his team went out to the site of the *Mary Rose* in small boats like the fishing trawler *Julie Anne*, owned by Tony Glover.

c) Alexander McKee and members of the 'Fire Brigade' team 1968. In the 1960's the *Mary Rose* team hired fishing vessels to visit the site and excavation was done using water jets to remove the over-burden of silts from

the area where the ship was believed to lie.

d) Pierhead briefing in Langstone Harbor, 1969. The author and George Clark (far right) explain how they intend to start digging with jets powered by a Portsmouth Fire Brigade pump. (Photo: Portsmouth News).

e) The pump mounted on a flimsy pontoon boat. Fireman Ted Peam is at the pump, while Sub-Officer Tom Smith holds the surface-demand air line to Station Officer George Clark, 50 feet down on the seabed. Tom is wearing overalls on top of a wet suit for work diving, which is hard on neoprene.

f) Mr. S.J. Utley, a Portsmouth Dockyard diver, about to go down to the *Mary Rose* in 1969, the first 'hard hat' man to do so since 1840. Talking to him at the top of the ladder are the author (left) and George Clark (right).

g) The Royal Engineers arrive in 1969, the successors to Colonel Pasley's Sappers and Miners who worked at Spithead from 1839 to 1844.

h) Aboard the 74-ft. landing craft used by the Royal Engineers. Note the size of the compressor required to power an 8-inch airlift.

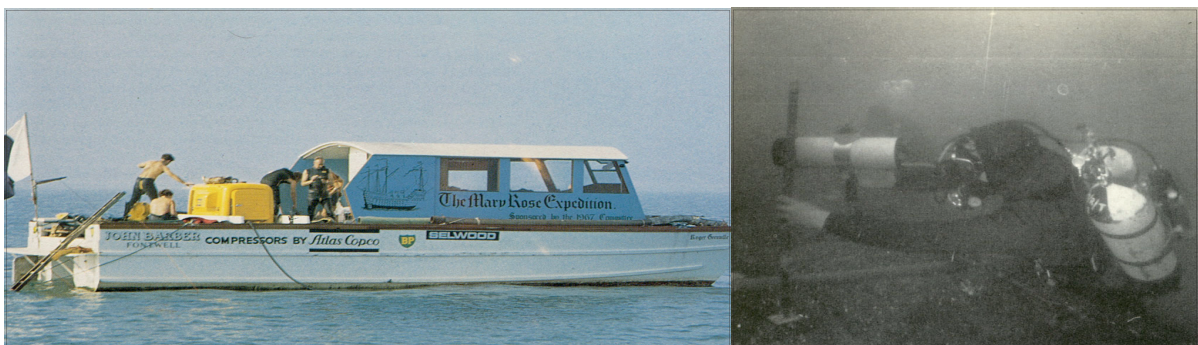
i) Up Top: the water heaves between the compressor barge and the Naval pinnacle from the working of a 4-inch airlift.



j) 6-inch airlift.

k) Diver with airlift.

l) Concreted gun, September 1970.



m) The 40 ft catamaran *Roger Grenville* (Rule 1982).

n) A hand-held sonar.

Fig. 19 Continued (Early day works and equipments).

j) Down Below: careful excavation with the 6-inch airlift. While one diver (background) holds the tube in position, the excavator (foreground) uses his left hand to move soil towards the mouth of the tube which will take it away. This was an early model; later airlifts were rigged so that one man could handle them on his own.

k) Using the airlift, a diver excavates at the stern of the *Mary Rose*.

l) The crew of the dredger did not believe that this weirdly concreted object could be a gun. But it was, and it possibly identified the *Mary Rose*.

m) *Roger Grenville* from which the team worked between June 1971 and the advent of the *Sleipner* in 1979.

n) A modern measuring instrument: a hand-held sonar 'gun' that records distances with precision and speed.

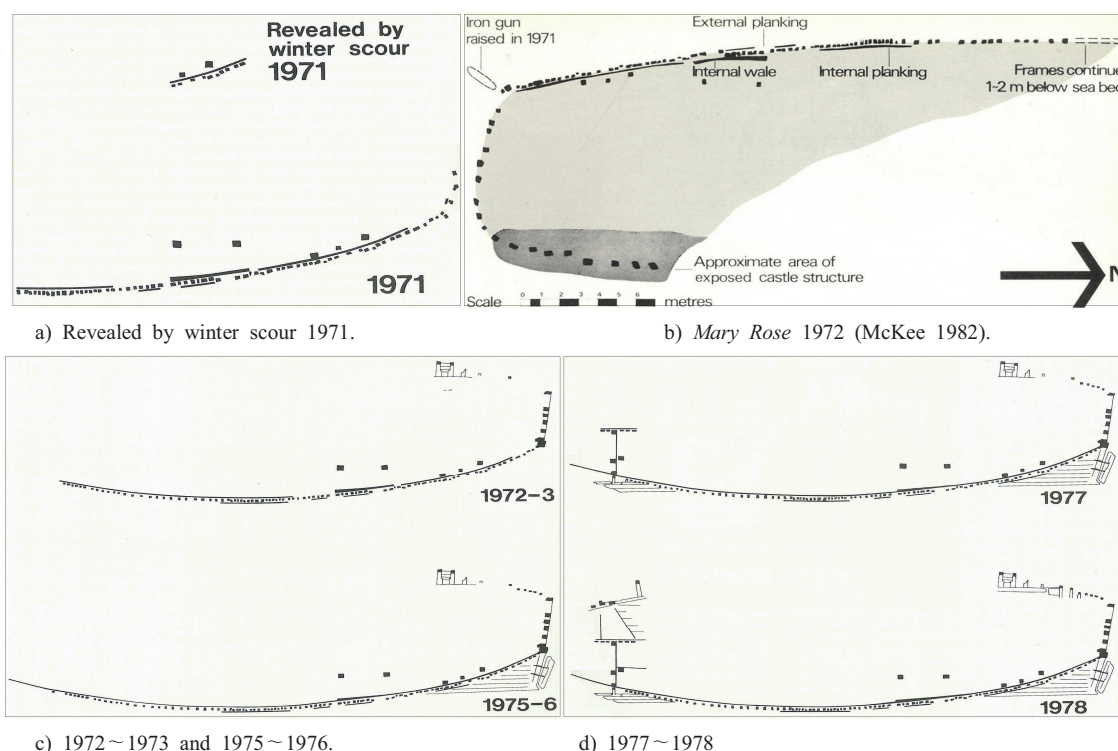
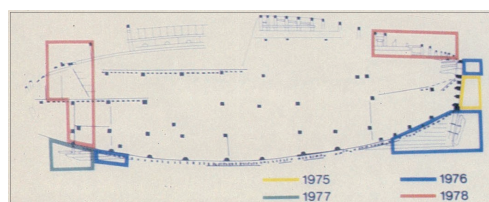


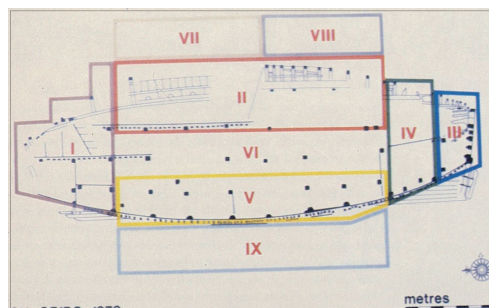
Fig. 20 The state of the surveys 1971~1978 (Rule 1982; McKee 1982).

The state of the surveys between 1971 and 1978 charts the painstaking progress of the excavation during the early years of the project.

b) At the end of 1972 the 'outlining' process of a shallow excavation along frame heads had reached this stage. A deep dig had been made at one point only - between the 'internal wale' and the iron gun raised in 1971. It was not then clear that the rudder lay below the iron gun; this was revealed by deep excavation in 1975.



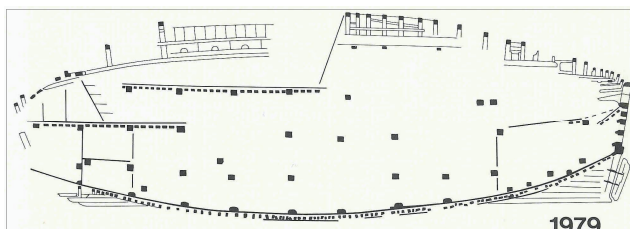
a) Trench grids 1975~1978.



b) Trench grids 1979.

a) In the earlier years when excavation was done mostly at weekends, deep excavation was only undertaken outside the hull but during 1978 a large trench was dug across the bow from the port to the starboard side which revealed the remains of two decks in situ.

b) When the *Mary Rose* Trust was formed in 1979 it became possible to work a full season on site and trenches II, V and VI were excavated above the midship section to remove the burden of secondary silts. By the end of 1979 most of the secondary silts had been recovered and the structure of the ship was beginning to be revealed.



c) The 1979 survey of the site.

Fig. 21 Plan of trenches excavated 1975~1979 (Rule 1982).

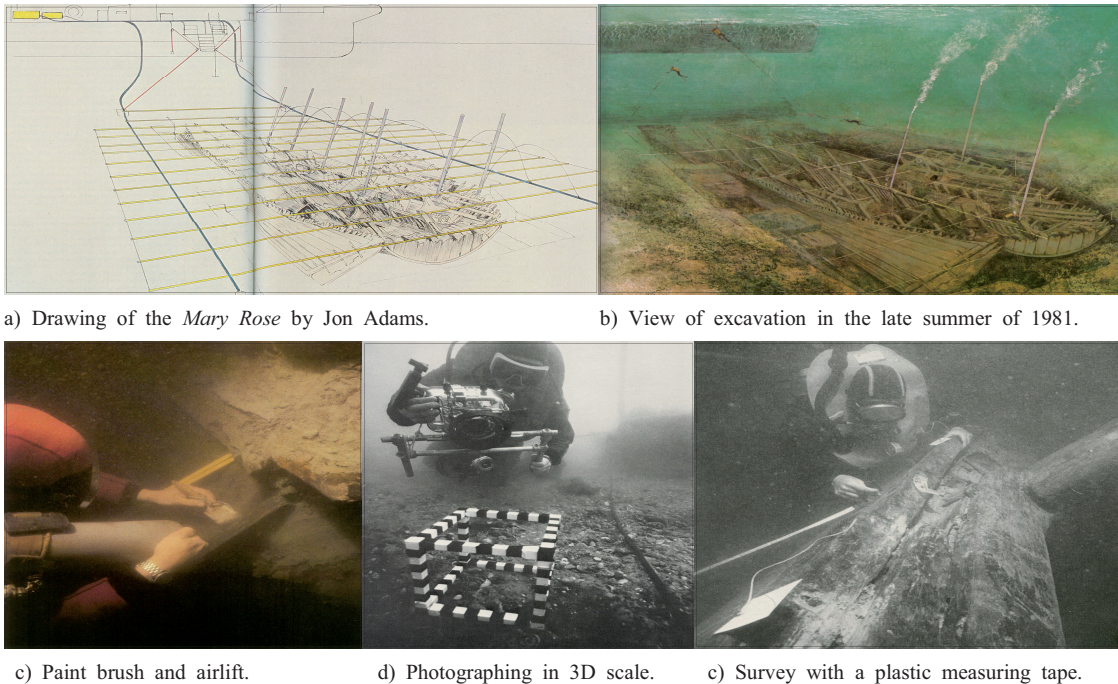


Fig. 22 Full excavation and salvage, 1979~1982 (Rule 1982).

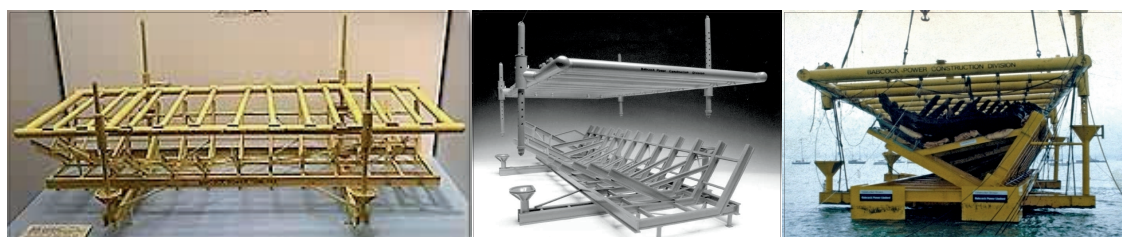
a) Drawing of the *Mary Rose* lying on her starboard side in the seabed by Jon Adams. A grid 3m square was erected above the site to divide it into a series of trenches which were excavated layer by layer using hand tools and an airlift to take away the unwanted 'spoil'. All objects were surveyed in relation to the hull and the grid was never used as a datum for survey - it simply served as a trench location aid in the poor underwater visibility which was usual on this site.

b) View of excavation from the south-west in the late summer of 1981. A grid of steel poles divides the area of the excavation into 3m squares and the debris of silt is being removed by three airlifts, which jettison the debris down-tide. This overview of the whole excavation is never possible in reality underwater on the *Mary Rose* site. Divers can be seen descending from the diving salvage vessel *Sleipner* via a rope shot-line which leads to the air manifolds on the seabed and them to the steel grid. Painting by Jon Adams, a diving archaeologist and Deputy Archaeological Director in 1981.

c) Fragile items were excavated by removing the soft silts with a paint brush which were then carried away by an airlift. The diver's right hand partially seals the orifice of the airlift, thus controlling its power.

d) Nic Rule preparing to photograph the sterncastle using a calibrated three-dimensional scale.

e) A diver surveying the maindeck planking using a plastic measuring tape.



(Dobbs 1995, www.maryrose.org).

(Nordic Underwater Archaeology, abc.se).

Fig. 23 Lifting frame & cradle for the salvage of the *Mary Rose* (The *Mary Rose* Trust).

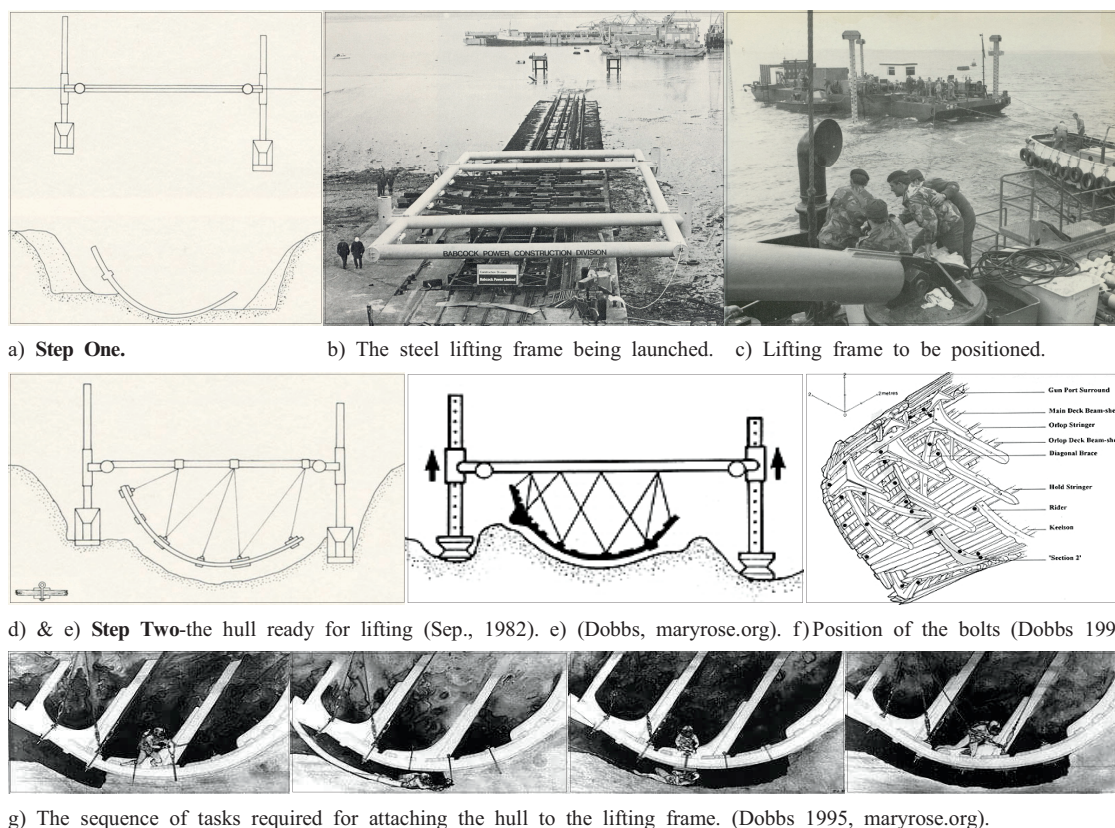


Fig. 24 The raising of the *Mary Rose* (Rule 1982; McKee 1982; The *Mary Rose* Trust).

All salvage operations present their own particular set of problems but an important factor in trying to salvage the *Mary Rose* was that the remaining hull was an open shell, consisting mainly of the starboard side of the hull, rather than a complete cross section with transverse strength. Many methods were considered and the Trust had the benefit of expert advice from an Advisory Committee under the chairmanship of Professor G. Goodrich. The problem of the open shell led to an important decision being taken: namely to carry out the lifting operation in three very distinct stages. In the first stage, the problem of 'bottom suction' had to be overcome. This was achieved by raising the first few centimetres over a period of several days using an ingenious system of twelve hydraulic jacks which raised the lifting frame slowly up the four legs. It was only when the hull was hanging freely from the lifting frame, clear of the sea bed and the suction effect of the surrounding mud, that the salvage progressed to the second stage when the hull was lifted completely clear of the sea bed and transferred underwater into the lifting cradle (fig. 1b). For this lifting operation the giant floating crane Tog Mor was the ideal vessel as the 'Stielcken derrick' enabled it to position the hook and the load very accurately without the need for continually adjusting the four point mooring system. The third and final stage was to lift the entire structure into air, by which time the hull would also be supported from below (fig. 1c). This would ensure maximum support for that crucial period at the interface between water and air. The *Mary Rose* will be lifted from the seabed and brought ashore on a barge cradled in a steel supporting structure. In order to achieve this, the programme of work breaks down into six operations.

a) **Step One.** After excavation within the hull is completed, a tubular steel framework is placed in position above the hull. This underwater lifting frame stands on four legs firmly supported in the geological clay.

b) The steel lifting frame being launched at Hythe on Southampton Water in March 1982. This steel frame will be used to carry the weight of the hull as it is lifted from the seabed and placed underwater on a supporting steel cradle. When the lifting frame has been attached to the cradle, the hull of the *Mary Rose* will be completely

supported within a steel box and she will then be lifted into the air by a giant crane and placed on a barge to be towed ashore.

c) On 14 June, 1982, the lifting frame to be positioned on the seabed above the *Mary Rose* by divers of the Royal Engineers, was towed to Spithead suspended beneath a barge. (McKee 1982).

d) **Step Two.** Holes are drilled through the hull at predetermined points and steel bolts and backing plates are secured to the timbers. Eye bolts are fastened to the internal ends of the steel bolts, and from these points wire ropes are passed up to the cross-members of the underwater lifting frame. As each wire is firmly secured in position tunneling can proceed beneath the hull.

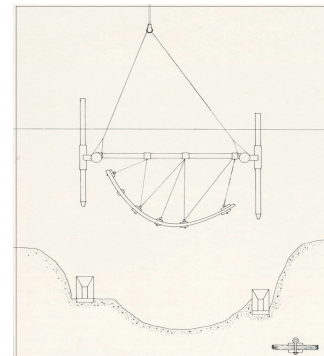
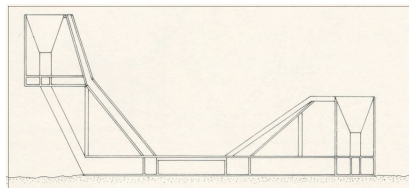
e) The hull is wired to the lifting frame from the bolt positions. Hydraulic jacks, operating on the legs of the frame then raised the hull the first critical centimetres until it was free of the suction effect of the silt below.

f) The philosophy behind the positioning of the bolts. Looking at these cross sections of the hull, the typical sequence of structural elements chosen as the strong points can be seen. The points were spread evenly across the section and corresponded to the major structural elements such as the keel, rider, a hold stringer, diagonal brace, orlop deck beam shelf, an orlop deck stringer, main deck beam shelf etc. There were exceptions to this pattern but the rationale of selection was similar in each area.

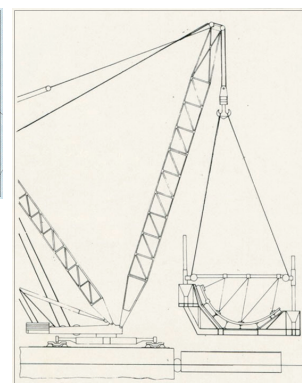
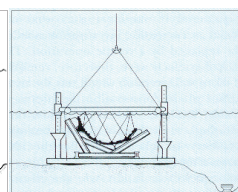
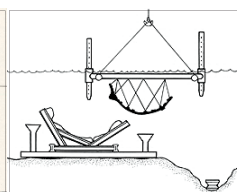
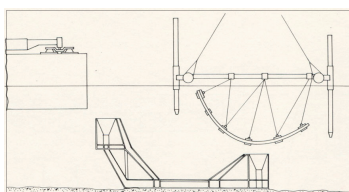
g) Every single lifting point had to be individually located and drilled, the bolt placed in position, the hull undercut to enable the backing plate to be fitted, and the bolts tightened up.

The sequence of tasks: drilling the hull → fixing the bolts → tightening the bolts → fitting the wires.

h) **Step Three.** A prefabricated steel cradle which has been designed to conform with the lines of the *Mary Rose* is placed in position on the seabed close to the *Mary Rose* site



i) **Step Four.** The hull of the *Mary Rose* suspended from the steel wires is lifted from the seabed using the hydraulic jacks in the legs of the underwater lifting frame. After the hull is free from the seabed, the frame is lifted by a crane barge and moved to a position immediately above the support cradle.



j) **Step Five.** The underwater lifting frame within which the suspended *Mary Rose* is moved into position above the steel cradle, and the legs of the frame are securely locked to the rising supports on the cradle. The space between the hull and the steel cradle is filled with water, to accommodate the chain-wale and other features which need special support. The cradle with the hull ready for the lift into the air. The lifting frame now acts as a spreader for the wire stops from the crane hook. (11 Oct., 1982).

k) **Step Six.** The *Mary Rose* securely sandwiched between the supporting mattress, the cradle, and underwater lifting frame is then lifted from the sea onto a barge for transport ashore. As the *Mary Rose* comes through the surface, water inside the hull will be pumped out and the water in the supporting mattress will be replaced with air (11 Oct., 1982).

Fig. 24 Continued (The raising of the *Mary Rose*).

"Nanhai No.1" in China
and Total Excavations of the Sunken Shipwrecks-I

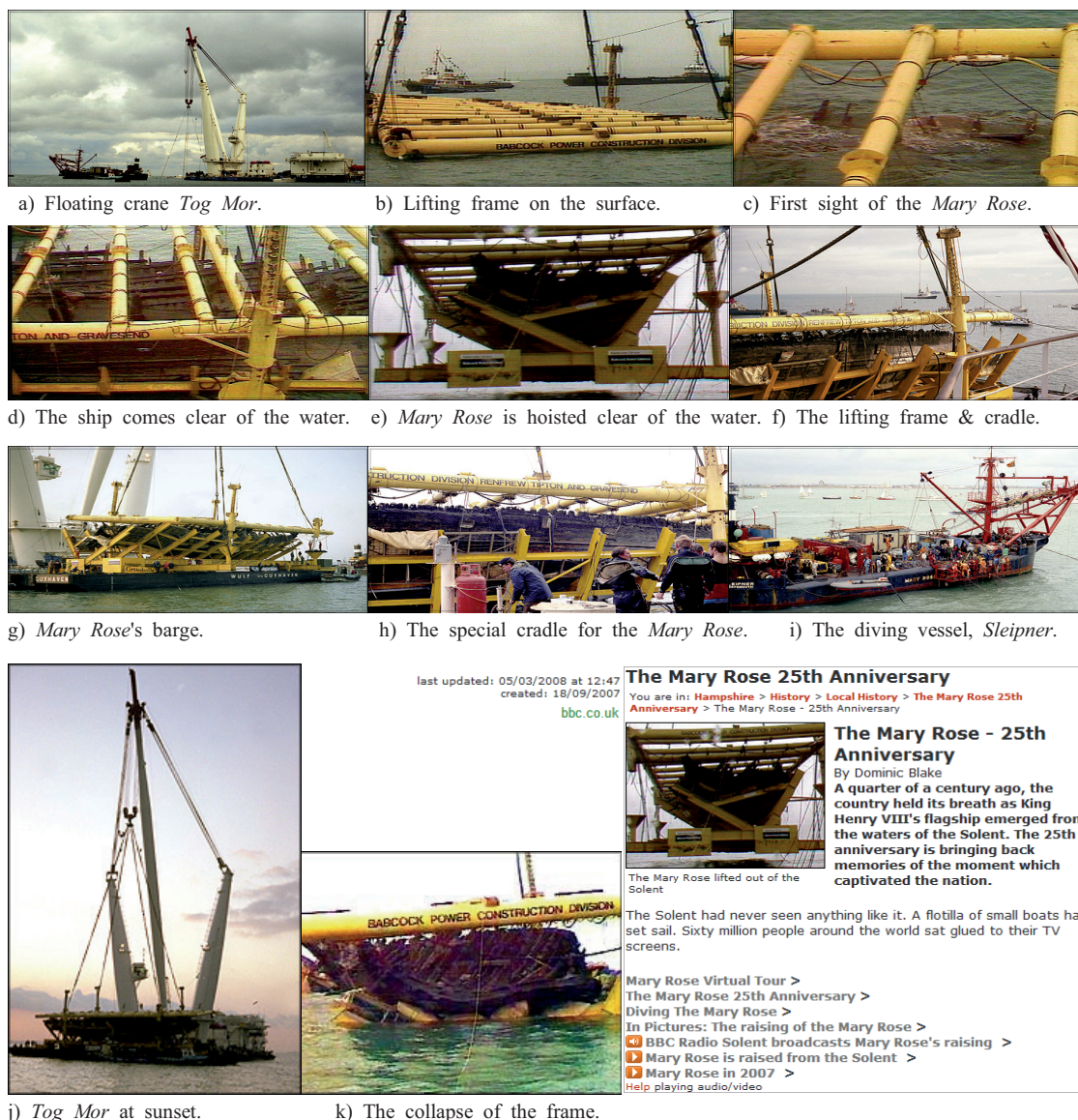


Fig. 25 The raising of the *Mary Rose* - on the BBC.

- a) The giant floating *Tog Mor* before the planned lift - an ambitious project in terms of both archaeology and engineering.
- b) Preparing to lift *Mary Rose* above the surface of the Solent. The wreck had been re-discovered in the 1960s by a team led by Alexander McKee - Mad Mac's Marauders.
- c) The first sight of the *Mary Rose*'s timbers since July 1545 when she sank while preparing to attack the French fleet, watched by King Henry VIII from Southsea Castle.
- e) The project had captured the imagination of millions of people watching on television around the country.
- f) The lifting cradle, part of which collapsed as the ship was lifted from the water.
- h) The special cradle for the *Mary Rose*. After being raised, she was taken into Portsmouth naval base's No.3 Drydock. She was wrapped in protective foam and polythene and constantly sprayed to keep her wet.
- k) The collapse of the frame nearly scuppered the ?4 million operation.

The long-anticipated £4 million operation, twice postponed, was beset by technical problems with the complicated

salvaging apparatus and floating cradle. But the ship's skeletal remains of mud-caked timber were in the end successfully re-floated and experts can now begin the long process of restoring the *Mary Rose* in a dry dock in Portsmouth.

Historic moment

Lifting of the wreck from its location at 50 feet below sea level began at 07:00 local time and within two hours the first jagged edges of timber had broken the surface. A cannon was fired from the ramparts of Southsea Castle to signal the historic moment. Yet just before midday one of the pins holding the lifting frame sheared, a steel line snapped and part of the 80 tonne frame smashed down on the hull. Speaking after the accident, Prince Charles, President of the *Mary Rose* Trust, and a seasoned diver at the wreck spoke of his shock: "I was slightly horrified but I thought the best thing to do was to be British and not panic." Inspections showed the damage to be slight, but further mishaps meant the wreck was not safely installed onto its transport barge until 1500.

Margaret Rule, archaeological director of the privately-sponsored project said the raising of the "fascinating and rare Tudor artefact" was the culmination of a "dream that had gripped the imagination of the world".

The *Mary Rose* was rediscovered in 1966 by Alexander McKee, a historian and amateur diver. Since then over 10,000 well-preserved items have been excavated including weapons, clothes and even a backgammon set.

© **The Mary Rose Trust**, The final stages of the raise of the 16th century carrack *Mary Rose* on 11 October 1982, Portsmouth, United Kingdom. The determination of the *Mary Rose* Trust, whose declared mission it is "to find, to record, to excavate, raise, bring ashore, preserve, publish, report on and display for all time the wreck in Portsmouth", culminated in the raising of the hull in 1982. After many intermediate stages, it will result in the creation of a new specially dedicated museum. The project has been and continues to be a process of learning on the job. More than 20,000 individual items were raised, described and treated. Over the decades, many hundreds of employees and volunteers have been involved in the project. Research that leads to a new understanding of 16th century shipbuilding, on board organisation, naval warfare and society at large is and continues to be one of the objectives. In practical terms, such research is both stimulated and impeded by all kind of practicalities and priorities, as well as variations in funding and staff. It is quite certain that the *Mary Rose* documentation and assemblage will in the long run continue to be an invaluable resource for historical research, but it is equally clear that the scale of the experiment is such that it is not easily or wisely repeated. (UNESCO).



[flickr.com](https://www.flickr.com/photos/maryrosetrust/)

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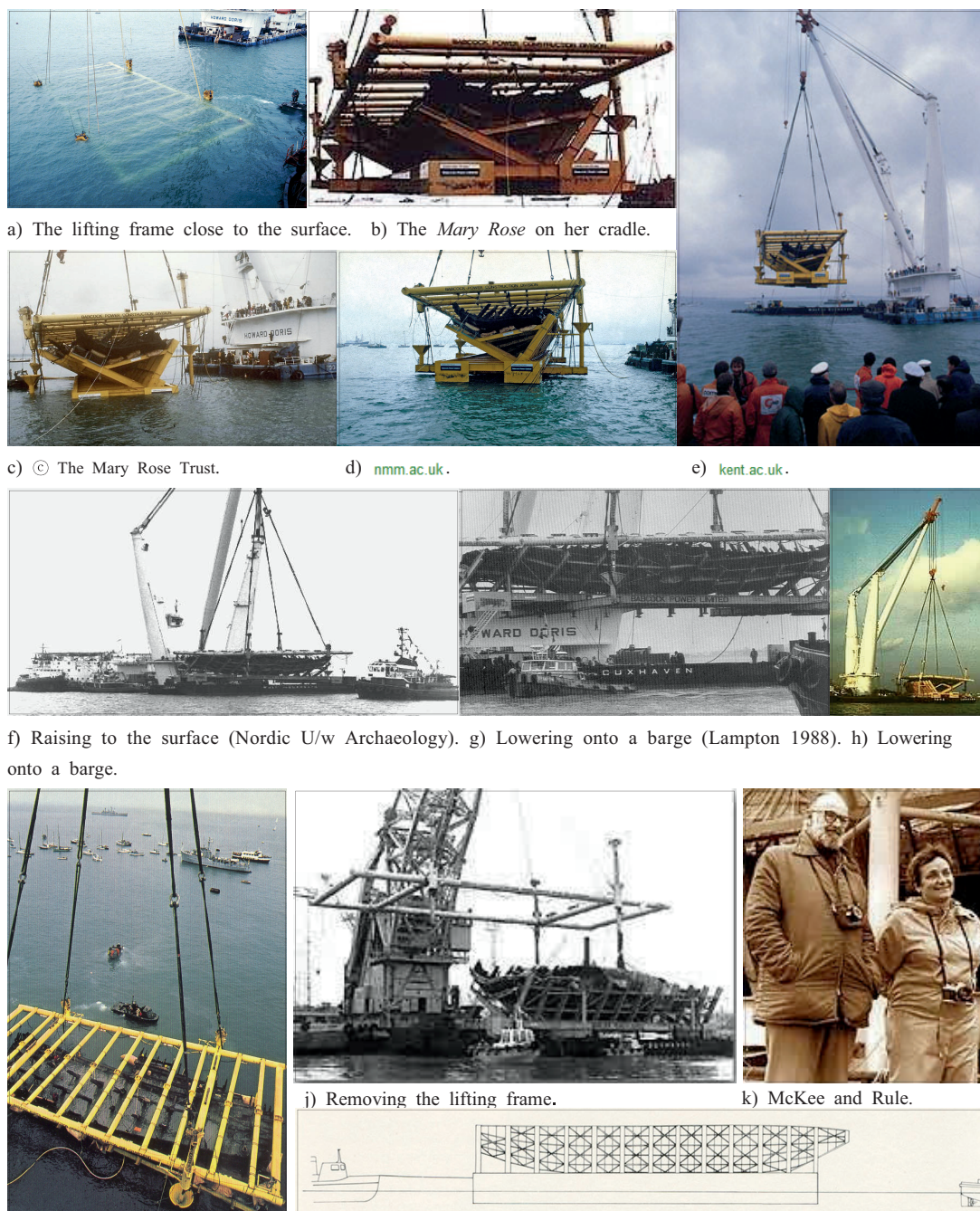


Fig. 26 The *Mary Rose* on the air in a cradle and lifting frame (The *Mary Rose* Trust).

- a) The lifting frame holding the wreck of the *Mary Rose* can be seen just below the surface of the water, about to be lifted (wikipedia). c), d) & e) The hull of the *Mary Rose* being raised, 11 October 1982, 437 years after she sank.
- g) The hull of the *Mary Rose* is lowered onto a barge after it is raised from its watery grave.
- i) The starboard half of the lost ship's hull - the only part preserved by the Solent's thick sediments - rose dripping from its grave in a giant steel cradle and lifting frame. k) Alexander McKee and Margaret Rule seeing their dream of raising the *Mary Rose* reach a successful conclusion.



a) No.3 Drydock ready to receive the hull. b) & c) In No.3 Dry dock.



d) Building the ship hall. e) Mary Rose being sprayed with water. f) Turning the ship.

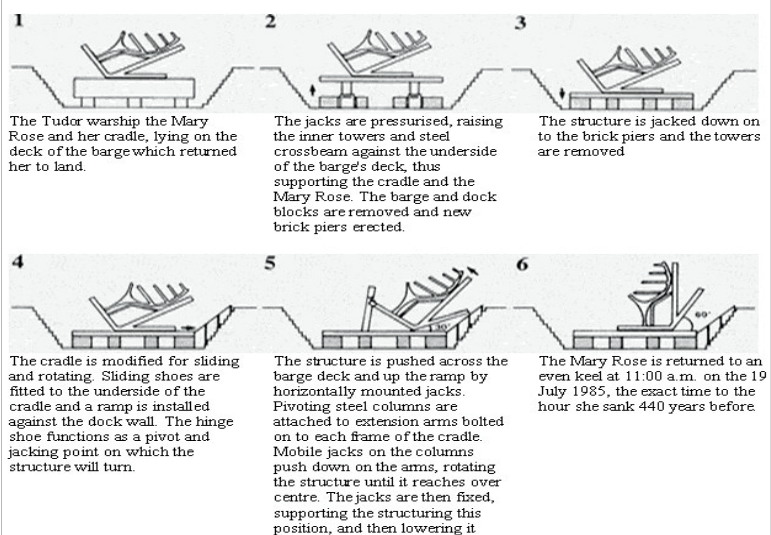


g) During the sliding operation.



h) 10:45 19th July 1985.

The Rotation of the Mary Rose



The procedure used by BYGGWIK to rotate the 'Mary Rose' into an upright position (byggwik.com).

Fig. 27 The *Mary Rose* after recovery (The *Mary Rose* Trust; Rule 1982).

The ship herself had to be housed in a suitable environment, there were thousands of artefacts to store, record and then conserve, and a new museum had to be built to house them. After the ship was raised she was towed into Portsmouth naval base. She was wrapped in protective foam and polyethylene and constantly sprayed to keep her wet.

a) The *Mary Rose* will be housed in the Royal Naval Base, Portsmouth for the first two years after her recovery from the sea. The historic setting is appropriate for the rebirth of the ship, being close to Nelson's flagship HMS *Victory* and the site of the dock where she was built in 1509. (Rule 1982). b) & c) She had been found a new home in No.3 Drydock, (just behind HMS *Victory*) and preparatory work began by removing the lifting frame. After that she had to be jacked up and wheeled onto a smaller barge, the one she was on was too large to fit into the dock. She was moved into the dock on December 8th 1982. d) Work was started on constructing a ship hall for the *Mary Rose*. This was completed in 1983. The building is a lightweight aluminium and fabric structure, double skinned with insulation between the skins. The outer skin was replaced in 1998. e) The Tudor period carrack *Mary Rose* being sprayed with water to keep her timbers from drying out. View looking towards the stern. March 1984 (wikipedia). Between December 1984 and July 1985 the steel cradle was gradually rotated to stand with the keel in an almost upright position.

f)~h) In 1985 the ship was turned upright and a new system of titanium supports installed to support the internal structure. Once the ship was upright, a new series of viewing galleries was constructed.

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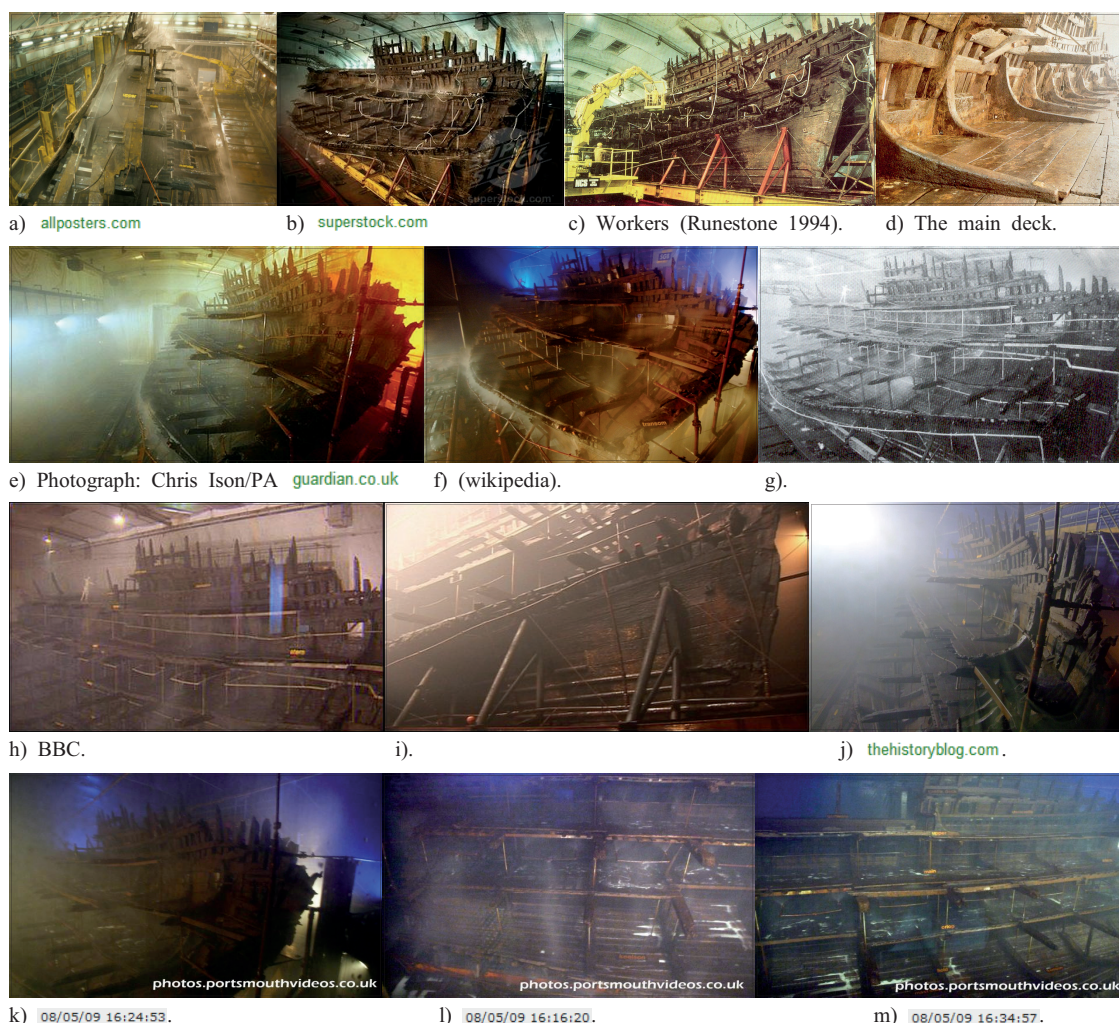


Fig. 28 The *Mary Rose* under restoration and reconstruction (The *Mary Rose* Trust; Runestone 1994).

The timbers were replaced using two cranes. Titanium beams were manufactured to replace missing or broken timbers. This metal was chosen both for its physical properties and also because we didn't want to mislead the visitor by putting modern timbers in the ship. All the timbers had to be drawn and many of them were photographed before being replaced in the hull. While the timbers were being replaced the conservation team were busy installing a new spray system and making sure the ship was kept in perfect condition. The last timber to be replaced before active conservation started was fixed into place in 1993.

The reinstatement of timbers surveyed and removed underwater was completed prior to the start of active conservation in September 1994. In 1994 switched over to active conservation, spraying the ship with a solution of Polyethylene Glycol. This wax will gradually replace the water content of the timbers, eventually allowing us to stop spraying the ship in about 20 years time.

c) Workers restore the waterlogged hull.

d) The main deck looking from the bow photographed in Jul. 1992 before work started on the upper deck above.

e) The remains of the Tudor warship *Mary Rose* as it sits in an atmospherically controlled dry dock.

h) Conservation work to preserve the timbers - *Mary Rose* is constantly sprayed with chilled, recycled, fresh water to prevent the wood drying out, but also to inhibit fungi and bacteria from growing on the timbers.

i) The hull of the *Mary Rose* has to be sprayed with a preserving chemical to maintain the timbers.

j) The *Mary Rose* has become such a popular attraction she needs a new home.

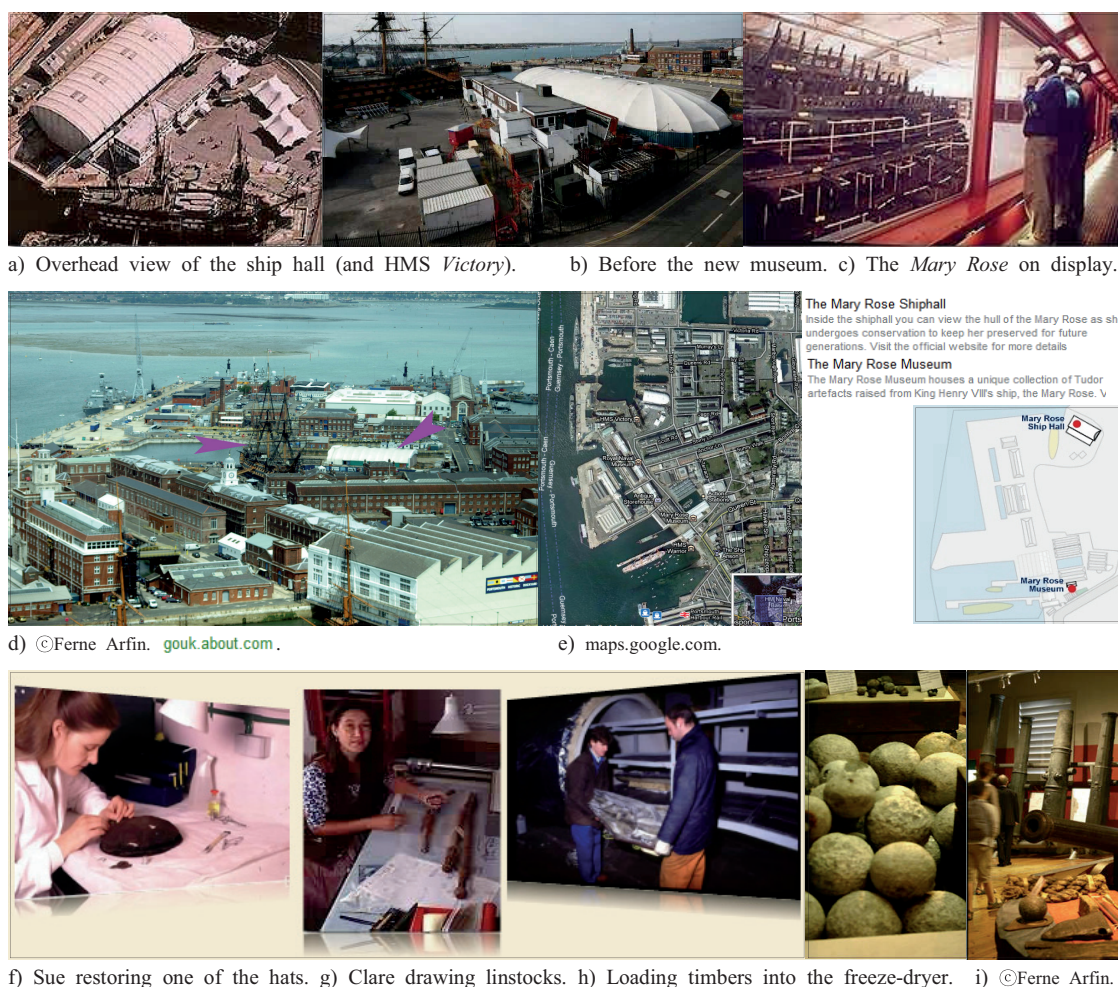


Fig. 29 The *Mary Rose* Ship Hall and Museum (The *Mary Rose* Trust; Runestone 1994).

While the *Mary Rose* was being excavated, around 20,000 artefacts were found in the wreck.

The majority of these were cleaned and recorded aboard the diving vessel, bought some, particularly things like chests and their contents, would be bought ashore to be excavated under more controlled conditions.

After an artefact had been sent ashore, the "Finds Department" would process it. This included making sure it was stored correctly, cleaned, passing it on to be drawn and photographed, and finishing off the recording. The artefacts passed from the Finds Department to Conservation. Led first by Howard Murray and then by Dr Mark Jones, the *Mary Rose* Conservation Department helped pioneer many of the techniques used in the preservation of waterlogged materials.

The conservation process varied depending on the type of material being treated. Wood was generally treated with Polyethylene Glycol (PEG) and then freeze-dried. Other objects, such as the bricks from the galley, were simply washed free of salt over a period of time and allowed to air-dry.

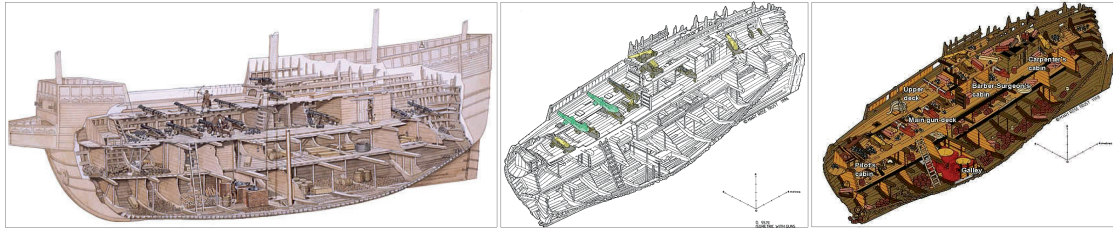
More delicate artefacts required careful conservation and restoration. This applied particularly to items such as the Barber-Surgeon's hat.

a) A new spray system was constructed, the ship was constantly sprayed with chilled (5 degrees centigrade or less), recycled, fresh water. This was not only to prevent the wood drying out, but also to inhibit fungi and bacteria from growing on the timbers. A viewing bridge was built in the ship hall to allow the public to view the ship for the first time for over 400 years.

c) The visitor can now view the ship from climate controlled viewing galleries.

d) Aerial view from the Portsmouth Spinnaker Tower shows the Historic Dockyards, the location of the new *Mary Rose* Museum(right arrow) and HMS *Victory* (left arrow). The new *Mary Rose* Museum is believed to be where the HMS *Mary Rose* was built, 500 years ago.

i) Roughly formed cannon balls were carried on the HMS *Mary Rose* and carved for use by gunners aboard the ship. The bronze cannons were retrieved from the seabed wreck of the HMS *Mary Rose*.



a) Cutaway view.

b) Isometric showing positions of the guns.

c) user.chol.com.

Fig. 30 Construction illustrated (The *Mary Rose* Trust).

The *Mary Rose* had a keel length of 32m and a breadth of 11.66m. Her length at the waterline is estimated to have been 38.5m and her draught 4.6m. The surviving height of the ship is 13m, measured on the starboard side at the aftercastle. The weight of the ship increased during her lifetime, she was rated at 500 tons in 1512 and at 700 tons when she sank. The *Mary Rose* underwent two recorded major refits, one in Portsmouth in 1527~28 and the other in the Thames around 1536, it is assumed her burden was increased to 700 tons during this last refit.

The ship appears to have been skeleton built and carvel planked from her inception. There is no available evidence to suggest that she was converted from a clinker to a carvel built ship during her career. The keel is constructed from three pieces of elm, scarfed together and bolted to the keelson which sits on top of the floor timbers. The keelson is oak, again consisting of three sections scarfed together, with the main mast step acting as the central sector. Just behind the mast step there is a circular hole by the keelson to make room for the lower end of the pump.

The majority of the frames do not appear to be attached to the floor timbers in the hold or to each other, but are held in place by the longitudinal stringers. In the hold the gaps between these stringers are filled with ceiling planking. The outer planking of the hull is fastened through the frames, stringers and ceiling planking by hand-cut wooden treenails. These are hammered into pre-drilled holes and may be up to a metre long. A considerable number of the trennels have caulking cuts in their outboard ends, packed with pitch, possibly to fulfil the same function. The butt ends of the outer planks are further secured by being fixed to the frames with large iron nails and are carefully staggered. These planks are oak, finely adzed on their outboard faces and approximately 100mm thick. The seams of the first few planks above the keel were covered by seam ribands, packed with caulking. This may have been a method of ensuring the caulking didn't fall out of seams loosened either by age or stress.

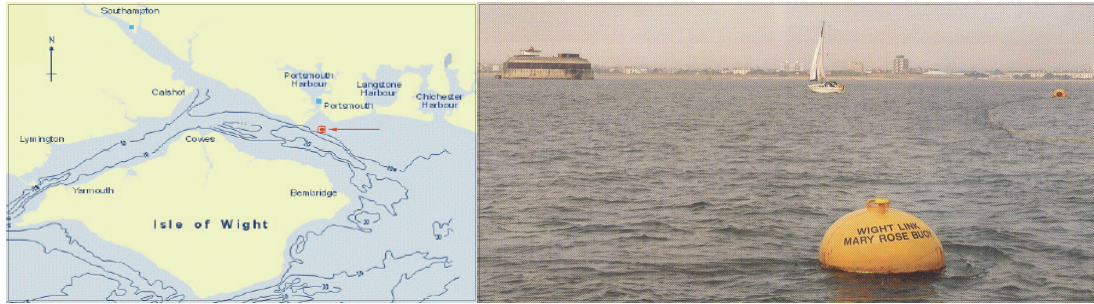
Dendrochronology work by Dr. Martin Bridge of the Institute of Archaeology, University College London, (who did the work whilst at the former London Guildhall University), has confirmed that there was a considerable degree of extra strengthening inserted in the hull after the ship had been built. We have obtained dates from some riders, transom knees and diagonal and vertical braces that proves they were inserted during the two major refits undergone by the ship.

From surviving information, the *Mary Rose* appears to have to have had a hold and four decks: the orlop, main, upper and castle decks. There may have been more than one deck in the forecastle, and perhaps a small deck at the rear of the aftercastle, but due to erosion we lack archaeological evidence in these areas.

e) Isometric showing positions of the guns recovered from the *Mary Rose* (green guns are extrapolated).

영국 군선 *Mary Rose*호를 통해서 선원들이 어디에서 살며, 어떻게 일 하는지 등 "범선에 서의 생활상"을 보여 줍니다. 군인은 upper-deck에 배치되었고, 포수는 main gun deck에 항해가, 이발사, 의사, 목수는 각각 자신의 cabin에 배치되었다. 물론 요리사는 galley에 배치되어 선원들의 식사를 책임졌다.

영국 국방부가 포츠머스항을 45형 구축함들과 미래의 항공모함 {Type 45 destroyers and the future aircraft carrier (CVF)} 의 모항으로 결정함에 따라, 수로 폭 250m 이상의 수심이 최소 14.3m를 유지하도록 준설이 필요하게되었다. 하지만 메리로즈호를 인양한 곳의 수심은 저조 때 12m이었고, 이 곳도 향후의 준설로 영향을 받게되었다. 이에 2003 ~ 2005년 3년에 걸쳐 발굴조사를 하여, 2005년 10월에 닻과 5미터 길이의 선수 재목을 인양하였다.⁵⁾



a) *Mary Rose* site and Portsmouth Harbour (Holt 2003). b) The *Mary Rose* mark buoy (Bevan 2005b).



c) DSV *Terschelling* (Bevan 2005b). d) *Terschelling* on site (The *Mary Rose* Trust).

Fig. 31 The *Mary Rose* site and DSV *Terschelling*.

c) DSV *Terschelling* prepares for diving operations with a four-point mooring over the *Mary Rose* site.

5) www.3hconsulting.com; Holt 2003, p.2.

'The UK Ministry of Defence may need to widen and straighten the channel approach to Portsmouth Harbour to accommodate their new aircraft carriers. The dredging work could affect the site of the *Mary Rose* historic wreck so what remains on the site had to be removed. When the hull of the *Mary Rose* was recovered from the seabed some of the ship was not recovered, some timbers and artefacts were reburied while the remains of the bow castle were never investigated.

A multi-phase project was put together by the *Mary Rose* Trust with the aim of recovering the buried artefacts and debris, excavating the spoil mounds to remove any artefacts, undertaking visual and magnetic searches and delimiting the extent of the debris field.

The fieldwork for 2003 included using an excavation ROV to remove the top layer of silt that had covered the wreck leaving the delicate excavation to be done by divers with airlifts. Site Recorder was used for mapping, finds recording and providing decision making information for the archaeological director, Alex Hildred. A Sonardyne Fusion Acoustic Positioning System (APS) was used on the 4 week project to provide high accuracy positioning for support vessel, ROV and divers. The positioning system was connected to Site Recorder and allowed the GIS program to display the positions of divers on the site plan in real time.

At the end of the 2003 season the first evidence of the remaining bow structure was found, a 5m long section of stem timber. The mission for 2004 was to investigate the size and condition of the remaining timbers in this area, in association with the stem timber were sections of articulated port side lower hull timbers including partial remains of inner (ceiling) planking, frames and outer hull planking. A 5m long anchor was also located.'

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Table 2 Excavation project 2003~2005 (The *Mary Rose* Trust).

2003	Project Design	Excavation of secondary deposits on the protected historic wreck <i>Mary Rose</i> . 1. Remote sensing of the site. 2. Excavation of objects and timbers purposely left on the site. 3. Excavation of the spoil mounds left from the 79~82 excavation. 4. Recovery of site related debris and any newly deposited debris.
	Summary of the Results	1. Andrews Survey Ltd. undertook a multibeam, sidescan and magnetometer survey of the site in advance of diving. The positions of prominent features or anomalies were fed in advance into the Sonardyne Pharos navigation system and a prototype site plan of targets was drawn up. 2. A 25 day diving programme was undertaken from a vessel moored over the site for the duration. All diving was undertaken using surface supplied diving equipment deployed through a wet bell. In addition to divers, a remotely operated crawling vehicle equipped with an airlift suction head was used to excavate trenches into the linear spoil mounds. 3. Divers used a lightweight 2.5m long survey staff fitted with a lightweight Mini RovNav transceiver with an acoustic transducer fitted to the top to position points on the seabed (such as the perimeter of the hull hole at a particular depth, or elements of structure or site hardware). 4. In addition to the airlift mounted on the ROV, excavation to uncover previously buried items was undertaken using conventional 100 mm diameter open-ended airlifts operated by divers. 5. The majority of the targets were achieved. 6. An estimated 10% of the spoil was excavated, with each trench having a minimum depth of 2.5m. Six trenches were excavated, three on the east side of the hull depression and three on the west. Within these trenches 86% of the 358 finds were recovered. In addition there were 48 timbers (many from the stored area) and 60 samples. 7. A total of 131 man dives was undertaken totalling 219.2 hours. twelve(12) ROV dives provided another 59 hours. The total for 25 days was 278.2 hours. 8. Only two(2) of the magnetometer anomalies were explored. 9. It is proposed to follow the project design as closely as possible. 10. Etc.
2004	Scope of Works	1. Further gathering of information regarding the size and condition of the buried structural remains in the bow area of the <i>Mary Rose</i> 2. To institute further ground-truthing of anomalies found within the CVF route survey by starting with those on the <i>Mary Rose</i> site
	Summary of the Results	1. The season lasted 22 days and include 208 dives totalling 352.3 hours. 2. An estimated 300 tons of sediment was removed, 147 artefacts, 62 timbers and 68 samples were raised and recorded. 3. Dives were carried out over a two day period three weeks later to check and adjust membrane and sand bags stabilizing the site. 4. A 16 × 8 meter aluminium grid was manufactured and placed on the seabed oriented west/east across the extreme north end of the site. This position was selected to include the stem timber and an area to the west, where two(2) timbers had been noted in 2003, and an area to the east of the stem. This grid was manufactured to incorporated trolley which could be moved over the 16m length of the grid at a predetermined height above the grid. This was to support a parametric sub-bottom profiling unit loaned by Tritech. This was towed over the length of the grid at a constant height of 4m above the seabed both before and during excavation. 5. The stem was excavated to expose its entire length, 10 meters. 6. Excavation to the west of the stem timber revealed several large sections of articulated timber structure, including excavations for the designated areas. 7. The targets within the exclusion zone around site included; five(5) multi-beam anomalies, twenty- three(23) side-scan anomalies, sixteen(16) Remus(AUV) side-scan anomalies (close to seabed), thirty-nine(39) magnetometer anomalies. * A decision has not been made regarding the choice of route for the CVF. The original dredge date was 2007. We have prepared a detailed plan (still following the original Project Design) outlining the immediate work required as a result of the findings of 2004, and the phses required to completely excavate the site should the route through the protected area be adopted.
2005	Project Design	Recovery and or in situ preservation of bow structure and artefacts from the protected historic wreck site ' <i>Mary Rose</i> ' Aims and objectives : The aims of the 2005 project are either to recover th the surface for analysis, study, interpretation, conservation and display some or all features uncovered during 2004 or to increase the level of recording of these features and leave them in situ. Following this the area will be backfilled and a system of environmental monitoring will be installed.
	Summary of the Results	1. Recovered the stem and the anchor. 2. Etc. * The final task was to put the site to bed. The excavated area has been covered with an industrial geotextile called 'Terram', which has been held down by 800 sandbags and 100 tons of sand. This should ensure the preservation of the area uncovered by the last two seasons of excavation and keep the site safe for future generations.

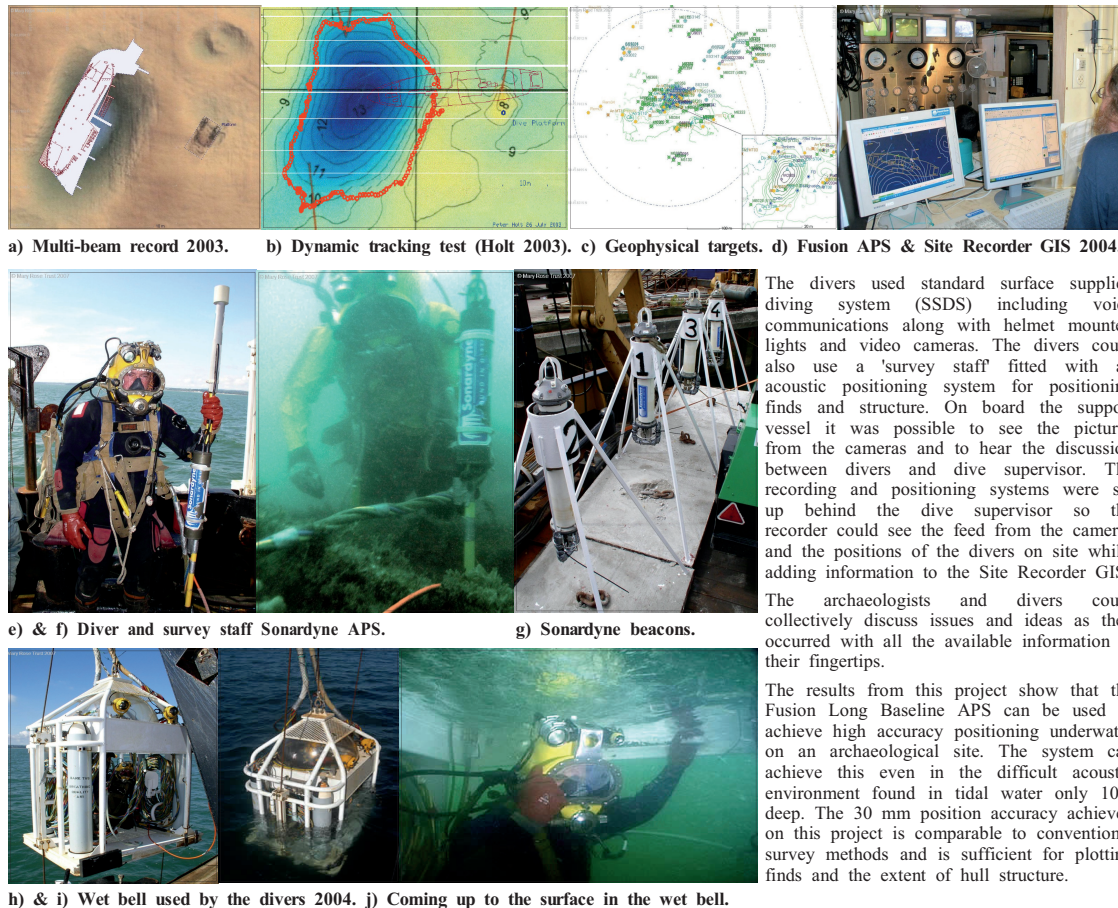


Fig. 32 Excavation 2003~2004 (The *Mary Rose* Trust; Holt 2003).

The Sonardyne Fusion Long Baseline acoustic positioning system (APS) used on this project is more often found on oil & gas projects (Offshore, Oil-field), being used to position ROVs or structures on the seabed.

The Long Baseline (LBL) or 'range-range' acoustic navigation method involves measuring distances from a transceiver mounted on a vessel, ROV or diver to four or more transponder beacons deployed at known locations on the seabed. The transceiver can transmit acoustic signals into the water that can be received by the beacons. If a beacon receives a signal it recognises then it sends back a different signal to the transceiver. If the time taken for the signal to go out to the beacon and back is measured then it is possible to calculate a distance from the transceiver to the beacon. By measuring the travel time and thus the distance to four or more beacons at known locations then it is possible to calculate the position of the transceiver.

a) Hull location on Reson / ADU MBES 2003.

b) The results from one dive show the quality of positioning that can be achieved using the Fusion long baseline APS. The diver carrying the survey staff was asked to walk around the perimeter of the hole left by the original excavation work. The track of the diver is shown. The diver leaves the dive cage on the port side of *Terschelling* and travels clockwise around the hole, occasionally stopping to look at debris and artefacts.

d) Note dive control panel at background.

g) Sonardyne beacons (transponders) before deployment.

The four(4) Sonardyne COMPATT transponders were deployed on the seabed in a 70m × 80m array. The project required the highest position accuracy possible so Extra High Frequency (EHF) transponders were used, operating at frequencies up to 100 kHz. In addition, the beacons were deployed in rigid frames so that they would not move. Each beacon was fitted with a tilt sensor so could report if it was upright or on its side after deployment from the vessel.

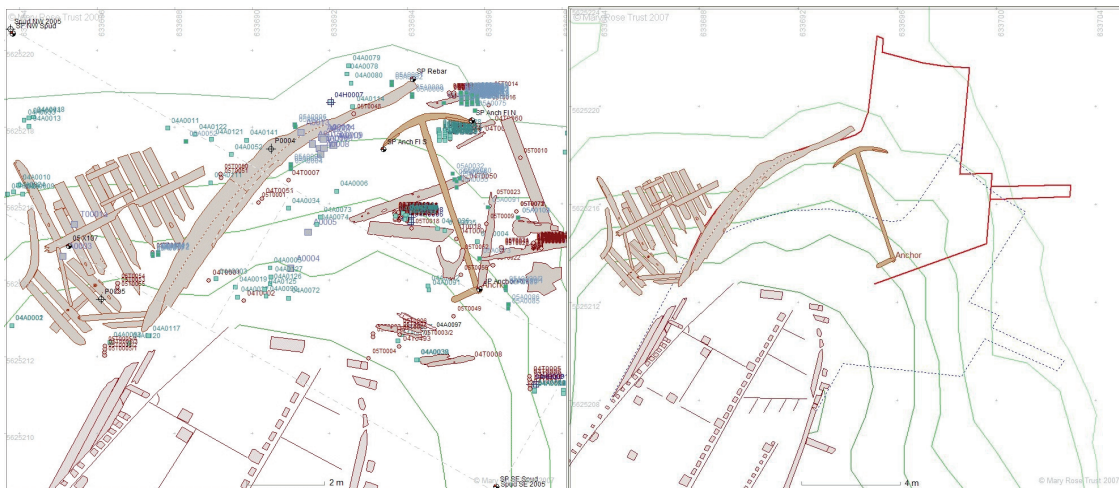


k) Swan 2002 Crawler ROV (Holt 2003).

l) Monica ROV excavator being deployed.

Fig. 32 Continued (Excavation 2003~2004).

k) The Swan 2002 crawler excavator ROV was custom built by Sea Boston Ltd. for excavation, burial and trenching work in 2003. The crawler is fitted with colour cameras and a Tritech scanning sonar so the ROV operator and team archaeologists can monitor the excavation. The crawler can also carry a Hyball free swimming ROV and a 5 function tool arm.



a) Bow site plan 2005.

b) Estimated position of bow based on stem location 2005.

Fig. 33 Excavation 2005 (The Mary Rose Trust).

a) Image shows detail around the excavation trenches, including the main stem timber, port side frames and anchor.



a) Spreader beam (inset) and lifting the stem timber (Bevan 2005b).

b) & c) The stem on its lifting frame.



d) Anchor raised from the seabed.

e) Anchor on deck.

f) Margaret Rule (Bevan 2005b).

Fig. 34 The stem timber and the anchor recovered in 2005 (The *Mary Rose* Trust; Bevan 2005b).

- a) *Mary Rose*'s five-meter stem timber breaks surface after more than 500 years on the seabed. The stem timber was stropped up to a 7 metre long spreader beam and was gently lifted from the seabed using a crane. The stem was transferred underwater onto a cradle ready for its final journey to the surface and ashore to Portsmouth. Similarly, the anchor was moved from its resting place to be alongside the cradle before raising.
- b) & c) The large stem timber recovered on its cradle (lifting frame, spreader beam).
- f) Margaret Rule, archaeological director of the excavation, examines the *Mary Rose* anchor.

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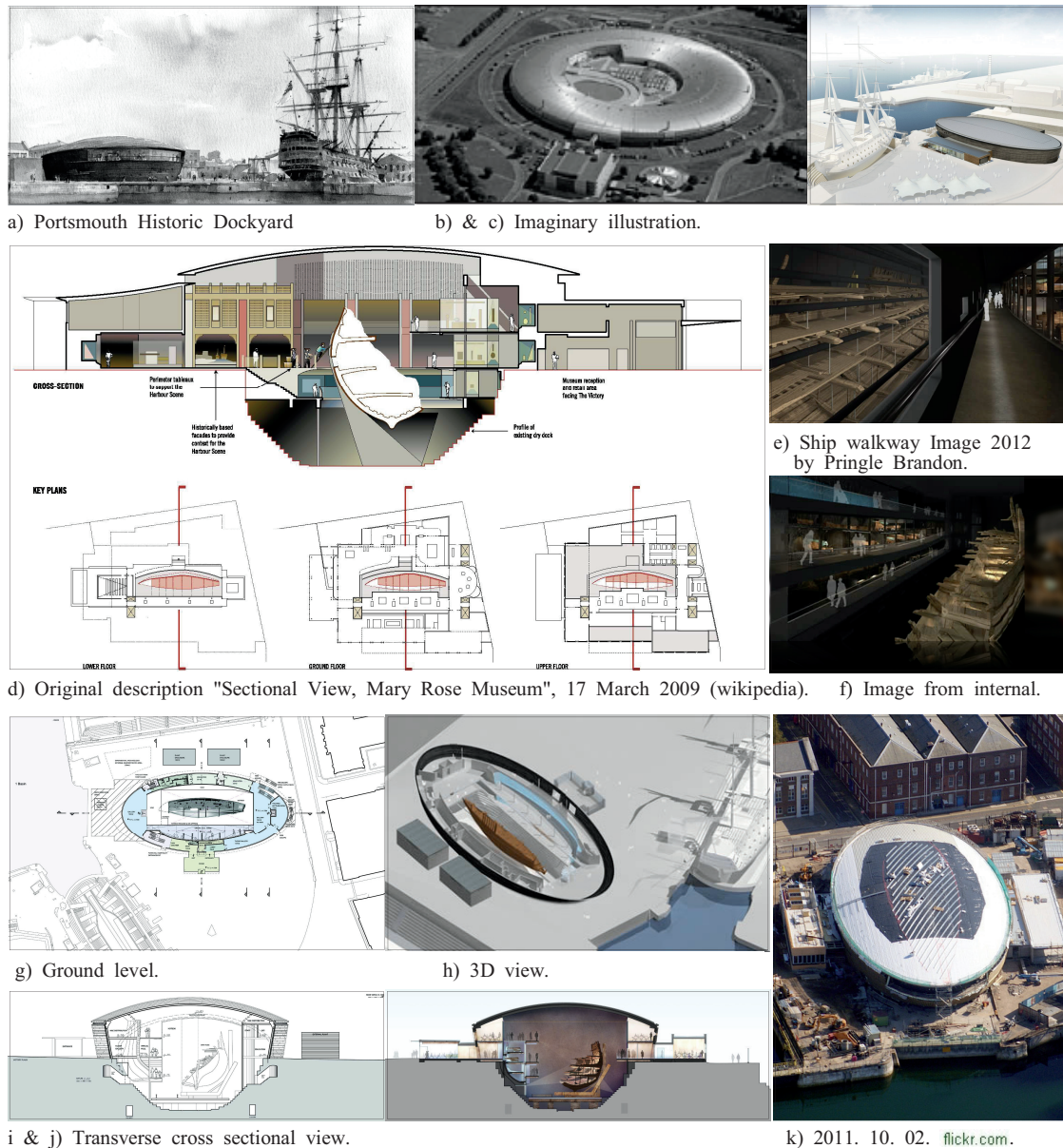


Fig. 35 New Museum for the *Mary Rose* (The *Mary Rose* Trust).

Her rediscovery and raising were seminal events in the history of nautical archaeology. On 14th May 1966, the first modern dive was made on the wreck site of the *Mary Rose*. That dive, in conditions of almost zero visibility, was the first of some 28,000 dives that led to the recovery of 19,000 artifacts and ultimately to the ship being raised in 1982. This represents one of the largest, most complex and successful underwater recovery and preservation projects ever attempted. The work of recovery, preservation and research is ongoing and may be viewed in the museum and ship display at the Portsmouth Historic Dockyard where a new £30m *Mary Rose* museum is planned for 2012.

Planning granted for Wilkinson Eyre's *Mary Rose* Museum design Friday 13 Feb. 2009 worldarchitecturenews.com

The £35 million project to build a new museum for the *Mary Rose* in Portsmouth's Historic Dockyard took significant steps forward this week with the news that the planning application has been approved by Portsmouth City Council.

The museum, designed by a team comprising Wilkinson Eyre Architects (architect), Pringle Brandon (interior architect) and Land Design Studio (exhibition design and interpretation), in collaboration with Gifford (structural and M&E engineer), will reunite the ship's preserved hull with many thousands of unseen artefacts for the first time in 500 years.

The museum building is conceived as a finely crafted wooden jewellery box discreetly enclosing the *Mary Rose* as its treasure. The curvilinear shape, which is derived from the historic dry dock below, responds to its unique context alongside HMS Victory and its dark stained timber cladding picks up on the 'carvel' construction of the *Mary Rose*

hull as well as traditional boat shed architecture.

The announcement coincides with confirmation from the *Mary Rose* Trust that they have raised over half of the £14million required to match the £21 million earmarked for the project by the Heritage Lottery Fund (HLF) in January 2008. The *Mary Rose* Trust can now progress to stage two and submit a further, fully developed application to the HLF to secure the full grant. The hull of the *Mary Rose* will be withdrawn from public view later this year as the new museum is built around her. It will continue to be interpreted in imaginative ways in the existing museum, which will remain open throughout.

She will continue to be sprayed with polyethylene glycol, a water-based wax solution, until 2011. The hull will be carefully dried within the new museum until she can be displayed fully in 2016.

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본고에 직접 인용되지 않은 참고 문헌과 자료들도 수록하였다. 현재까지 우리나라에서 수중고고학 관련 참고 문헌과 자료들의 정보가 미흡하다고 생각되기 때문이다. 본인이 수집한 자료들 중, 수중고고학과 해난구조(Salvage) 관련 자료들을 위주로 수록하였다. 저자 주 .

제2편은 다음호에 게재될 예정임

To be continued in the next issue

※ 편집위원장 주: 이 원고는 2011년 11월 故김도현 박사께서 수중과학회지에 투고를 요청한 원고를 故정창호 총무이사가 당시 편집위원장에게 전송한 원고로 2006년 12월 수중과학회지 제7권 1호 이후 수중과학회지가 발행되지 못하고 있던 시점에 2012년 12월 새롭게 수중과학회지의 편집을 맡은 편집위원장이 학회지의 ISSN 넘버를 부여받고 2012년 12월 제8권-13권 합본호로 재발행할 당시 게재하고자 하였으나 여러 사정에 의해 게재할 여건이 되지 않아 게재를 미루었던 원고로 이번 호에 게재하게 되었음을 밝히며, 원고의 분량이 너무 많아 원고를 I, II 편으로 나누어 게재하게 되었음을 알림.

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