NGU REPORT 2023.008

Summary report of datasets acquired for the purpose of method development within the Marine Base Maps for the Coastal Zone (Marine grunnkart i kystsonen) project at Fjøløy and Klosterøy, Stavanger, Norway

GEOLOGY FOR SOCIETY

SINCE 1858

GEOLOGICAL SURVEY OF NORWAY

· NGU ·

NGU REPORT 2023.008

Summary report of datasets acquired for the purpose of method development within the Marine Base Maps for the Coastal Zone (Marine grunnkart i kystsonen) project at Fjøløy and Klosterøy, Stavanger, Norway

NGU REPORT

Geology for society

Geological Survey of Norway
P.O. Box 6315 Torgarden
NO-7491 Trondheim, Norway
Tel. +47 73 90 40 00

Report no.: 2023.008	**ISSN:** 0800-3416 (print) **ISSN:** 2387-3515 (online)	**Grading:** Open	
Title: Summary report of datasets acquired for the purpose of method development within the Marine Base Maps for the Coastal Zone (*Marine grunnkart i kystsonen*) project at Fjøløy and Klosterøy, Stavanger, Norway			
Authors: Alexandre C.G. Schimel, Jonas Thormar, Ivar Oveland, Terje Thorsnes, Sigrid Elvenes, Tobias Kurz, Helge Welde		**Client:** Marine Base Maps for the Coastal Zone Project (Kartverket, NGU, HI)	
County: Norway		**Commune:**	
Map-sheet name (M=1:250.000):		**Map-sheet no. & name (M1:50.000):**	
Deposit name and grid-reference:		**Number of pages:** 35 **Price (NOK):** 200 **Map enclosures:** 0	
Fieldwork carried out: 2020-2022	**Date of report:** 10th May 2023	**Project no.:** 387900	**Person responsible:** Reidulv Bøe

Summary

Marine Base Maps for the Coastal Zone (*Marine grunnkart i kystsonen*) is a project aimed at producing user-oriented maps of the Norwegian coastal zone with a special focus on the seabed. In 2020, three coastal sites were permanently declassified to allow the acquisition of new types of datasets and the development of new methods to produce marine base maps. One of these sites is the seabed surrounding the Fjøløy and Klosterøy islands situated 25 km north of Stavanger. This report introduces the datasets that were acquired on this site between 2020 and 2022 for the purpose of method development. These include three airborne LIDAR surveys (including one from an Unmanned Aerial Vehicle), three airborne photography surveys leading to three orthophoto imageries, one airborne hyperspectral imagery survey, two multibeam sonar surveys (including one using Unmanned Surface Vessels), and a new set of ground-truth data from a variety of sensors including video transects, water sampling, and spectrometry. This report also summarizes pre-existing and relevant datasets on this study site, and introduces the preliminary methods developed to produce marine base maps from these datasets, whether from the contractors or the collaborators leading the project.

Keywords		
Marine base maps	Methods development	Airborne LIDAR
Green laser	UAV	Hyperspectral imagery
Multibeam echosounder	Airborne photography	Bathymetry

TABLE OF CONTENTS

1. INTRODUCTION

The Norwegian Mapping Authority (Kartverket), the Geological Survey of Norway (NGU) and the Institute of Marine Research (IMR) are working together to collect data and share knowledge about the seabed along the coast of Norway. This knowledge base is called "Marine Base Maps for the Coastal Zone". It provides the basis for the preservation and restoration of vulnerable and valuable nature, while helping build sustainable cities and strong districts by facilitating marine and maritime industries – without destroying valuable ecosystems. Good-quality marine information is important to avoid land conflicts and to better manage resources. The Norwegian Mapping Authority, NGU and IMR have the ambition to map and compile data (as well as disseminate data and services) for the entire Norwegian coastal zone from the tidal zone to the deep areas, that is approximately 100,000 square kilometres.

The marine base maps of interest are: a) Depth data and terrain models as well as derived products such as shadow relief, slope and roughness; b) Acoustic reflectivity (backscatter) where this exists; c) Geological maps such as sediment maps and landscape maps; d) Derived maps based on a, b and c such as sedimentation areas, diggability, and anchoring conditions; e) Map of the chemical state of the environment (pollution by heavy metals and organic pollutants); f) Nature types according to the Nature in Norway classification system; g) Vulnerable and valuable habitats; h) Classes of administrative priority nature; and i) Models for current, waves, salinity and temperature.

A “method development” sub-project was initiated to allow research on new approaches to produce marine base maps. Three pilot areas in coastal sites of Norway (Stavanger, Ålesund-Giske and Skjervøy-Kvænangen) were selected for the acquisition of new data by new technologies, which would form the basis of new methods to produce marine base maps. This report presents the datasets commissioned and acquired over the Fjøløy-Klosterøy sub-area of the Stavanger site for the purpose of this sub-project (Kartverket, 2020).

2. STUDY SITE

The study site is the seafloor down to 30 m surrounding the Fjøløy and Klosterøy islands (Figure 2.1, Figure 2.2), situated 25 km North of Stavanger in Norway (Kartverket, 2020). The area on dry land and depths down to 30 meters have been permanently declassified by the Norwegian Armed Forces’ Operational Headquarters for the purposes of the method development project (Figure 2.2).

Within this study site, 9 sub-areas (ranging between 0.03 and 0.13 km^2 in surface area) and 3 features (poles, boat ramp, pipeline) were designed for survey by technologies with limited coverage capacity such as Unmanned Aerial Vehicles (UAV) or Unmanned Surface Vessels (USV) (Figure 2.3). These sub-areas and features are identified by a number (within 1–12) and described in Kartverket (2020).

Figure 2.1. Aerial photo of Fjøløy (left of the bridge) and Klosterøy (right of the bridge). Photo by Åge Pedersen, Museum of Archaeology, University of Stavanger (CC BY-NC-ND).

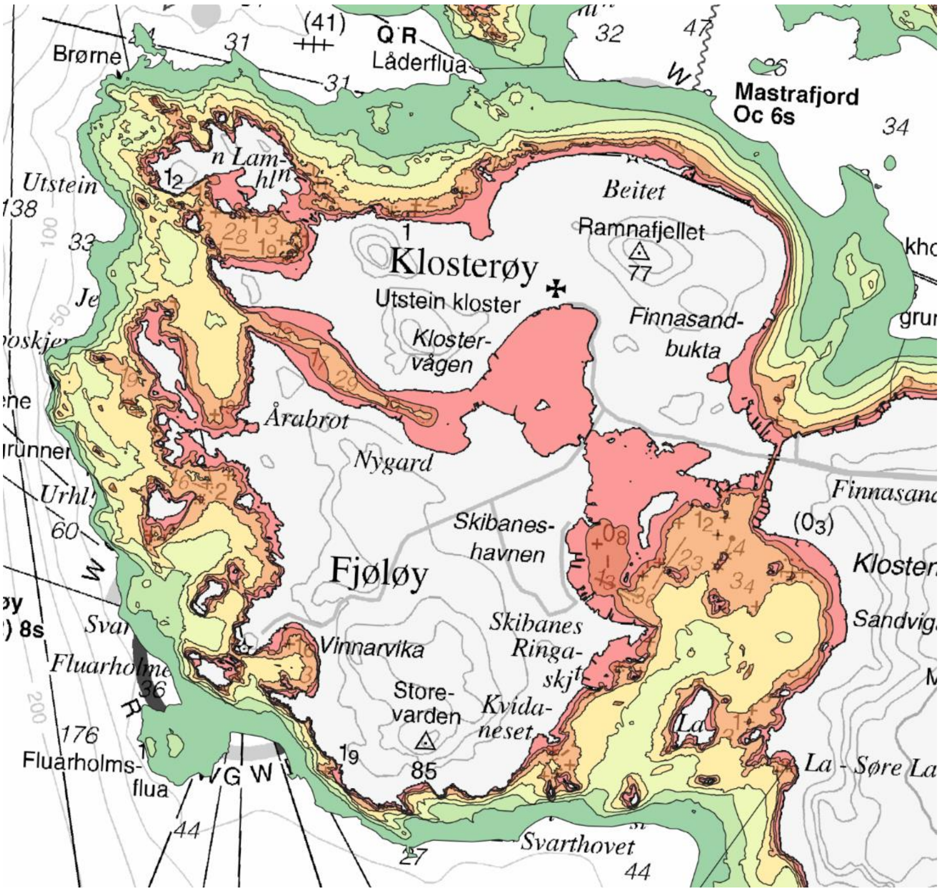

Figure 2.2. Overview of the study site with isobaths (and colours) at 5-meter intervals. The edge of the last coloured area (green) is the 30 m isobath. Figure copied from Kartverket (2020).

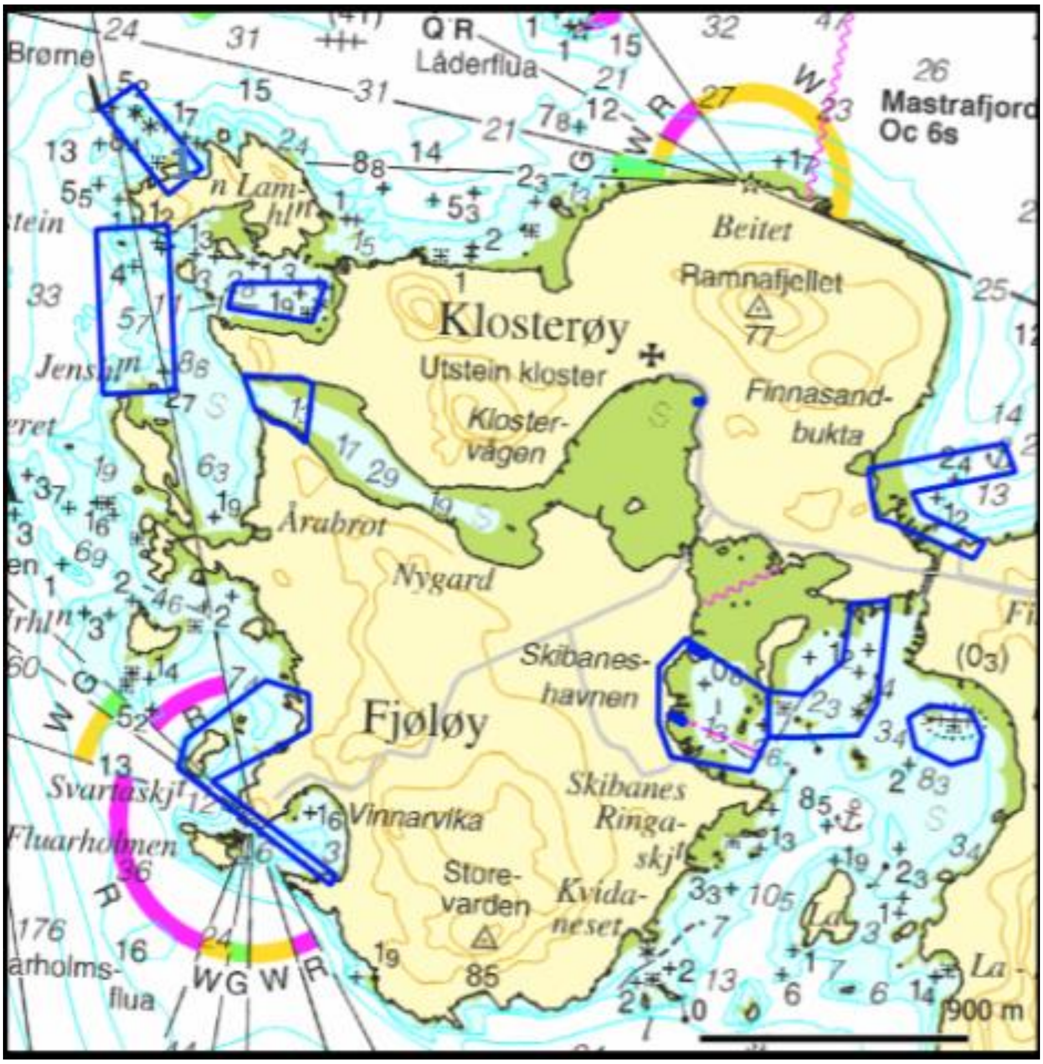

Figure 2.3. Location of the 12 sub-areas and features of interest defined over the study site (in blue). See Kartverket (2020) for detail of their nature and location. Figure copied from Kartverket (2020).

2.1 Regional geography

Fjøløy and Klosterøy lie in the outer part of the wide Boknafjorden fjord system, which opens towards the southwest. The two islands are connected by bridges and are surrounded by numerous smaller uninhabited islands and skerries. The western part of Fjøløy and the north-western part of Klosterøy are exposed to wind, waves and current, while the rest of the islands are more sheltered. The ca. 6 m deep Klostervågen basin between the two islands is almost entirely isolated from the other marine areas. Bedrock in the area is predominantly gneisses related to the Caledonian orogeny. On land, surface sediment cover is sparse, but areas of marine shore deposits and till have been identified (NGU, 2023a; 2023b).

2.2 Seabed geology

Seabed surface sediments in the Fjøløy-Klosterøy area were mapped in scale 1:20 000 in 2020, as part of the Marine Base Maps for the Coastal Zone project covering all marine areas in the Stavanger municipality. Mapping in Stavanger was originally restricted to areas with existing multibeam echosounder (MBES) data, and the portfolio of interpreted geological maps include sediment grain size, genesis and sedimentary environment. With access to the new data acquired as part of this project (LIDAR bathymetry, better orthophotos and more seabed observations), the maps could be extended to fill the gap between MBES data and the shoreline. Updated geological maps were published in 2022 (Figure 2.4).

Seabed in the north-western part of the study area is dominated by exposed bedrock and very coarse sediment (rocks and boulders). In more sheltered areas east of both islands, and in Fjøløysundet (between the two islands), sand and gravelly sand accumulates in depressions between outcrops of bedrock and bouldery deposits. In the very sheltered Klostervågen basin there is accumulation of muddy sediment.

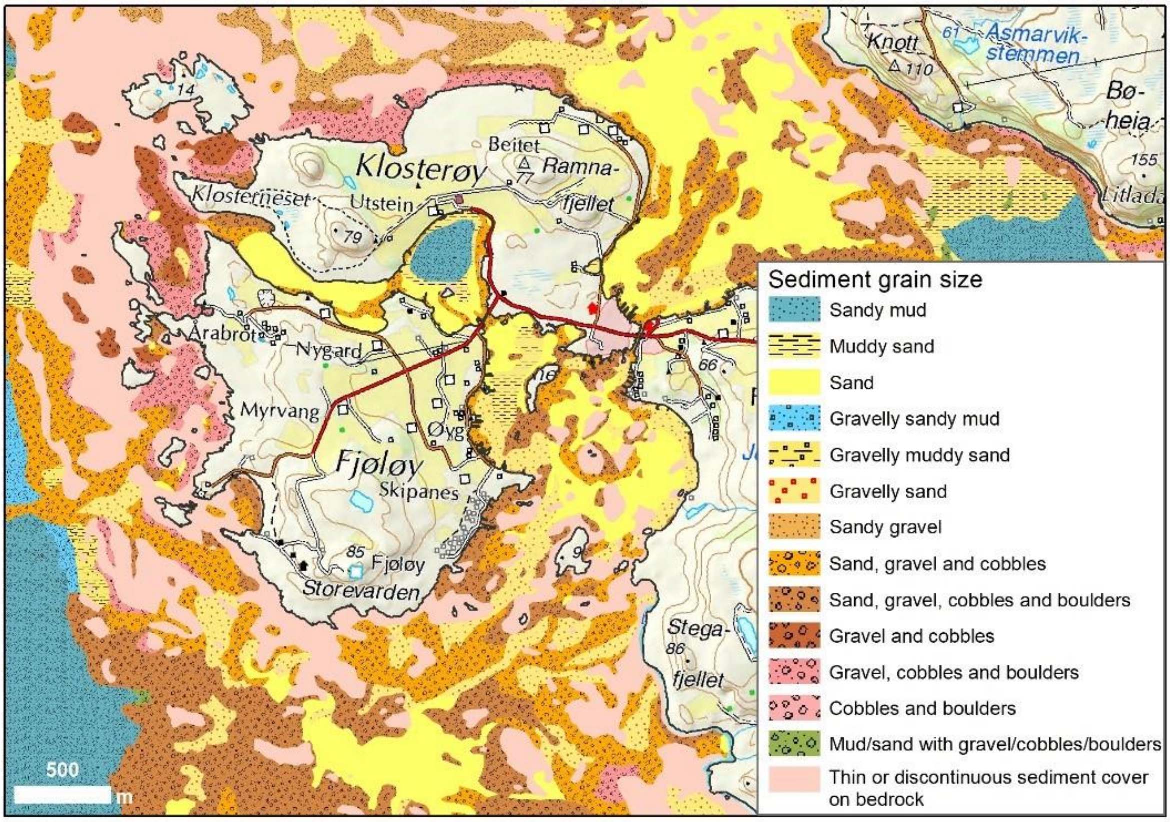

Figure 2.4. Map of seabed sediments (grain size) over the study site, scale 1:20 000.

2.3 Seabed biology

The biological habitats of the seabed surrounding Fjøløy and Klosterøy are overall structured by wind/wave exposure, depth and substrate. Western parts are generally exposed and dominated by the kelp Laminaria hyperborea on hard substrate to depths of around 20 m. Areas of intermediate exposure are mostly dominated by sugar kelp (Saccharina lattissima) and sheltered bays are covered with a multitude of habitats: mixed seaweeds, fucoid belts, loose algae, bare sand and mud, eelgrass, japanese wireweed (Sargassum muticum), and dead man’s rope (Chorda filum) (Figure 2.5). The shallow area between Fjøløy and Klosterøy is predominantly composed of soft sediments devoid of vegetation.

Figure 2.5. Examples of seabed habitats present in the study site. Sandy substrate dominated by a carpet of loose filamentous algae, 25% eelgrass and 15% bare sand (left), and full cover of kelp (right).

3. EXISTING DATASETS

This report focuses on presenting the datasets acquired specifically for the method development project over 2020—2022. However, other recent and relevant datasets are available. They are briefly described in this section.

3.1 Aerial photography

Aerial orthophotography imagery datasets are available from the Norge i Bilder portal (Norge i Bilder, 2023). Prior to the Marine Base Maps for the Coastal Zone project, the most recent orthophoto imagery overlapping the study site dated from 2017 and 2019. The two 2021 datasets on the Norge i Bilder portal (named “Fjøløy - MGK ALB Pilot 2021” and “Fjøløy Summer - MGK ALB Pilot 2021”) were acquired as part of the method development project and are thus described in this report. The portal also has several imageries from the multispectral Sentinel-2 satellite.

3.2 Multibeam sonar data

MBES data from earlier surveys carried out by the Norwegian Mapping Authority with EM 3000 and EM 3002 systems (August 2005, March 2013) are available in the Fjøløy-Klosterøy area. The extent of these data in the 0–30 m zone is very similar to the newer data described in this report, and no major changes to the seabed have been detected in either bathymetry or backscatter data. This dataset is available on the Høydedata portal (Kartverket, 2023) under the name “Batymetri Fjøløy 2013”.

3.3 Intertidal zone mapping

In 2019, the Norwegian Environment Agency commissioned a study to map and monitor the intertidal zone using free satellite data. This study was conducted by the Norwegian Research Centre AS (NORCE) and published in two reports (Haarpaintner & Davids, 2020; Haarpaintner & Davids, 2021b), and a peer-reviewed scientific article (Haarpaintner & Davids, 2021a). Map products with national coverage were also produced.

In this study, methods were developed and applied to map the areal extent of intertidal zones, calculate the duration of atmospheric air exposure, and classify substrates in the intertidal zone, using temporal integration of Sentinel-1 and Sentinel-2 satellite imagery. Data are available from the authors. While the intertidal zone in the Fjøløy-Klosterøy area is narrow, the methodology may be of greater areal use within other regions having larger tidal differences. While the spatial resolution of satellite imagery is lower than the other airborne methods applied, the temporal integration and use of free imagery provides advantages for monitoring.

3.4 SyriUS

In September 2021, contractors Maritime Robotics (Norway) and EOMAP GmbH & Co.KG (Germany) mapped part of the Fjøløy-Klosterøy study area as part of their European Space Agency-affiliated SyriUS demonstration project (SyriUS, 2023). The aims of the SyriUS project include combining satellite-derived bathymetry (SDB) with discontinuous MBES data acquired by USV. The Norwegian Mapping Authority had participated in an earlier phase of the SyriUS project (2019), and the Marine Base Maps for the Coastal Zone project was suggested as an example of a possible future user of this technology.

Transects over seven small test areas were mapped in detail with the Maritime Robotics USV Otter. The USV was equipped with an MBES and a single-beam echo sounder (SBES), as well as monocular and stereo vision underwater cameras. Evaluation of the delivered datasets concluded that MBES bathymetry quality was good (some backscatter data were acquired, but not fit for use) and that SDB might have uses in regional mapping or cruise planning even though resolution would be too coarse for producing geological maps at scale 1:20 000. A merged dataset of MBES and SDB data was produced, although it was found to have artifacts that obscured the real seabed features. A map of seafloor types was produced using high-resolution (2 m) Pleiades and Worldview-2 satellite imagery. The seafloor was classified into 4 types (fine sediment, rocks/hardbottom, dense brown algae, eelgrass). This map was relatively coarse, but the larger trends had decent correspondence with ground truth data. Satellite classification could thus be considered useful as a faster and initial way of generating habitat maps in the early stage of a mapping project and guide the more detailed mappings. The SBES (Biosonics MX) was used to map vegetation height and coverage and classify bottom types, but the interpretation appeared to require substantial manual corrections, and coverage was sparse with this technology.

4. AIRBORNE LIDAR

4.1 Hexagon

Hexagon undertook a bathymetric and topographic LIDAR survey of the study area on April 1st, 2021 (Hexagon, 2022). The LIDAR system was a Chiroptera 4X, which integrates a topographic LIDAR, bathymetric LIDAR, and an RGBI imaging sensor. The survey was carried out from a Piper PA-31-310 Navajo Chieftain SE-KCY airplane. Survey altitude was 450 m, leading to a swath width of 325 m. Line spacing was set at 300 m, ensuring an average 25% across track overlap (Figure 4.1). The average survey speed was 120 knots.

The LIDAR data were processed and classified into 11 categories (Table 4.1) using the Hexagon software LIDAR Survey Studio (LSS), and the Terrasolid software TerraScan (Figure 4.2). The deliverables consisted of one LAS file per flightline, with each file containing: classified point cloud, intensity, total horizontal uncertainty (THU), total vertical uncertainty (TVU), and depth-normalized intensity (Figure 4.3).

The THU and TVU were calculated using NOAA’s CBlue software. The depth-normalized intensity was obtained from the original intensity by applying a depth-dependent exponential decay compensation, considering a consistent water quality and clarity throughout the complete studied area (Figure 4.3).

Table 4.1. Categories from classification of LIDAR data from both Hexagon and Field surveys. Classes 1–17 are terrestrial points (points over the land surface). Classes 25–31 are bathymetric points (points over the marine/sea surface).

Code	Category	Description
1	Unassigned	Terrestrial points not classified as class 2, 7 or 17. Bathymetric points being higher than the sea level (vegetation, manmade structures) should also be classified as class 1 (unclassified).
2	Ground	Terrain/ground.
7	Low point	Points caused by clouds, birds, multipath and system induced errors. This class contain points with abnormal elevations (highs and lows).
17	Bridge deck	Points classified as bridge. All points above the bridge itself (railings, streetlights, cars) must be classified as class 1.
25	Rocks	Points located on large single stones in the sea or riverbed.
26	Bathymetric point (seabed)	Points on the water bottom (e.g., seafloor or riverbed).
27	Water surface	Points on the water surface (sea/river/lake surface from bathymetric or topographic-bathymetric lidar; distinct from Point Class 9, which is used in topographic-only lidar and only designates “water,” not “water surface”).
28	Derived water surface	Points for derived water surface (synthetic water surface location used in computing refraction at water surface).
29	Marine Vegetation	Points on vegetation within the sea surface.
30	IHO S-57 object	Points on non-mobile man-made objects within the sea surface (e.g., fish farms).
31	Not bed (unclassified)	All bathymetric points not classified in 25–30.

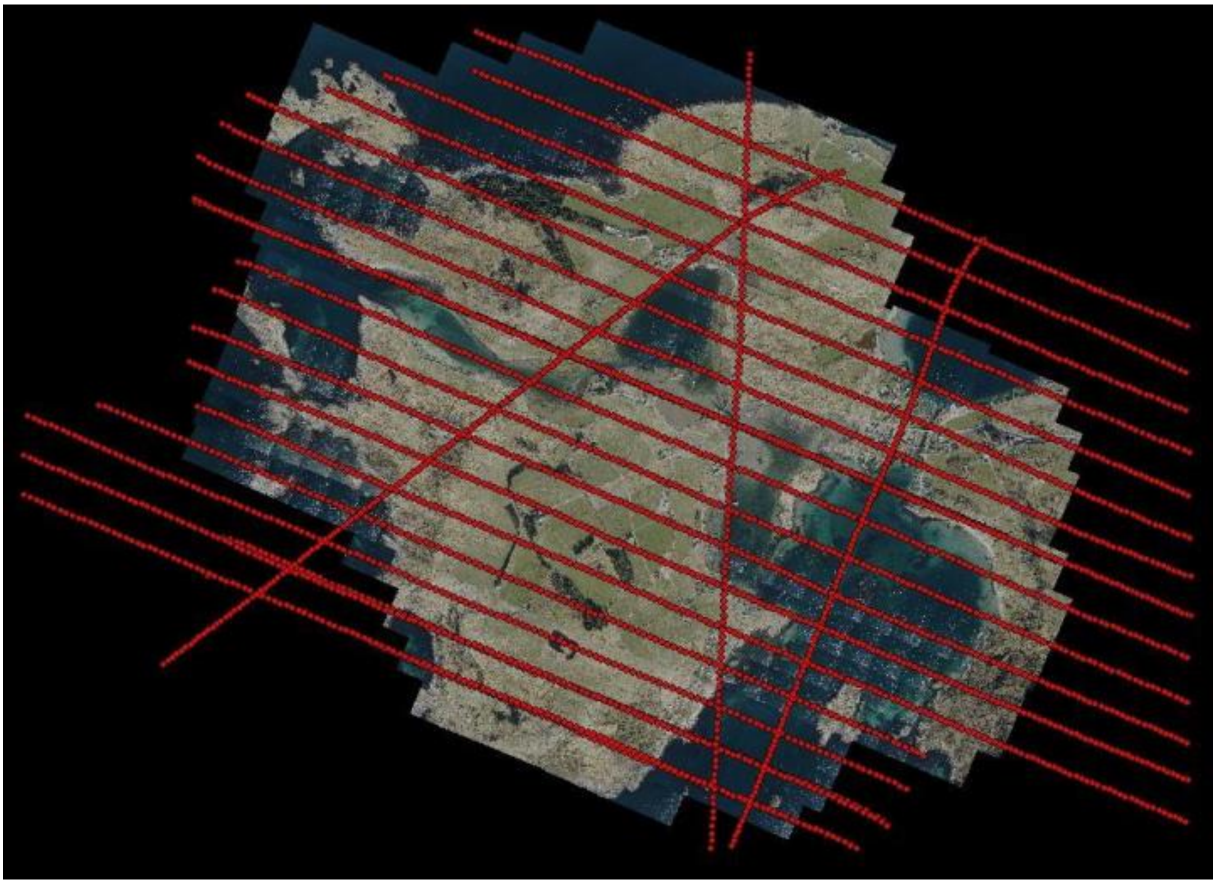

Figure 4.1. Hexagon LIDAR survey flight lines (red) overlaid on the orthophotography imagery produced from the RGBI images acquired concurrently. Figure copied from Hexagon (2022).

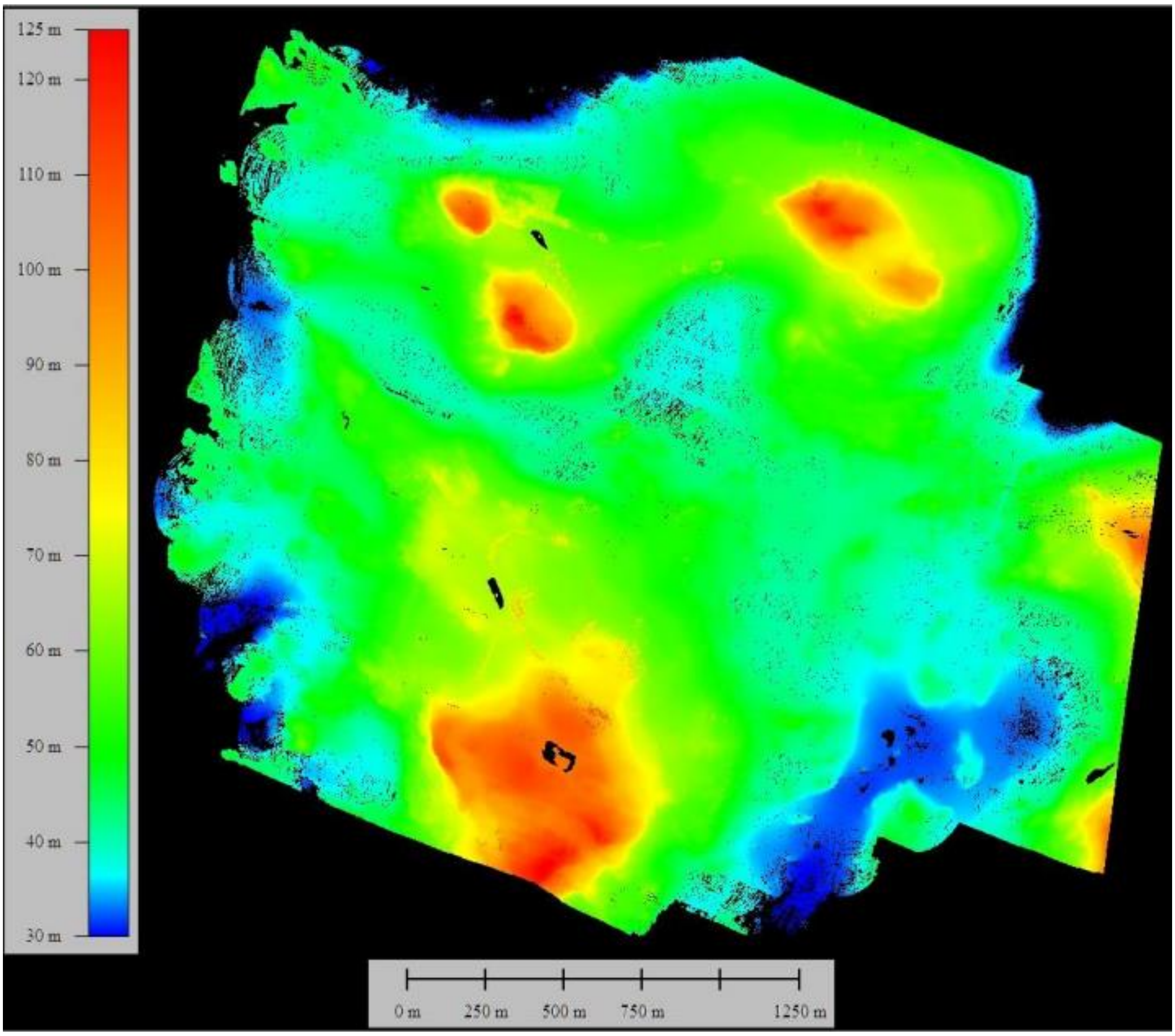

Figure 4.2. Topography and bathymetry point cloud obtained from Hexagon LIDAR survey. Figure copied from Hexagon (2022).

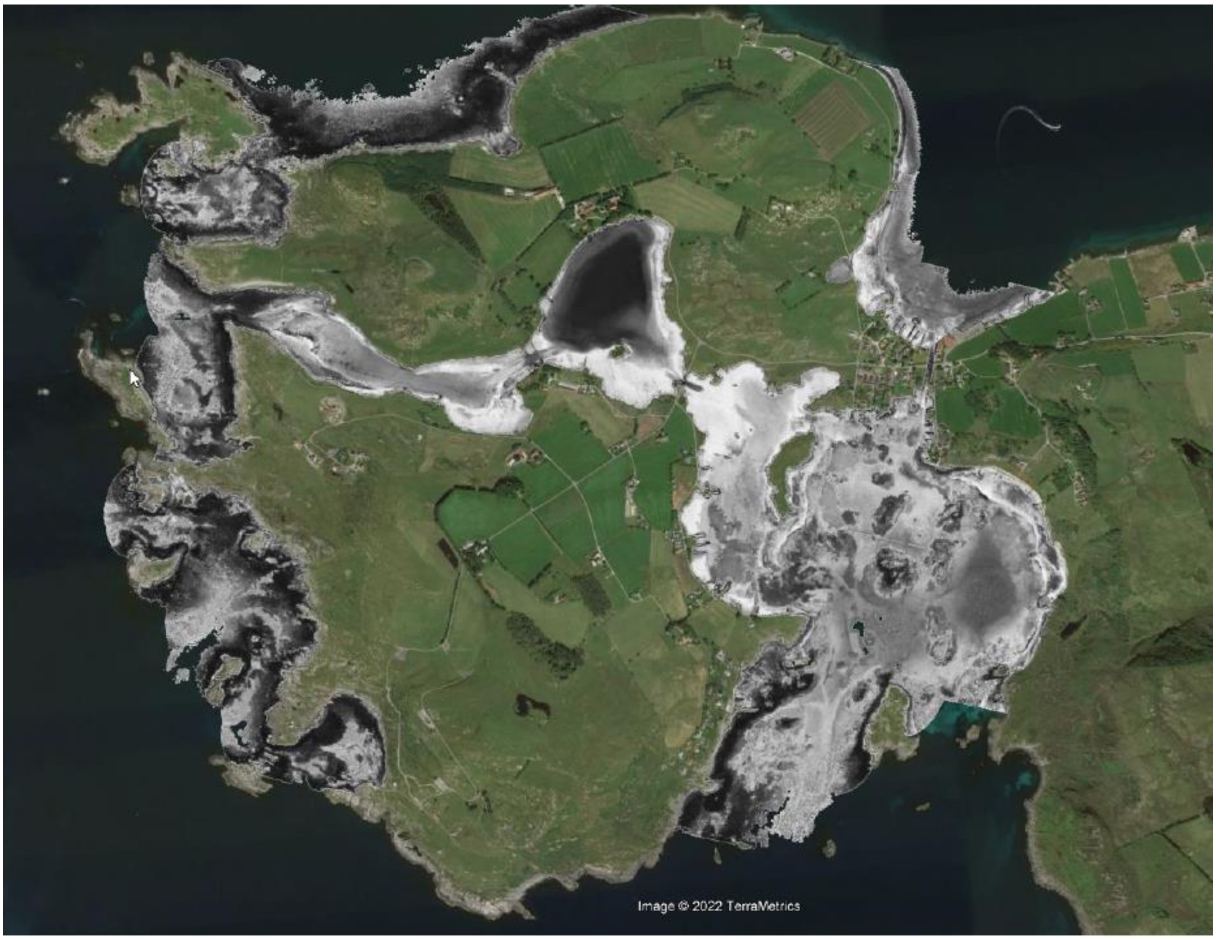

Figure 4.3. Depth-normalized intensity from Hexagon LIDAR survey. Figure copied from Hexagon (2022).

4.2 Field

Field (previously Terratec) carried out an airborne bathymetric LIDAR survey of the study site on April 25th, 2021 (Terratec, 2021a; Field, 2022). The sensor used was a Teledyne Optech CZMIL Supernova. The survey consisted of 32 flight lines for a total length of 110.9 km, carried out at an altitude of 400–600 m over ground and a speed of 120–140 kts (Figure 4.4). The aircraft also carried a Trimble Applanix POS AV 610 with PPRTX GNSS/IMU for navigation data, and a digital camera (discussed in the aerial orthophotography section).

The navigation data were processed with Field software TerraPos v2.5, and a point cloud was generated from the LIDAR data (Terratec, 2021a) (Figure 4.5), which was subsequently compared with reference data from a MBES survey (Field, 2022). The deliverables included LAS files, classified point cloud in LAZ format, and metadata. The data points were originally classified into 11 categories (Table 4.1). A preliminary automated classification was produced (delivered 27/08/2021), followed by a QC-controlled automated classification (delivered 10/09/2021).

In December 2022, Field produced a revised classification using a supervised Machine Learning approach (Figure 4.6). This supervised classification approach used the manual production of a training dataset from orthophoto imagery, the generation of derived features, and a Random Forest model (Field, 2022). The LIDAR points were classified into 8 new categories (Table 4.2).

Table 4.2. Categories from the revised classification of Field LIDAR data.

Code	Category	Description
10	*Bunn (klar)*	Bottom (bare sand)
11	*Bunn (vegetasjon)*	Bottom (vegetated)
12	*Stein*	Rock
13	*Lav vegetasjon*	Low vegetation
14	*Høy vegetasjon*	High vegetation
15	*Støy*	Noise
16	*Vannflate*	Water surface
18	*Land*	Land (above water)

Figure 4.4. Flight lines from the Field LIDAR survey. Figure from høydedata.no (Kartverket, 2023).

Figure 4.5. Shaded relief showing the bathymetric coverage of the Field LIDAR dataset. Figure from høydedata.no (Kartverket, 2023).

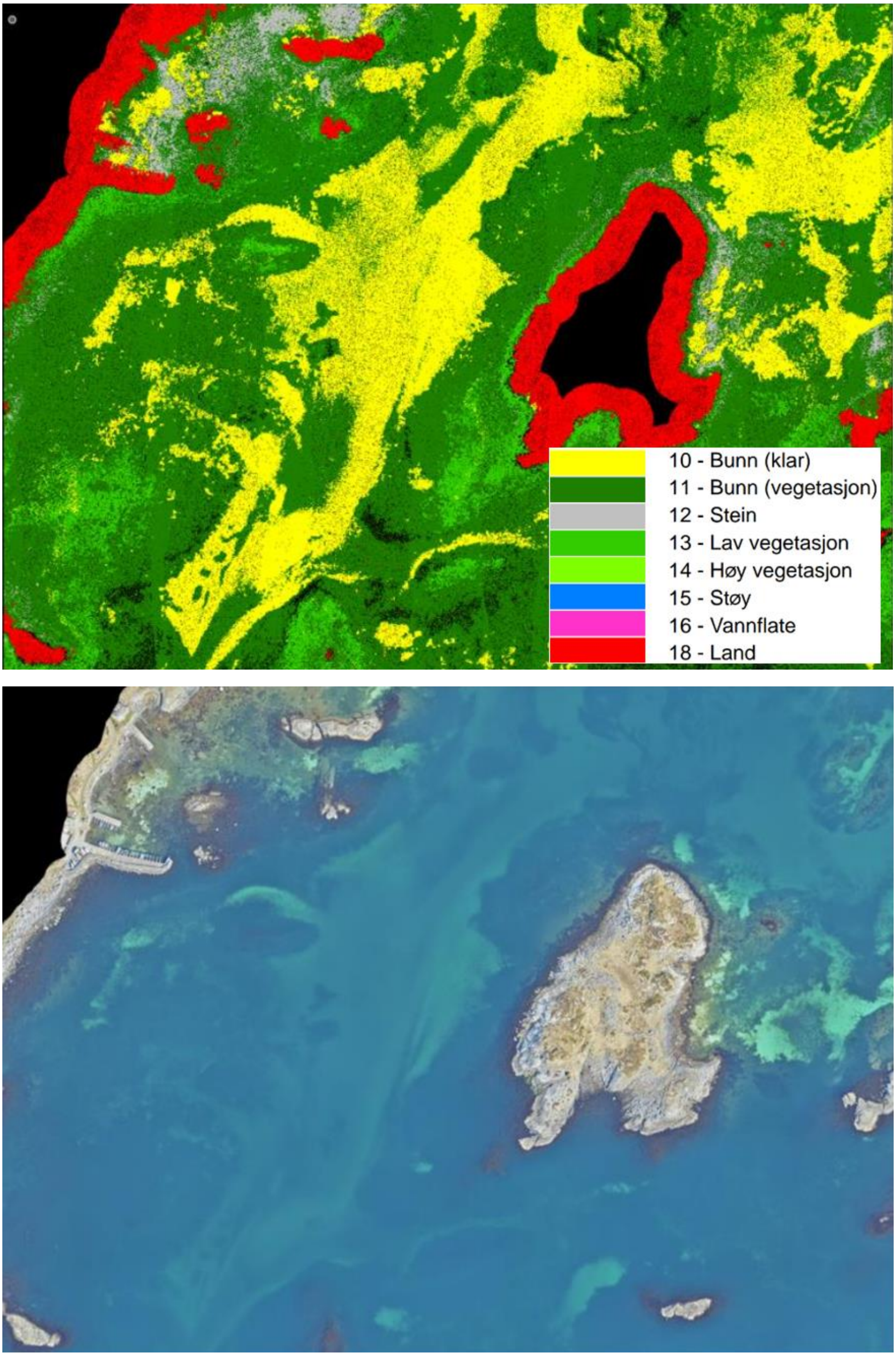

Figure 4.6. Extract of the revised classification of Field LIDAR data (top), and corresponding extract of orthophotography imagery (bottom), for comparison. Figure modified from Field (2022).

4.3 Nordic Unmanned

Nordic Unmanned performed an UAV LIDAR bathymetric survey (Nordic Unmanned, 2021) in five sub-areas (numbers 1, 2, 3, 9, 11) of the study site on October 14th and 15th, 2020 (Figure 4.7). The UAV used was a Staaker BG-200 (Figure 4.8), carrying an ASTRALite EDGE Green LiDAR sensor (Table 4.3). Weather conditions were considered ideal, allowing acquisition of bathymetric data down to 6–6.5 m. 28 flights were carried out for a total flight time of 9h55. There were some technical issues with communication with the UAV, and with the laser safety system, so that only 13 of these flights had data which could be processed.

Navigation data (GNSS and IMU) were processed using Applanix POSPac to obtain more accurate flight trajectories. After navigation data was processed, the ASTRALite software ParseEdge was used to generate and classify the points into 3 categories (Table 4.4). Data deliveries are listed in Table 4.5.

Table 4.3. Technical specification of the Nordic UAV platform and sensor.

UAV platform 1	Producer	Nordic Unmanned AS
	Model	Staaker BG-200
	Serial Number	20-BG200-26
	Call Sign	LN-0310-BH
	Type	X8 Multirotor
	Battery capacity	44.4 V – 32/44 Ah
	MTOW	25 kg
	Flight time without load	60/65 minutes
Sensor 1	**Producer**	ASTRALite
	Model	EDGE Lidar
	Serial number	EDGEHD2004-106
	Calibrated	02-10-2020
	Laser scanner	EDGE Green LiDAR

Table 4.4. Classification categories of the Nordic Unmanned LIDAR point cloud.

Code	Category	Description
1	Unclassified	Land/buildings/cars/vegetation
40	Bathymetric Point	
41	Water surface	

Table 4.5. Data deliveries from Nordic Unmanned.

Product	Delivery date	Description
Laser data	24/01/2021	4 Laz classified point cloud files of the processed areas – (original files sent on December 2020)
Trajectories SBET files	24/01/2021	SBET output files of the flight trajectories
Data area polygons shp	24/01/2021	Flown area with LiDAR data coverage
Flight lines shp	24/01/2021	Trajectories of the flights for the areas processed
Density maps	24/01/2021	Point density files on a 1 x 1 m grid – lattice format
Report:	24/01/2021	Project report
Navigation processing reports	25/01/2021	11 navigation reports – one per flight

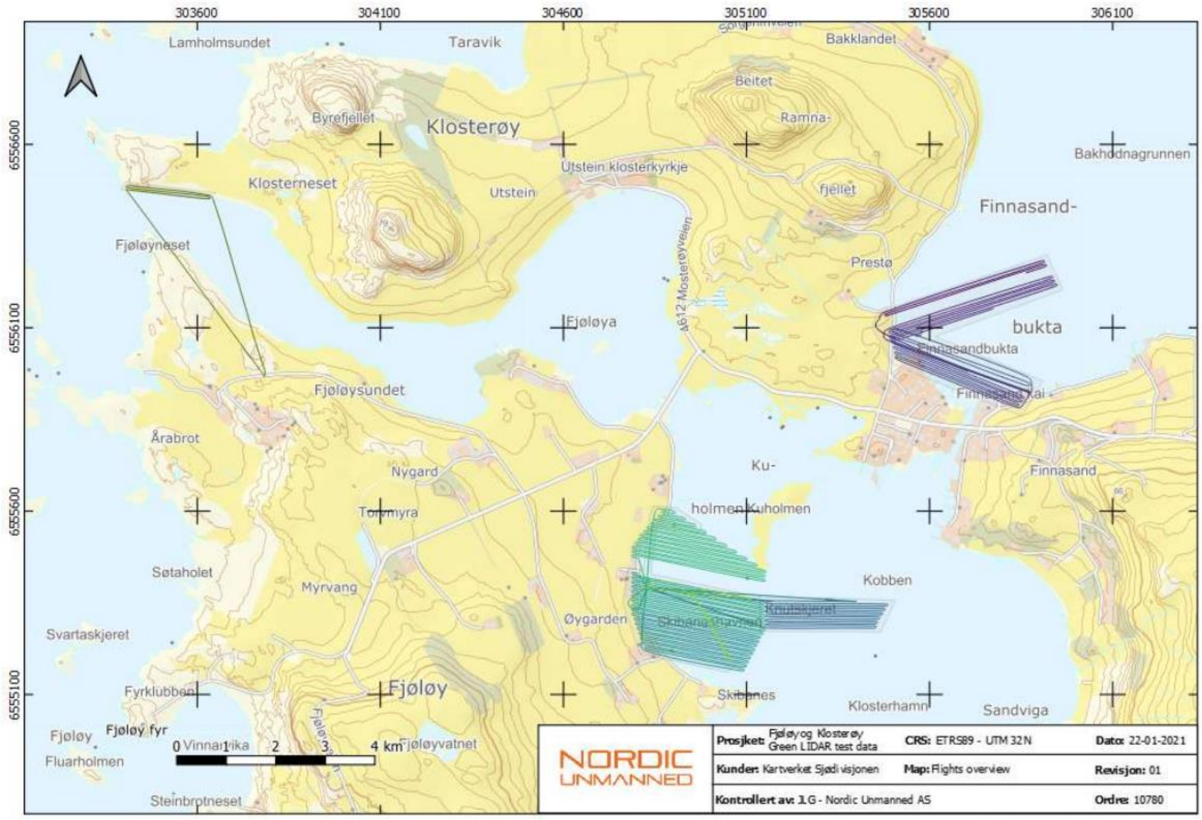

Figure 4.7. Sub-areas covered by the Nordic Unmanned drone survey.

Figure 4.8. Staaker BG-200 UAV.

5. HYPERSPECTRAL IMAGERY (FIELD)

5.1 Data acquisition, processing, and delivery by Field

Field (previously Terratec) carried out an airborne hyperspectral survey of the study site in July and August 2021 (Terratec, 2021b). The fixed wing, manned aircraft was flying at an approximate altitude of 1457 ft (444 m) over ground and a maximum speed of 120 kts (222 km/h). The width of a scan line covered approximately 315 m at the ground.

Two hyperspectral cameras from Norsk Elektro Optikk AS were used, mounted with a gyro-stabilising frame: The HySpex VNIR-1800 camera measuring within the visible to near-infrared (VNIR) and the HySpex SWIR-384 camera within the shortwave infrared (SWIR) spectral range (Table 5.1). These instruments are line sensors (also termed push broom cameras) acquiring all spectral information for a pixel-line at once. The flight plan was arranged to ensure sufficient overlap between scan lines and between the two spectral cameras despite slightly different field of views (FOV) and resulting slightly different footprints at the ground. The images acquired have a ground sample size of approximately 0.03 m for the VNIR and 0.07 m for the SWIR.

The data were acquired over three different days in July and August 2021 (Table 5.2, Figure 5.1). The raw data were transformed into radiance data (termed "spectral intensity" by Field) using the Norsk Elektro Optikk program HySpex_RAD and the camera radiance calibration. The unit of radiance is watt per steradian per square metre (W·sr-1·m-2). No further spectral processing was applied by Field.

The GNSS data were processed with Field software TerraPos. The imagery was georeferenced and orthorectified with the ReSe Applications LLC program Parge 3.5. Orthorectification used nearest neighbour interpolation to limit resampling of the measured spectra. The original hyperspectral scans were trimmed according to the boundaries of the study area and were provided with the datum projection EUREF89 UTM zone 32. The georeferenced and orthorectified hyperspectral images were delivered as multi-band TIFF files. Figure 5.2 shows all hyperspectral images (VNIR and SWIR) delivered by Field.

Navigation files for each hyperspectral image were also delivered. However, the navigation files were associated with the original hyperspectral scan lines and have not been edited to match the trimmed and delivered hyperspectral TIFF images. The navigation files were in ascii-format (tab delimited) and containing the following information: Scan-line, East, North, Height, Roll, Pitch, Heading, Time. The East and North coordinates are given in projection EUREF89 UTM zone 32. The Height is given in orthometric NN2000 heights. The time system is GPS time-of-week.

Table 5.1. Main technical specification of the hyperspectral cameras used in the survey by Field. The FOV nominal values of the cameras can be adjusted (doubled according to the manufacture) by using FOV expanders. The FOV values below are the nominal values indicated by the manufacturer, followed in parentheses by the values after adjustment, indicated by Field.

Camera	HySpex VNIR-1800	HySpex SWIR-384
Spectral range	visible to near infrared	shortwave infrared
Wavelength range	400-1000 nm	930-2500 nm
Spatial pixels	1800	384
Number of spectral bands	186	288
Spectral sampling	approx. 3.26 nm	approx. 5.45 nm
Field of view (FOV)	17° (40°)	16° (37°)
Bit resolution	16 bits	16 bits

Table 5.2. Field hyperspectral survey overview.

Date	Time (CEST)	Comments
01/07/2021	11:29 to 12:44	• Gyrostabilizer was not in use for 9 scanlines • 23 hyperspectral scan lines collected • Covering the Eastern part of the study site • Data acquisition effected by cloud and cloud shadows
25/07/2021	10:13 to 11:26	• 21 hyperspectral scan lines collected • Covering the Western part of the study site • Data acquisition effected by cloud and cloud shadows
04/08/2021	12:44 to 14:31	• 27 hyperspectral scan lines collected • Covering the Eastern and “central” part of the study site • Re-recording scan lines from 1.07 and partly from 25.07 • No cloud disturbance reported

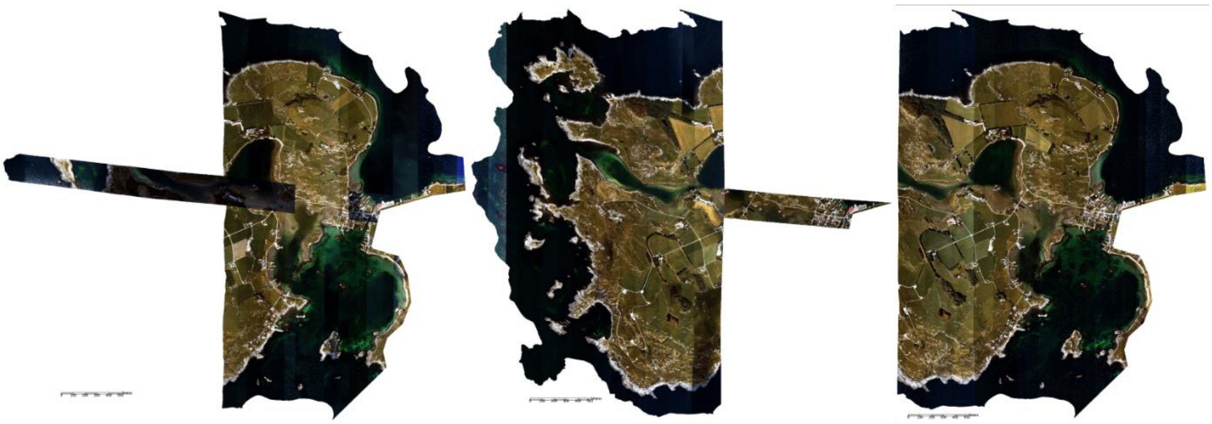

Figure 5.1. Data acquired by Field hyperspectral survey over 01/07/2021 (left), 25/07/2021 (middle) and 04/08/2021 (right). Images are the true-coloured VNIR with bands 618 nm, 519 nm and 420 nm visualised in red, green and blue (RGB).

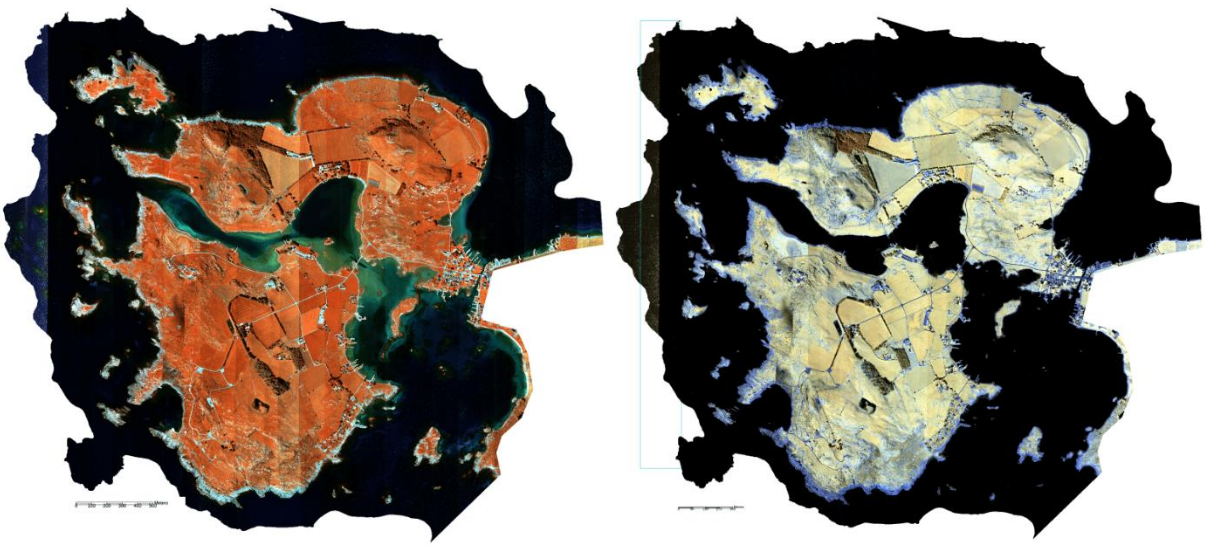

Figure 5.2. Mosaic of all hyperspectral images delivered by Field. False-coloured VNIR images with bands 497 nm, 592 nm and 720 nm visualised in RGB (left); and false-coloured SWIR images bands 1005 nm, 1169 nm and 1497 nm visualised in RGB (right).

5.2 Further data corrections and analysis by EOMAP

The hyperspectral data delivered by Field was radiance, which requires further corrections (atmosphere, adjacency to land, water surface such as sun-glint, and water-column effects) to allow classification and analysis. The company EOMAP GmbH & Co.KG (Germany) was contracted to conduct these corrections and deliver datasets of Subsurface Reflectance (SSR) and Seafloor Reflectance (SFR) (Borngraeber et al., 2023). Their proprietary “Modular Inversion Program” makes use of a physic-based inversion method and detailed spectral information to derive bathymetry as well as optical properties of the water column. It then uses this information to remove the spectral attenuation effect of the water column from each channel to provide the seafloor reflectance.

In addition, the project requested a comparison of potential differences by correcting to SFR using bathymetry derived directly from the hyperspectral data versus using bathymetry derived from MBES and LIDAR. A description of the corrections and the comparisons are detailed in the delivery report from EOMAP (Borngraeber et al., 2023).

5.3 Further data corrections and analysis by NGU

Corrections for atmospheric effects and a preliminary seabed classification were carried out by the Geological Survey of Norway (Kurz, 2023). Kurz (2023) also includes recommendations for future hyperspectral data surveys in the context of the Marine Base Maps for the Coastal Zone project.

6. AERIAL ORTHOPHOTOGRAPHY

Concurrently with their April 2021 LIDAR survey, Hexagon acquired aerial RGBI imagery (Hexagon, 2022). The sensor used was a digital camera integrated in the Chiroptera 4X LIDAR sensor. An orthophoto of 5 cm resolution was produced using Leica software HxMAP (Figure 4.1).

Concurrently with their LIDAR survey, Field acquired aerial RGB imagery on April 25th, 2021 (Terratec, 2021c). The sensor used was a Phase One iXM-RS 150F digital camera (Terratec, 2021a). An orthophoto of 2.5 cm resolution was produced using Trimble software OrthoMaster and OrthoVista (Figure 6.1). The orthophoto is published under the name “Fjøløy - MGK ALB Pilot 2021” on the Norge i Bilder portal (Norge i Bilder, 2023).

Concurrently with their hyperspectral survey, Field acquired aerial RGB imagery on July 1st, 2021 (Terratec, 2021d). The sensor used was a Vexcel UltraCam Eagle M3 camera. An orthophoto of 2.5 cm resolution was produced using Trimble software OrthoMaster and OrthoVista (Figure 6.2). The orthophoto is published under the name “Fjøløy Sommer - MGK ALB Pilot 2021” on the Norge i Bilder portal (Norge i Bilder, 2023).

Figure 6.1. Aerial orthophotography acquired by Field in April 2021 concurrently with the LIDAR survey. Entire dataset (left) and detail (right).

Figure 6.2. Aerial orthophotography acquired by Field in July-August 2021 concurrently with the hyperspectral imagery survey. Entire dataset (left) and detail (right).

7. MULTIBEAM SONAR

7.1 Mapping Authority surveying

MBES data of the study site were acquired by the Norwegian Mapping Authority in August and October 2020, using the two survey vessels MB Havelle and MB Lomvi equipped with Kongsberg EM2040 systems. The bathymetry data were processed in 2020 at the Norwegian Mapping Authority into a Digital Elevation Model with grid size 20 cm (Figure 7.1). In 2023, the Norwegian Mapping Authority did a revised processing of the data, to better distinguish the actual seabed from the marine vegetation (Figure 7.2). This resulted in two gridded bathymetry datasets, one representing the assumed marine vegetation above the seabed, and one representing only the seabed surface (Figure 7.3).

Backscatter data (indicating relative seabed hardness) were processed by NGU into 1-m-resolution grids for the purpose of updating the interpreted seabed geology maps in the area. Note that in the shallowest areas, the high raw data point density would allow displaying backscatter data in higher resolution if needed.

Figure 7.1. Shaded relief terrain model (grid size 20 cm) of the MBES data acquired by the Norwegian Mapping Authority in 2020.

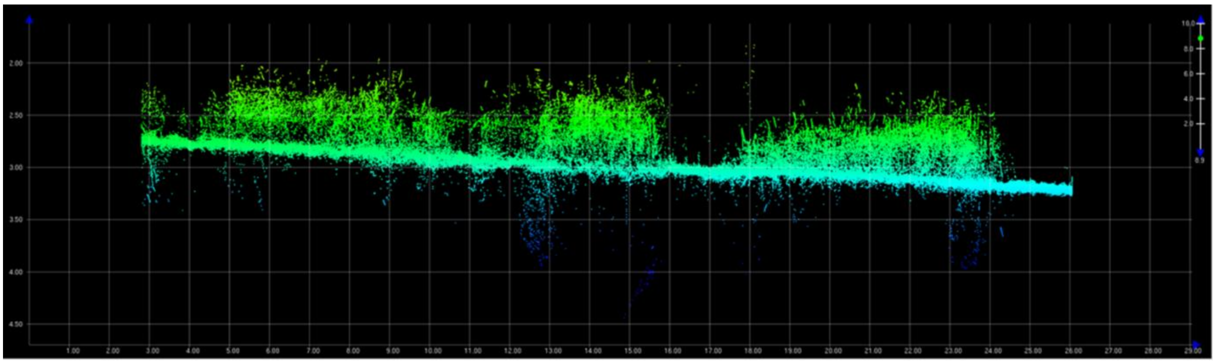

Figure 7.2. Side-view of an example of unprocessed MBES bathymetry data from the study site as a point cloud. This shows the assumed vegetation (mostly green points) and noise above (mostly green points) and below (mostly blue points) the seabed. The 2023 re-processing was aimed at removing this assumed vegetation and noise.

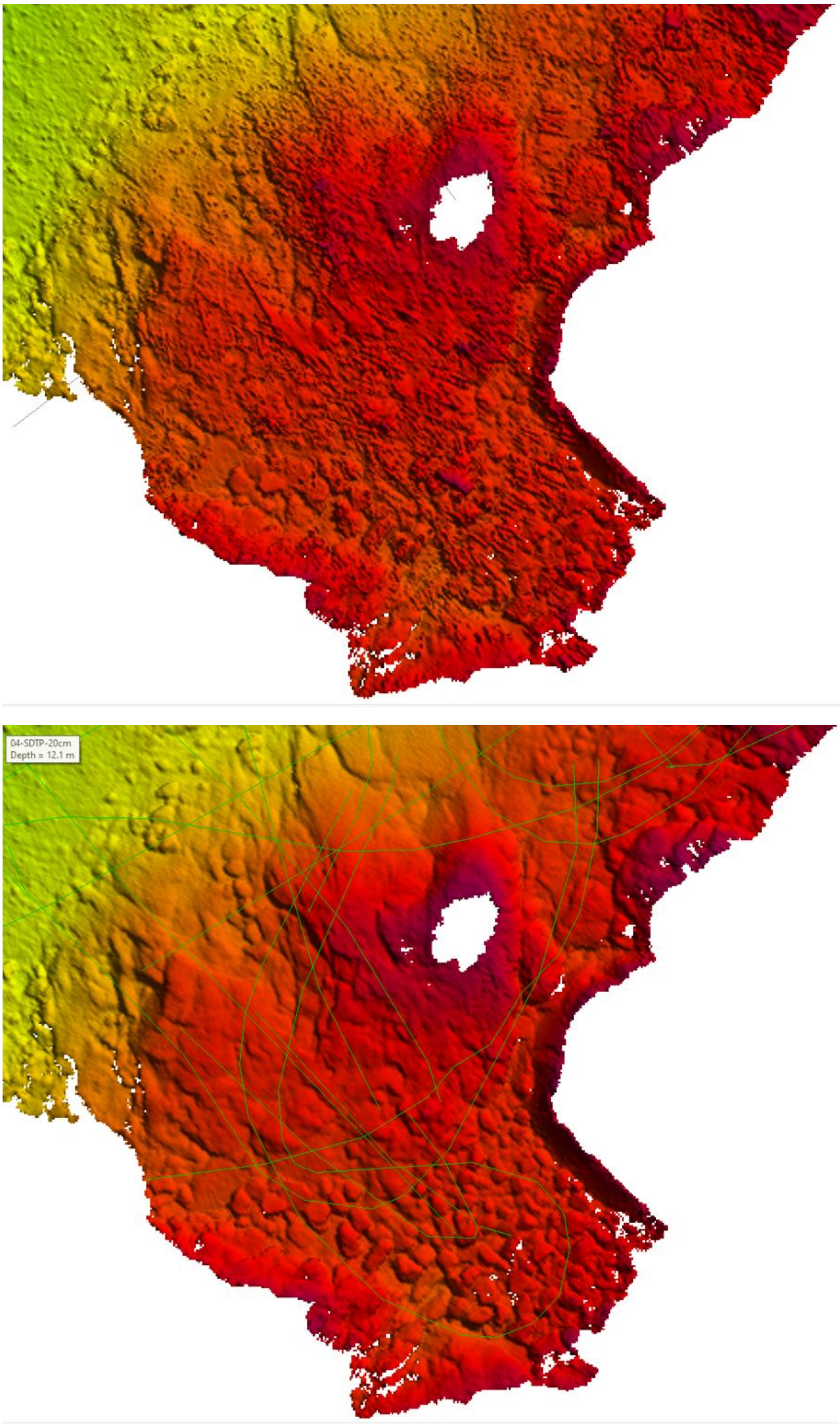

Figure 7.3. Bathymetric terrain model obtained from the 2023 revised processing of the 2020 MBES surveys. The raw data were processed into two datasets showing respectively the top of the assumed vegetation cover (top), and the underlying seabed (bottom).

7.2 Unmanned Surface Vessel (XOCEAN)

Over two days in October 2021, XOCEAN conducted MBES surveys in three focus areas of the study site (Figure 7.4), using an XO-450 USV (Figure 7.5) (Mallace, 2021). The USV was equipped with a Norbit Winghead i77 MBES. Table 7.1 lists the technical specifications of the USV and the MBES. The raw data were collected with BeamworX software NavAQ. The navigation data were processed with Applanix software POSPac MMS 8.6. The bathymetry data were cleaned and exported to the .gsf format with BeamworX software AutoClean. Derivatives of backscatter data were produced with QPS software FMGT. Figure 7.6 shows shaded-relief terrain models (50 cm grid size) and backscatter images of the three focus areas.

The raw and processed backscatter and bathymetry data were delivered to the Norwegian Mapping Authority, where data quality was compared to the full-coverage MBES data acquired by the Norwegian Mapping Authority (Welde & Ofstad, 2021). The XOCEAN MBES data were found to show a good consistency with the reference data, particularly in flat areas. In less flat areas, a slight vertical difference between datasets was found. The aim of the survey was to map the three areas to 100% coverage, with a sounding density better than 9 soundings per square meters. This density target was not hit everywhere, creating some gaps in the data in steep or densely vegetated areas.

Table 7.1. Specifications of the equipment of the XOCEAN USV

Function	Equipment
Survey Platform	XOCEAN XO-450 (Name “XO-04”)
Primary Positioning System	Applanix POS MV Wavemaster II
Primary Gyro and INS System	Applanix POS MV Wavemaster II
Sonar System	Norbit Winghead i77 (0.5 by 1.0 degrees system (400kHz), 200-400 kHz broadband MBES. Also recording backscatter)
Sound Velocity Measurement	Valeport miniSVS (at the MBES transducer) Valeport SWiFT SVP (winch deployment)
Data Acquisition System	Beamworx NavAQ

Figure 7.4. Planned focus areas for the XOCEAN USV survey. Red: Priority 1, green: Priority 2, blue: Priority 3.

Figure 7.5. The XOCEAN XO-450 USV during mapping of priority area 3, October 26th, 2021

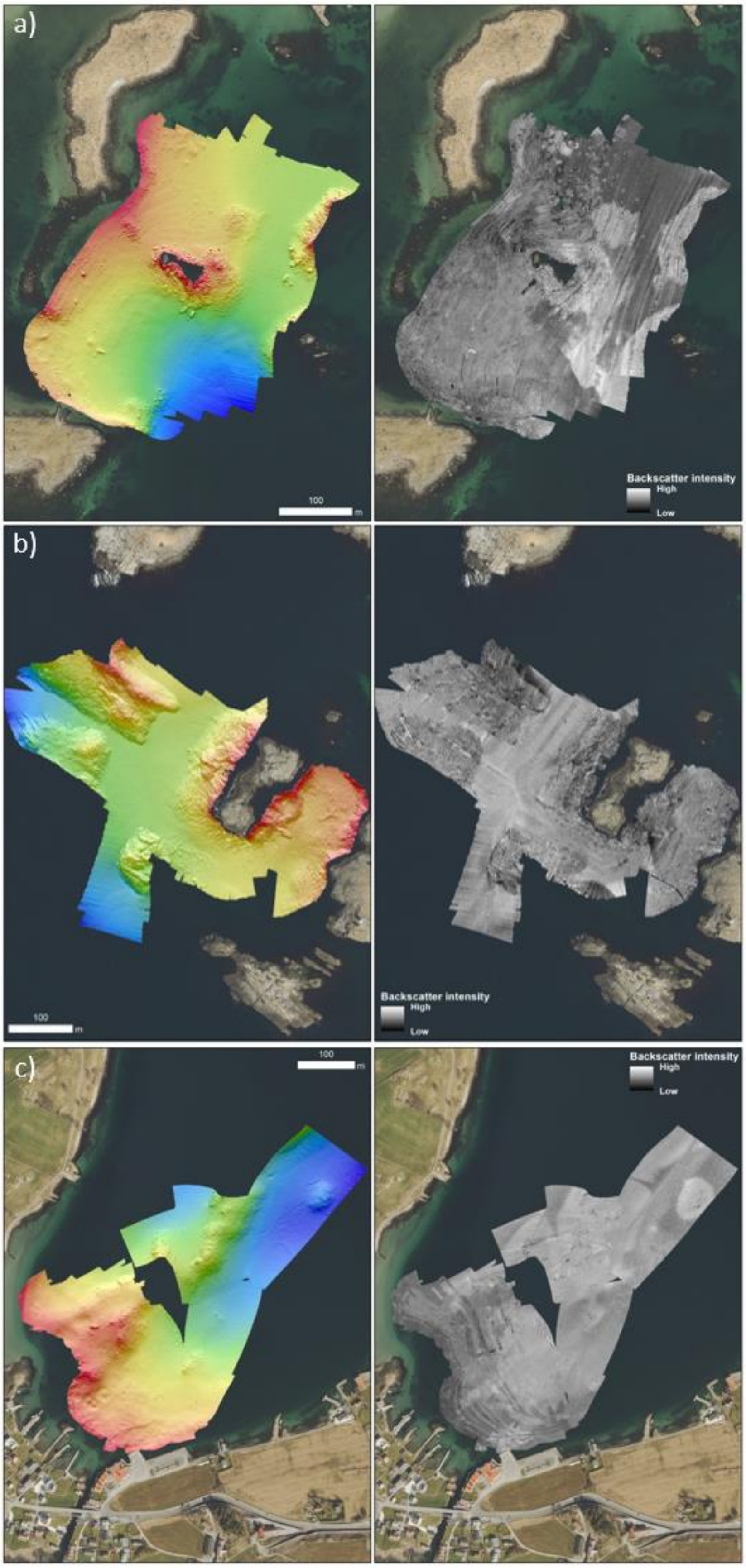

Figure 7.6. Coloured shaded relief (grid size 50 cm, left) and backscatter images (right) from USV priority areas 1 (a), 2 (b) and 3 (c). For relief maps, colours indicate relative depth (red is shallower, blue is deeper).

8. GROUND-TRUTH

8.1 Seabed

8.1.1 IMR/NGU 2020 survey

Video transects were recorded within the study site area as part of the main sampling program of the Marine Base Maps for the Coastal Zone pilot project in Stavanger (Figure 8.1). On May 20th, 2020, four 50 m-long transects were surveyed with a Blueye Robotics ROV (IMR station names “Nye Stavanger” 377, 429, 448, and 455). On June 1st, 2020, two 200 m-long transects were surveyed using a towed camera from the NGU vessel Seisma (IMR station names “Nye Stavanger” 498 and 524, NGU numbers 107 and 160). Biotic and abiotic parameters were obtained from the videos and used as input for NiN habitat modelling and geological classification.

8.1.2 IMR 2021 survey

Additional ground truth data of underwater vegetation and bare substrates were acquired by IMR from May 26th to 29th, 2021, using a handheld towed video rig deployed from a small vessel (Figure 8.1). The rig was equipped with a drop camera providing a live video feed for surface personnel to keep a stable altitude above the seafloor. Since the quality of the drop-camera video is not sufficiently high for the task, the rig was equipped with two additional cameras: a forward-facing GoPro Hero9 Black in a GoPro housing and a forward-facing Paralenz Vaquita “1st Gen” underwater camera (Figure 2.5). The GoPro was set to record with “Wide” field of view setting and 1080p 60 fps. The Paralenz Vaquita was set to record 12 MP still images with a time interval of 2 seconds. The Paralenz camera also logs depth, temperature and salinity every second.

Positions were recorded by manually adding sample points (about every 5 meters distance travelled) on a tablet using the QField software that was set to receive coordinates from a Trimble R2 GNSS receiver with a 7 cm positional accuracy. The Trimble R2 was placed at the drop-camera's entry point into the sea, but with increasing depth and vessel speed, the towed rig trails a few meters behind the vessel, adding some positional inaccuracy. Each position was matched with the subsequent image closest in time, thus either the image taken within the same second or the one taken 1 second later.

The coastline of the study site was divided into 12 evenly sized sectors of 3 areas each, for video surveying. Out of those 36 areas, 24 were surveyed using 3 parallel transects with a 50-meter spacing. The transects were run perpendicular to the coast, thus covering a depth gradient from 1-2 m down to 5-25 m, depending on location. The 72 transect lines thus surveyed lead to the recording of 2430 positions/sampling points to be used for classification or validation (Figure 8.1).

The substrate at each sampling point was classified based on the image from the Paralenz camera, with GoPro video used for identification assistance. Percent-cover of vegetation was annotated for each species or group, while bare substrate was classified on a 6-step scale. The classification did not assign a single habitat-type, and the user thus needed to decide the criteria for such classification. For example, whether a kelp forest needs a minimum of 25% or 50% cover, or how to decide the habitat class of a site with 50% bare sand, 25% eelgrass and 25% sugar kelp, will depend on use case.

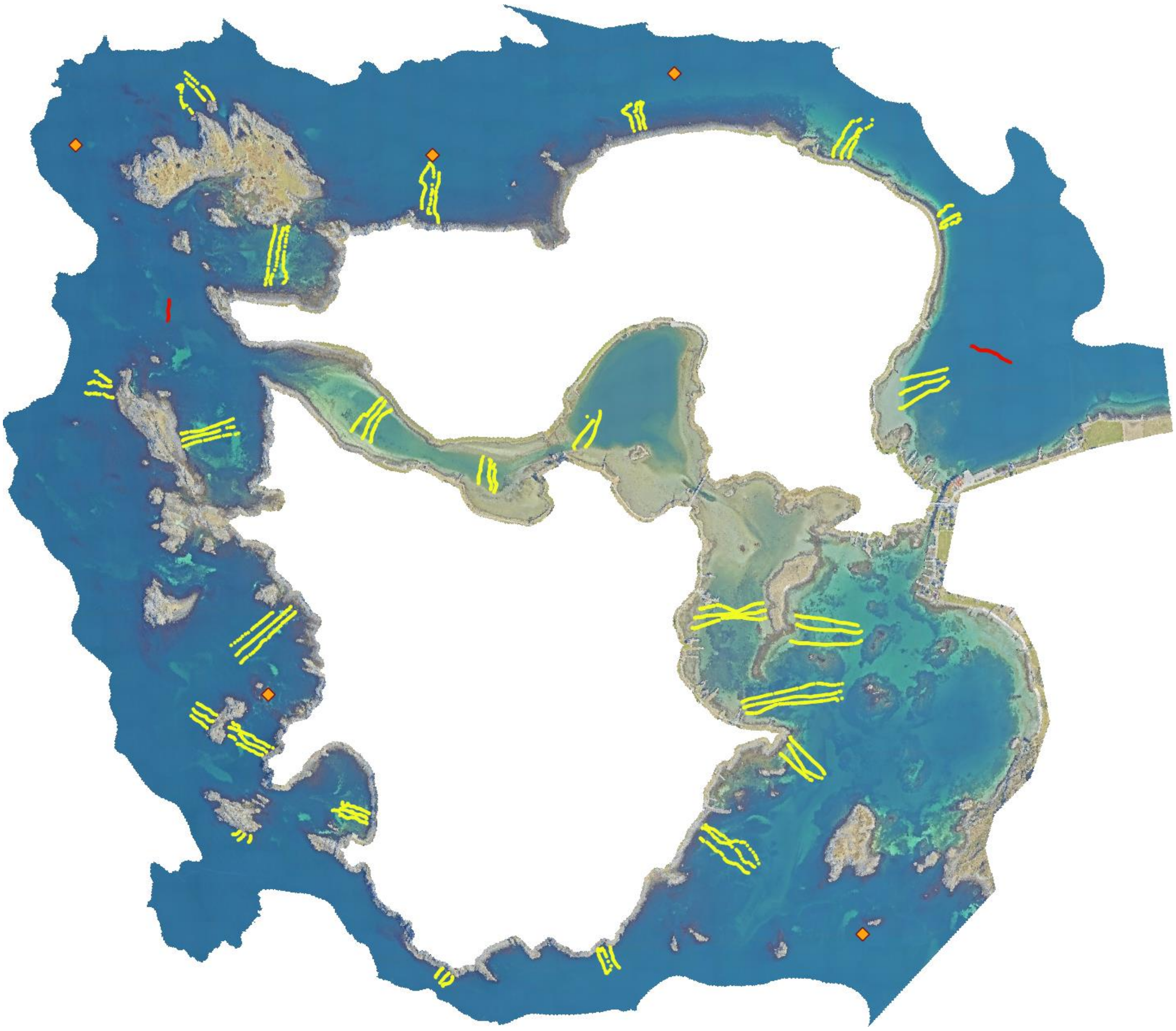

Figure 8.1. Seabed ground-truth survey. Orange: location of IMR 2020 50 m transects. Red: IMR/NGU 2020 400 m transects. Yellow: IMR 2021 transects.

8.2 Water

Water samples were collected (from surface down to the seafloor) at 6 locations on July 1st, 2021, for use in interpretation of hyperspectral data (Figure 8.2). Salinity, temperature, and density were measured with a SAIV CTD Profiler (model SD204) with added turbidity and fluorescence sensors. The diffuse attenuation coefficient (Kd) was measured using a Biospherical Instruments Inc. radiometer with parallel surface and subsurface sensors. The surface water (0–2 m) at five of these locations was sampled and analysed for Total Suspended Matter (TSM) and Coloured Dissolved Organic Matter (CDOM).

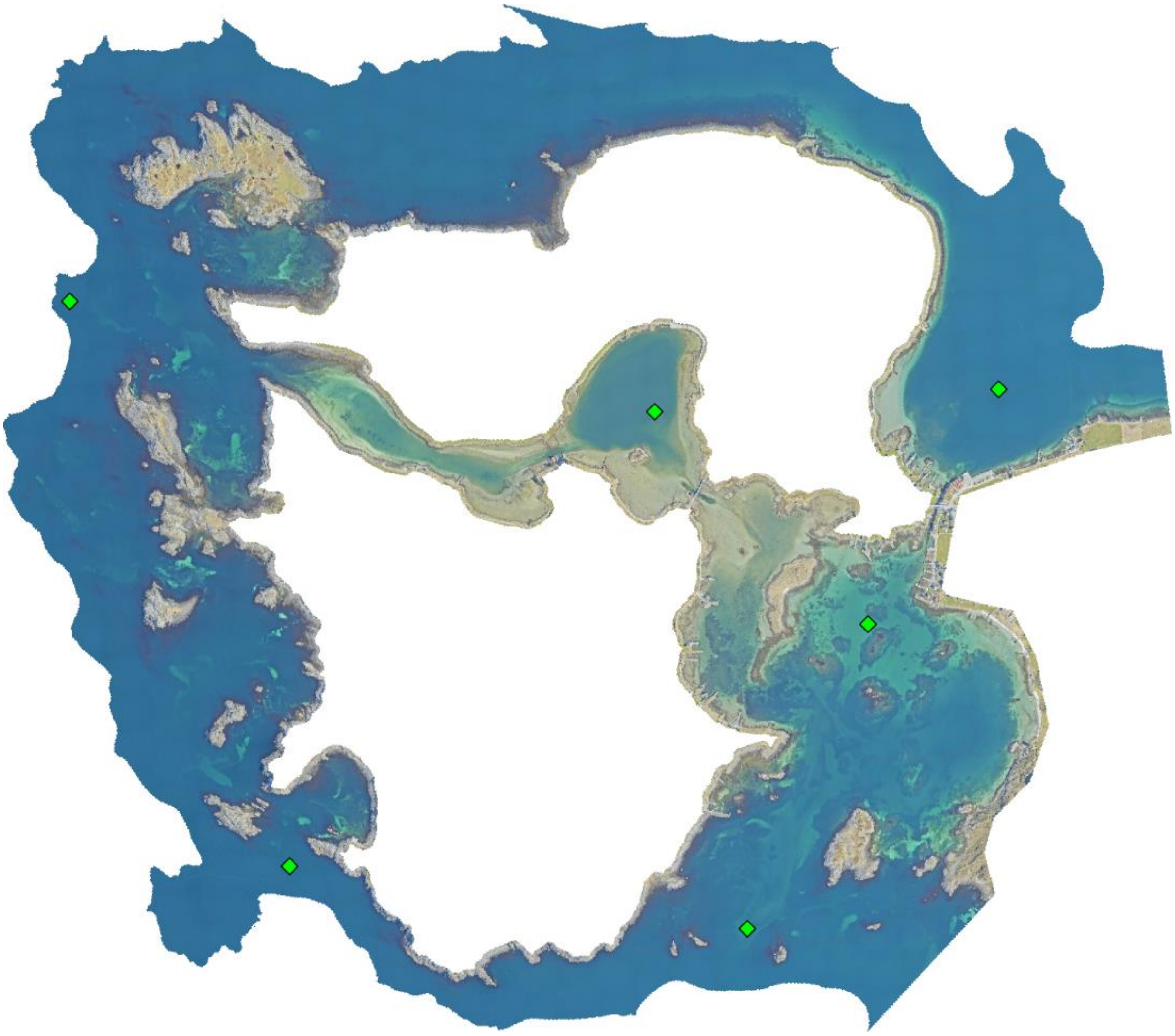

Figure 8.2. Green: location of water sampling over the study site.

8.3 Light spectrum

Spectrometer ground truth data were collected by the Norwegian Mapping Authority and IMR on July 1st and 2nd, 2021. The purpose was divided into two objectives. The first objective was to create a spectral library for different types of aquatic vegetation and seabed substrate type on the study site, and the second objective was to create spectra of reference objects on land for calibration of remote-sensing hyperspectral data (Neishem et al., 2022). All reflectance measurements were done using a Spectro 1 Pro spectrometer by Variable Inc. (Figure 8.3), which measures reflectance in the 400–700 nm range by interval of 10 nm.

For the first objective, 26 underwater “objects” (kelp, eelgrass, sand, etc.) were collected using a claw designed for this field work and lowered from a boat (Figure 8.3). The spectral signature of each object was measured in the boat placed on a white surface. The GNSS position at the drop site and the approximate depth read on the claw were logged. For the second objective, 11 land objects were selected (Figure 8.4) and their reflectance spectrum measured. Measuring the difference between the spectra of objects measured with remote-sensing and on-site allows correcting the remote-sensing imagery for sensor and atmospheric effects.

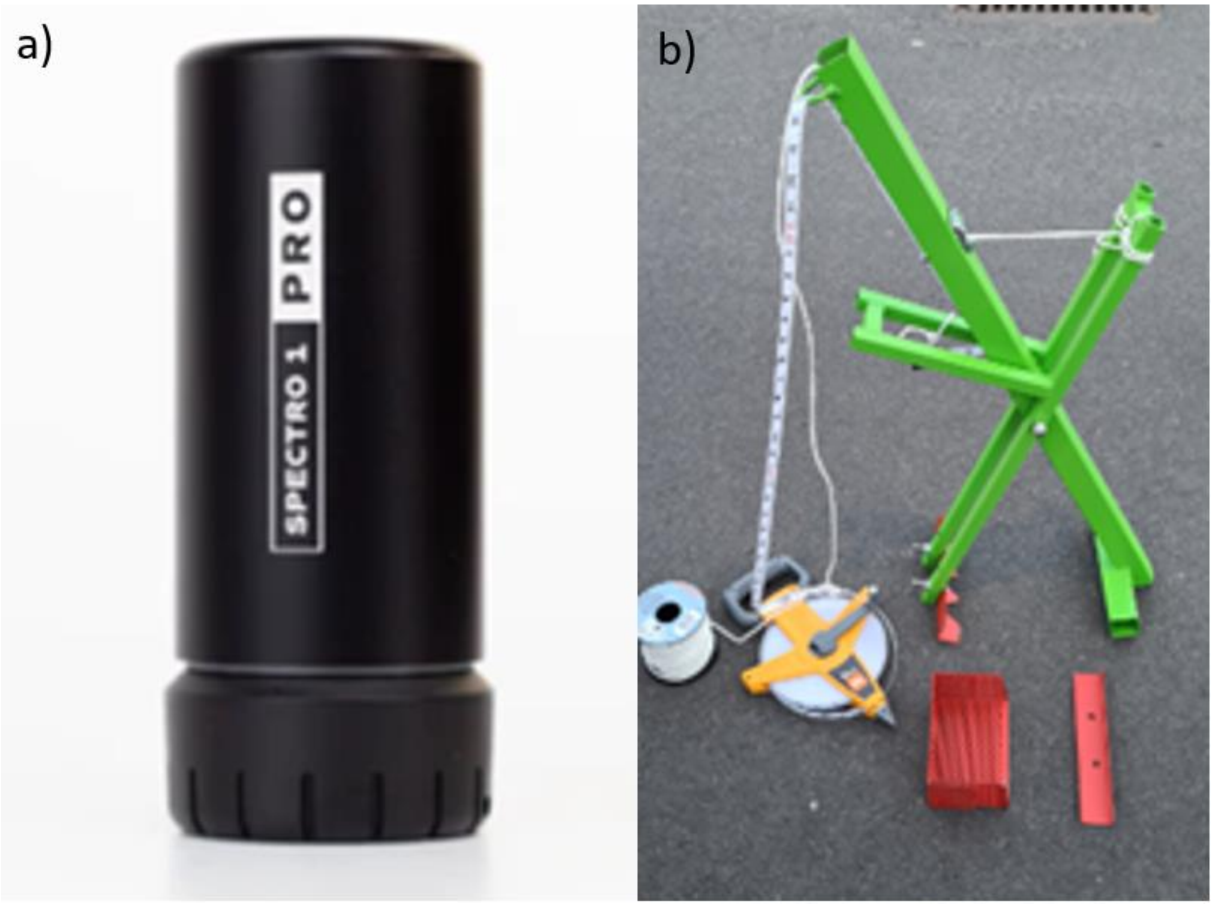

Figure 8.3. Spectro 1 Pro spectrometer by Variable Inc (left); and claw with built-in depth measurement (right).

Figure 8.4. Locations of spectrometer ground-truth measurements on land.

9. LIST OF ABBREVIATIONS

Abbreviation	Meaning
CDOM	Coloured Dissolved Organic Matter
CEST	Central European Summer Time
CTD	Conductivity, Temperature, and Density (sensor)
FOV	Field of view
GNSS	Global navigation satellite system
IMU	Inertial measurement unit
MBES	Multibeam echosounder
MTOW	maximum take-off weight
NiN	Nature in Norway (Habitat classification system) https://artsdatabanken.no/NiN
RGB	Red, Green, Blue
SBES	Single-beam echosounder
SBET	Smoothed Best Estimate of Trajectory
SDB	Satellite-Derived Bathymetry
SFR	Seafloor Reflectance
SSR	Subsurface Reflectance
SWIR	shortwave infrared
THU	Total Horizontal Uncertainty
TSM	Total Suspended Matter
TVU	Total Vertical Uncertainty
UAV	Unmanned Aerial Vehicle (drone)
USV	Unmanned Surface Vessel
VNIR	Visible to near infrared

10. REFERENCES

Borngraeber S, Hartmann K, Bödinger C (2023) Atmospheric and water correction of hyperspectral HySpex data, Fjøløy, Norway. EOMAP Delivery Report 20220623.1250_IMR_NOR_Fjoloy. Version 1. EOMAP GmbH & Co.KG. 25p.

Field (2022) Marine Grunnkart utvikling. Project number 16777. Rev 4 22/12/2022. 46p.

Haarpaintner J, Davids C (2020). Satellite Based Intertidal-Zone Mapping from Sentinel-1&2. Final Report, NORCE Klima Report nr. 2-2020, Norwegian Environment Agency report M-1646. https://www.miljodirektoratet.no/publikasjoner/2020/mars-2020/satellite-based-intertidal-zone-mapping-from-sentinel-12/

Haarpaintner J, Davids C (2021a). Mapping Atmospheric Exposure of the Intertidal Zone with Sentinel-1 CSAR in Northern Norway. Remote Sensing 2021:13, 3354. https://doi.org/10.3390/rs13173354

Haarpaintner J, Davids C (2021b). Satellite-Based National Intertidal-Zone Mapping of Continental Norway with Sentinel-1&2. Final Report, NORCE Klima Report nr. 1-2021, Norwegian Environment Agency report M-1994. https://www.miljodirektoratet.no/publikasjoner/2021/mai-2021/satellite-based-national-intertidal-zone-mapping-of-continental-norway-with-sentinel-12/

Hexagon (2022). Survey Report, Topographic and Bathymetric Lidar Survey, Fjøløy. Rev 1. Hexagon project number 10067. 30p.

Kartverket (2020). TEST SITE FJØLØY-KLOSTERØY. 22.09.2020. 22p.

Kartverket (2023). Altitude data. https://hoydedata.no/. Accessed 05/05/2023.

Kurz T (2023). Processing of the airborne hyperspectral data at Fjøløy (Stavanger, Norway). NGU internal Project Report. 12p.

Mallace D (2021). 00207-NHS-NOR-BATH Fjøløy Hydrographic Survey, Project Execution & Results Report. Rev01. 01.12.2022. 18p.

Neishem LK, Thormar J, Oveland I (2022) Rapport, Feltarbeid 1-2. Juli 2021, Fjøløy. 18p.

NGU (2023a). Berggrunn - Nasjonal berggrunnsdatabase. https://geo.ngu.no/kart/berggrunn_mobil/. Accessed 02/05/2023.

NGU (2023b). Løsmasser - Nasjonal berggrunnsdatabase. https://geo.ngu.no/kart/losmasse_mobil. Accessed 02/05/2023.

Nordic Unmanned (2021). Project report – Test project FJØLØY-KLOSTERØY. Bathymetry mapping with ASTRALite Edge Green LiDAR for Kartverket, Sjødivisjonen. Rev. 2. 25.02.2021. 13p.

Norge i Bilder (2023). https://norgeibilder.no/?x=-37784&y=6588955&level=12&utm=33. Accessed 02/05/2023.

SyriUS (2023). https://business.esa.int/projects/syrius. Accessed 05/05/2023.

Terratec (2021a). Editor: Petter Solli. Marine grunnkart i kystsonen – Pilot område Stavanger. Delområde 1 Fjøløy. Prosjektnummer: 13796 Marine Grunnkart Pilot, Dekningsnummer: 41435 Stavanger Pilot Delomr 1 Fjøløy, Terratec, Oslo. 14.09.2021. 21p.

Terratec (2021b). Editor: Kailainathan J. Rapport for datainnsamling og prosessering av hyperspektrale data. Prosjektnavn: Opsjon 1 Fjøløy HySpex, Prosjektnummer: 13796, Dekningsnummer: 41439, Terratec, Oslo, 29.10.2021. 9p.

Terratec (2021c). Ortofotorapport — Kartlegging med LIDAR, RGB og hyperspektral avbildning i Marine grunnkart i kystsonen. Pilot prosjekt. Delområde 1 Fjøløy, bildedekning TT-41435. 7p.

Terratec (2021d). Ortofotorapport — Kartlegging med LIDAR, RGB og hyperspektral avbildning i Marine grunnkart i kystsonen. Pilot prosjekt. Delområde 1 Fjøløy, bildedekning TT-14531 (kamera UltraCam Eagle M3). 7p.

Welde H, Ofstad A (2021). XOCEAN Survey at Fjøløy. 12.10.2021. 16p.

GEOLOGICAL
SURVEY OF
NORWAY
- NGU -

Geological Survey of Norway
PO Box 6315, Sluppen
N-7491 Trondheim, Norway

Visitor address
Leiv Eirikssons vei 39
7040 Trondheim

Tel (+ 47) 73 90 40 00
E-mail ngu@ngu.no
Web www.ngu.no/en-gb/