SeaBee Annual Report

2023-2024

NIVA Norsk institutt for vannforskning

NINA Norsk institutt for naturforskning

NTNU Kunnskap for en bedre verden

NR Norsk Regnesentral Norwegian Computing Center

GRID ARENDAL A UNEP Partner

TIEPOINT

SPECTRO FLY

RCN project ID number: **#296478**
RCN reporting period: **1. March 2023 to 29. February 2024**

Project title: **SeaBee – Norwegian Infrastructure for drone-based research, mapping, and monitoring in the coastal zone**

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This report represents a simplified version of the more elaborate report delivered in the Research Council's online portal. This document also contains some supplementary information about key achievements and deliverables for SeaBee during the project year lasting from 1. March 2023 to 29. February 2024.

Content

List of abbreviations used in the report.

Term	Explanation	Term	Explanation
AI	Artificial Intelligence	PDRA	Predefined Risk Assessment
BVLOS	Beyond Visual Line of Sight	PPK	Post Processing Kinematics
CDI	Communication, Dissemination, and Impact	RCN	The Research Council of Norway
Cristin	Current Research Information System in Norway	RFF	Regionale Forskningsfond
HSI	Hyperspectral Imaging	RGB	Red-Green-Blue colour bands
IR	Infrared	ROV	Remotely Operated Vehicle
LIDAR	Light Detection and Ranging	RS	Remote Sensing
ML	Machine Learning	RTK	Real Time Kinematic
MSI	Multispectral Imaging	STS	Standard Scenario
NEA	Norwegian Environment Agency	UAV	Uncrewed Aerial Vehicle
NIRD	National Infrastructure for Research Data	USV	Uncrewed Surface Vehicle
OOI	Objects of Interest	VLOS	Visual Line of Sight

1 Popular science summary

Norway's coastline is more than 100,000 km long, including all islands and skerries. However, only a fraction of its species and habitat types have been mapped. These include threatened seabirds and mammals, essential and diverse ecosystems that capture and store carbon, and that serve as nursery grounds and food for countless species, as well as great commercial resources.

The coastal zone is rather inaccessible, where research vessels rarely enter, and small, rubber boats provide limited spatial coverage. This is where the use of flying and smaller surface drones can revolutionize environmental research, mapping, and monitoring in Norway and abroad.

During the five-year period 2020 to 2025, SeaBee will establish a national center for drone-based services for use in coastal and aquatic research, mapping and monitoring of species and habitats, algae and animal communities, and anthropogenic impacts. This is a blue-green investment that will benefit research communities, management, and coastal industries throughout the country. Also, it positions Norway at the forefront of international drone research and monitoring applications.

Through pre-programmed flight planning and automated procedures, SeaBee is streamlining drone data collection and analysis and making high-quality products available in a timely and cost-effective manner. Flying drones equipped with cameras and sophisticated spectral sensors are used to take images on demand and at centimeter resolution – more than a hundred times better than available satellite products. Recorded species and nature types are classified using state-of-the-art artificial intelligence tools. Products are verified from ground truth observations by experienced ecologists. 'Data and mapping products are stored in cloud-based solutions and made freely available for research and management applications through the customized online data interface. SeaBee is thus establishing novel and cost-effective solutions for use in aquatic research, and for mapping and monitoring of nature in coastal zones, and hereby setting new standards for environmental research and management.

SeaBee is a cooperation between the Norwegian Institute for Water Research (NIVA, lead), the Norwegian University of Science and Technology (NTNU), the Norwegian Computing Center (NR), the Norwegian Institute for Nature Research (NINA), the Institute of Marine Research (IMR), and GRID-Arendal (GRIDA), with Tiepoint (former Andøya Space) and SpectroFly ApS as industrial partners.

SeaBee aims to deliver an interdisciplinary national center for drone-based research, mapping, and environmental monitoring with world-leading expertise. In this spirit, we are happy to invite anyone with an interest in the coastal zone or technical enhancements to contribute to the continuous development of methodology and drone-based solutions for a sustainable future.

Read more at www.seabee.no

2 Populærvitenskapelig framstilling

Norges kystlinje er mer enn 100 000 km lang, inkludert alle øyer og skjær, men bare en brøkdel av artene og naturtypene er kartlagt. Her finner vi truede sjøfugler og pattedyr, områder med livsviktige naturtyper som ålegress, tang og tare, som har betydning som karbonlagre, oppvekstområder og matfat for et rikt dyre- og planteliv langs kysten. Og som i tillegg har betydelig kommersiell interesse som tilgjengelige naturressurser.

Kystsonen representerer en utilgjengelig stripe der slagstøvler ofte blir for korte for å nå ut fra land og forskningsfartøy blir for store for å kartlegge på grunna. Det er særlig i denne sonen bruk av droner kan revolusjonere kartlegging og overvåking av marin natur i Norge.

I løpet av femårsperioden 2020-2025 skal SeaBee etablere et nasjonalt senter for dronebaserte tjenester til bruk i kyst- og havforskning, kartlegging og overvåking av arter og naturtyper, alge- og dyresamfunn og menneskeskapte påvirkninger. Dette er en blågrønn satsing av verdi for forskningsmiljøer, forvaltningen og kystindustrier i hele landet. Og som vil gjøre Norge til et internasjonalt foregangsland innen bruk av droner og kunstig intelligens.

Gjennom forhåndsprogrammert flyruter og automatiserte prosedyrer samler, analyserer og tilgjengeliggjør SeaBee dronedata av høy kvalitet på en tids- og kostnadseffektiv måte. Flyvende droner utstyrt med kameraer og avanserte spektralsensorer brukes til å ta bilder med centimeteroppløsning – mer enn hundre ganger bedre enn satellittbilder. Artene og naturtypene i bildene blir klassifisert ved bruk av bildegjenkjenning og kunstig intelligens, og verifiseres av erfarne økologer i felt. Data og kartprodukt blir lagret i skybaserte løsninger og gjort fritt tilgjengelig for forskning og forvaltning.

SeaBee bidrar dermed til etablering av nye og kostnadseffektive løsninger til bruk i forskning og for kartlegging og overvåking av naturressurser i kystsonen, og gjennom dette nye standarder innen miljøforskning og forvaltning. SeaBee er et samarbeid mellom Norsk institutt for vannforskning (NIVA), Norges teknisk-naturvitenskapelige universitet (NTNU), Norsk Regnesentral (NR), Norsk institutt for naturforskning (NINA), Havforskningsinstituttet (HI) og GRID-Arendal, med Tiepoint (tidligere Andøya Space) og SpectroFly ApS som industripartnere.

SeaBee har ambisjon om å levere et tverrfaglig nasjonalt senter for dronebasert forskning, kartlegging og miljøovervåking med kompetanse i verdensklasse. I den ånden inviterer vi gjerne inn alle med en relevant interesse i kystsonen eller teknisk kompetanse og lyst til å bidra til en stadig utvikling av metodikk og dronebaserte løsninger for et bærekraftig samfunn.

Les mer på www.seabee.no

3 Project status (1.3.2023 - 29.2.2024)

The SeaBee project entered its third year during 2023 and is well on track. Large parts of the infrastructure are now operational and SeaBee is already providing data and services to a range of end users. This includes Horizon EU research projects, RCN and RFF research and developing projects, as well as mapping and monitoring projects for national environmental agencies and industry. During 2023, SeaBee invested in new drones and sensors that significantly expand the capabilities and applications of the infrastructure and increase both spatial and spectral resolution. Purchases include fixed-wing and rotor drones, multispectral and thermal cameras, and novel laser-based sensors (LIDAR).

SeaBee's data pipeline took another leap in 2023 and is now fully operational, anchored at the national Sigma2/NIRD platform. The pipeline provides an automated, end-to-end data processing platform for RGB and multispectral (MSI) datasets and is capable of automated storage and processing of drone data. A GeoNode interface was established to make SeaBee datasets publicly available online. Now, drone pilots can upload hundreds of raw images directly from the field and, within hours, study the finished georeferenced orthomosaic, based on their data, in the online visualization portal. The AI-based image analysis module was further developed and now consists of two generic modules for object detection and pixel-classification, respectively. These provide cloud-based data analysis and can inform SeaBee users with habitat classification maps and tools for identification of seabirds and marine mammals (seals).

For validation of the AI-based data products, the SeaBee team undertook several field campaigns during 2023 and collected ground truth data for training and validation. In collaboration with other research and development projects and national monitoring programs, SeaBee researchers collected ground data of benthic habitats, seabirds, marine mammals (seals), and water quality, using manual observations, diving, small boats, surface drone (USV's) and underwater robots. Communication of SeaBee activities and achievements was published continuously through 2023 on SeaBee's website and social media platforms (LinkedIn, X, YouTube) as well as in scientific journals, reports, and conferences. In total SeaBee has made ~20,000 impressions in social media, published 39 contributions of which >20 were scientific publications (papers, talks, posters).

SeaBee has contributed to more than 20 field campaigns in the reporting period 01.03.2023-29.02.2024. During these campaigns SeaBee pilots have completed ~780 flying drone missions and collected and processed >570 unique datasets. In total, SeaBee drones have been in the air >186 flight-hours and drone pilots in the field for >72 days. SeaBee's two surface vehicles (USVs) have been involved in 6 projects, collected >22 datasets and been on the water for >36 hours. The USV operators spend >34 days in the field.

A VTOL drone just after its vertical take-off at Ølbergholmen in the Oslofjord outside Larvik, June 2023.

4 Results and highlights

4.1 The hardware infrastructure

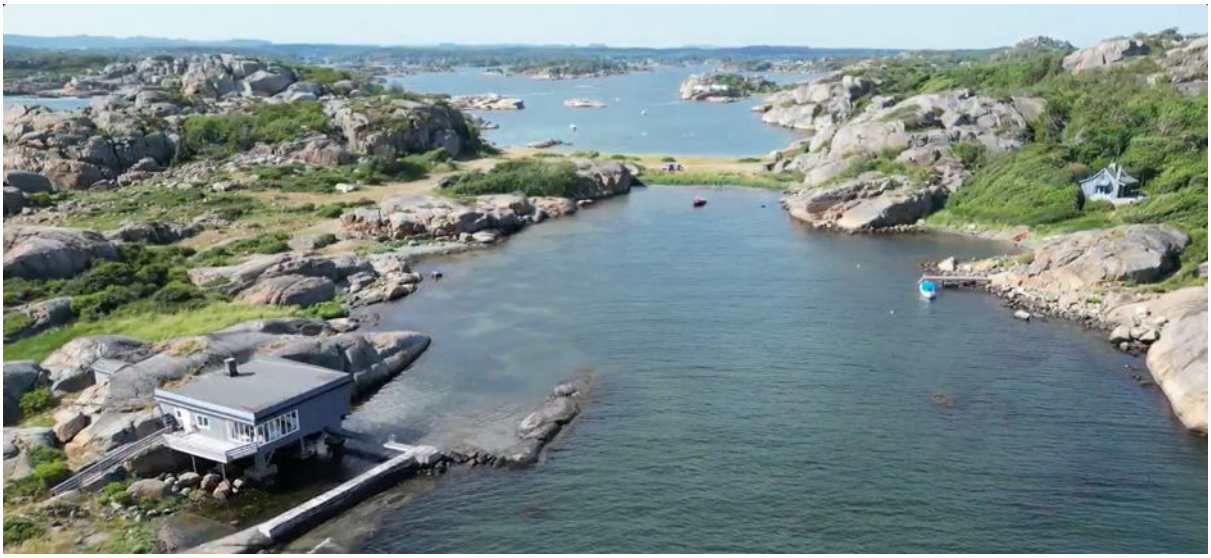
In 2023, the project continued to further equip the infrastructure with state-of-the-art drone hardware and sensors, while also conducting essential system integration, testing and maintenance of the existing drone park.

4.1.1 Current fleet and operational status

The current UAV fleet consists of six relatively large rotor drones (DJI M300-M600 equivalent), two large Mugin-2 Vertical-Take-Off-and-Landing (VTOL) drones, two DeltaQuad EVOs (VTOL), one medium sized Mavic 2 with thermal imager, and five small DJI Minis. The USV fleet consists of two Marine Robotics Otter vehicles. One of the Otters is equipped with sonar (for bathymetry, plant canopy depth, plant density, and bottom class measurement), water quality sensors (temperature, salinity, CDOM, Chl a, turbidity) and an RGB camera. The other Otter has an underwater HSI sensor and supporting optical instruments, including a beam attenuation sensor. The two USVs are battery powered with an endurance/range of about 20 hours / 75 km at 1 m/s, weigh about 75 kg, have a draft of 30 cm and a top speed of 3 m/s. Two small ROVs are also part of the fleet.

The project utilizes advanced technology to ensure high precision in geodata and imagery collection. Drones are equipped with RTK and PPK technology for high-accuracy data collection. Additionally, ground-based GNSS systems, such as Leica GS18, are used for precise geodata collection and ground-truthing. This enables SeaBee to deliver accurate and reliable data to the stakeholders. Also, high precision ground-truth data is crucial for training the machine learning algorithms and validation of the mapping products.

In addition to various sensors and the mentioned equipment for accurate geo-localization, the sensor part of the fleet consists of multispectral imagers (MSI), hyperspectral imagers (HSI), infrared (IR) cameras, and RGB-cameras for a wide range of applications, which will be presented later in the report. The VTOL´s with a flight time of up to three hours has the capability to cover larger areas and reach further than the rotor drones. Examples of some of SeaBee's flying drones and onboard sensors are shown in Figure 1.



Ølbergholmen in the Oslofjord outside Larvik, seen from the south by a DJI Mavic Mini3 drone. June 2023.

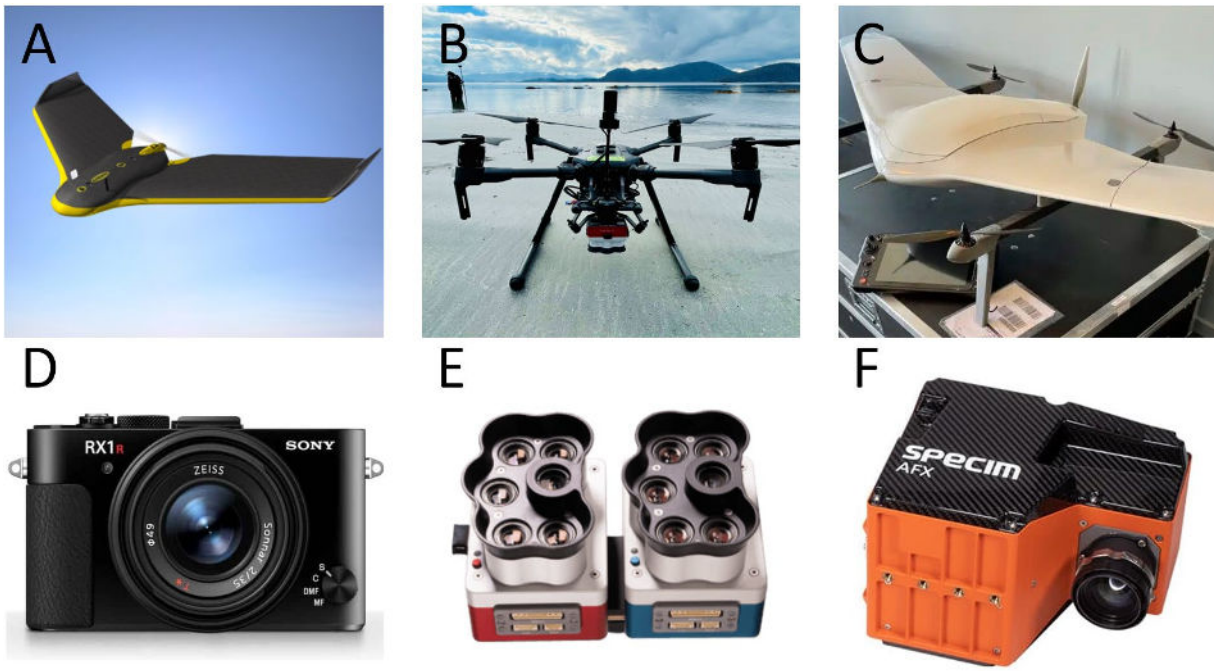


Figure 1. Examples of drone- and sensor types commonly used for coastal habitat mapping and other applications: A) fixed-wing drone (eBee X mapping drone, AgEagle Aerial Systems); B) rotor drone (DJI Matrice 300, photo by SeaBee); C) vertical take-off and landing (VTOL) drone (DeltaQuad EVO, DeltaQuad, photo by SeaBee); D) Red, green and blue (RGB) sensor (Sony RXR II, Sony Group Corporation); E) multispectral imagery (MSI) sensor (MicaSense RedEdge-P dual, Ag Eagle Inc.); F) hyperspectral imagery (HSI) sensor (Specim AFX10, Specim, Spectral Imaging Ltd.). Modified from Kvile et al. (submitted).

4.1.2 New purchases in 2023

Of the purchases and arrivals of 2023, most notably are the two VTOL DeltaQuad EVO drones equipped with onboard RGB and MSI sensors. Throughout the year, these drones have undergone rigorous testing and fine-tuning. The units are currently with the manufacturer receiving service and upgrades and are expected to be back with NIVA within April 2024.

Two new DJI Matrice 350 RTK were acquired in 2023 with the aim to increase drone capacity at the NIVA node in Oslo and strengthen the SeaBee activities in Denmark in addition. Both will excel in situations where a classified 'C' type of drone is needed. This can include missions near people, property or infrastructure that demands use of classified / 'C' type drones. The two drones are fitted with Zenmuse P1 RGB sensors and can carry most of the sensors in the SeaBee-fleet including the red LIDAR. The two large Mugin-2 VTOLs were made ready for deployment at NTNU early this year for sea mammal population monitoring using high resolution RGB and infrared imagery.

At the end of 2023, SeaBee purchased two LIDAR systems for acquiring detailed topography and bathymetry data (red and green LIDARs, respectively). The two instruments are from YellowScan – a market-leading European manufacturer. The two LIDAR systems are expected to be delivered to NIVA in Q2 2024. A Hexadrone Tundra 2 XL UAV was purchased as platform for the green LIDAR, complying with the ambition to add more UAVs from European drone manufacturers to the fleet.

4.1.3 Application examples

The current SeaBee drone fleet possesses impressive versatility, enabling a wide range of applications and drone data collection opportunities. Table 1 provides a list of infrastructure purchases done in 2023 and includes examples of the application for the different hardware. See section "Drone data

validation and groundwork" for additional examples. A comprehensive assessment of pros and cons of the different drones and sensor types are provides in Kvile et al., (submitted).

Table 1. New purchases of infrastructure hardware done in 2023 of drones, sensors, and ground truth equipment. Examples of application are listed in the right-hand column.

Unit	Quantity	Category	Application*
Mugin-2 Pro VTOL	2	Fixed wing (VTOL)	LM, MA, BI, BM, WA, TM
DeltaQuad Evo VTOL	2	Fixed wing (VTOL)	LM, MA, BI, BM, WA, TM
DJI Matrice M350	2	Rotor	SM, MA, BI, BM, WA
DJI Mavic Mini 3 and 4	1	Rotor	DO, SM
YellowScan Navigator (Delivery Q2 2024)	1	Green LiDAR	SM, GT, BM, BA, TM
YellowScan Explorer 2 (Delivery Q2 2024)	1	Red LiDAR	SM, GT, TM
Emlid Reach GNSS Receiver	1	High precision GNSS	GT
Sony A7R RGB Camera	1	RGB sensor	LM, SM, MA, BI, BM, TM, DO
Wiris Pro Infrared Camera	1	Infrared sensor	MA, BI
MicaSense Altum MSI Camera	1	MSI and IR sensor	LM, SM, BI, BM, WA
MicaSense RedEdge P Dual	1	MSI sensor	LM, SM, BI, BM, WA
DJI Zenmuse P1	2	RGB sensor	LM, SM, MA, BI, BM, TM, DO
MicaSense RedEdge_P Blue MSI Camera	1	MSI sensor	LM, SM, BI, BM, WA

* LM = large area mapping, SM = small area mapping, GT = ground-truthing, MA = mammal identification, BI = bird identification, BM = benthic habitat mapping, WA = Water quality assessment, BA = bathymetry mapping, TM = topography mapping, DO = documentation purposes.

4.2 Status on pilot education and operational legislation

In total, 17 drone pilots and nine USV and ROV pilots are currently operative as part of the SeaBee infrastructure. These are located at the involved institutions as follows. Six drone pilots from NIVA are now educated for A1/A3 Open operations. Two of which are currently being trained for STS (specific) operations. From NTNU, two pilots are trained for specific operations. In NINA (available for SeaBee), six pilots are trained for A1/A3, of which two are also trained for A2. Within IMR, currently three pilots are trained for A1/A3 and undergoing training for A2.

A PDRA S02 application was finalized in 2023 (submitted to Civil Aviation Authority Norway, 26 January 2024). If accepted, it will allow flying BVLOS (Beyond Visual Line of Sight) over a controlled ground area within a sparsely populated region. It can be flown up to 1 kilometer from the pilot, or up to 2 kilometers with the use of an airspace observer.

4.3 Data handling and visualization

During 2023, the SeaBee data processing pipeline (Figure 2) has been further developed and was fully deployed for the first time on Sigma2's NIRD platform. Key achievements include:

- Establishing a MinIO interface providing S3-compatible cloud-based storage for all SeaBee datasets. This includes a web UI and a comprehensive API, making it possible to up- and download large volumes of data using any S3-compatible client software (Rclone, etc.).
- Establishing a cloud based JupyterHub providing researchers and developers with powerful tools to analyse and visualise SeaBee data, without needing to install software locally.
- Deploying a customised GeoNode to make SeaBee datasets publicly available online, including interactive map visualisations and WMS layers (for integration with third-party applications). See Figure 3.

- Creating an automated, end-to-end data processing pipeline for RGB and multispectral datasets. Using the SeaBee platform, drone pilots can now upload raw images directly from the field and expect to find georeferenced orthomosaics and other data products available online within hours.
- Publishing data standards, protocols, and information for technically skilled users on the SeaBee documentation website.
- Publishing popular science "GeoStories" that combine interactive maps, videos and data visualization to communicate SeaBee activities to a non-technical audience.

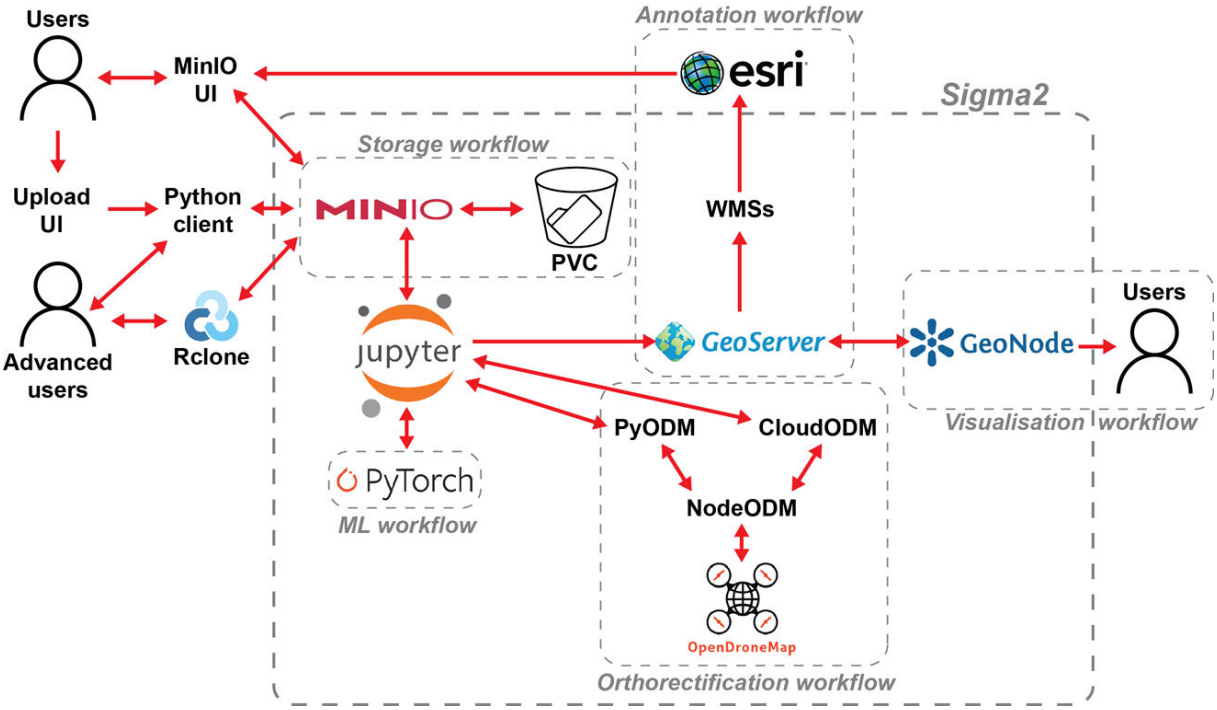


Figure 2. The SeaBee end-to-end data processing pipeline were further developed in 2023 and deployed on Sigma2's NIRD platform.

The first major stress-test of the SeaBee platform came in May 2023, when it was used to support NINA's annual seabird surveys. Over a period of two weeks, the SeaBee pipeline processed data from more than 400 drone missions, with pilots uploading raw images directly from the field and using the orthomosaics published soon afterwards on GeoNode to check data quality and adjust flight settings. These missions generated more than 15 TB of data and were the first large-scale demonstration of SeaBee performing as national research infrastructure handling geospatial drone data. We estimate that without the use of the SeaBee infrastructure, processing NINA's bird survey data would have required three to four months of full-time work using regular desktop data analysis.

As of February 2024, the SeaBee platform stores around 30 TB of data from more than 720 missions. This brings the total area surveyed by SeaBee drones and processed by the platform to 144 km2 (97 km2 for habitat classification and 47 km2 for seabird surveys).

During spring 2024, it is anticipated that the SeaBee platform will help NINA to undertake an even more extensive seabird survey that is expected to generate 2 to 3 times the data volume acquired in 2023. To accomplish this, we are working to improve the scalability of the processing pipeline, in close collaboration with Sigma2 staff.

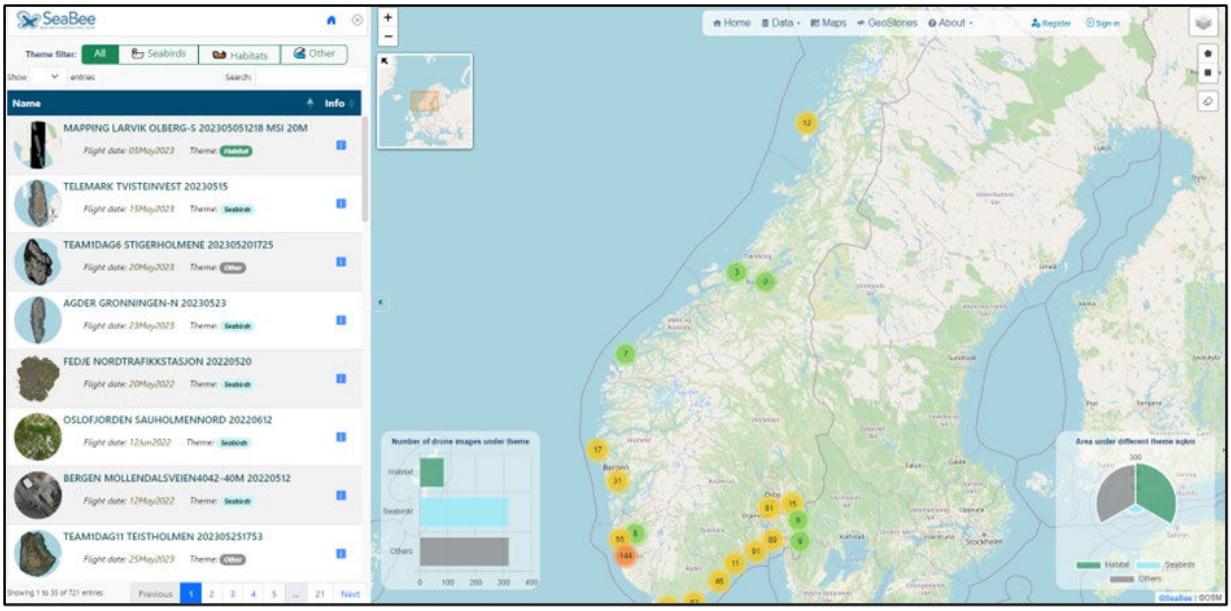


Figure 3. Screen dump of the SeaBee GeoNode interface where SeaBee missions and drone data products can be explored. All SeaBee data are open access and freely available for research and other stakeholders through the platform. At https://geonode.seabee.sigma2.no/.

4.4 Data analysis

In 2023, we focused the work around SeaBee's data AI/ML analysis on the following activities:

- Extended the detection pipeline to support multiple tasks, for instance for seabirds this included species, age, activity, and sex.
- Improved the segmentation pipeline to support annotations in different levels of granularity following a hieratical structure and by including a test for out-of-distribution samples.
- Advanced the process of the data analysis pipelines from 'development' stage to 'implementation' stage on Sigma2 data platform.
- Performed large-scale image analysis for seabird counting following NINA's seabird surveys mentioned above. Object identification applications tuned for performance analysis were completed and weaknesses were identified, which will be improved during 2024.
- Applied the segmentation pipeline to perform pixel-based classification of coastal habitats. A data set from north of the island Vega (Nordland) was collected as part of the KELPMAP project (funded by Norwegian Environment Agency) were used as test case (Figure 4).

The operational status for the data analysis component in the SeaBee pipeline, is that two generic modules for object detection and pixel-classification, respectively are implemented on Sigma2. During 2023, initial tests and a few iterations were complete for both of the modules. Next steps will be completed during 2024 and will include:

- Improve the pipeline quality for the seabird detection application, particularly the multi-task part, to make the data analysis useful for seabird counting, monitoring and registration purposes. In close collaboration with NINA.
- Test and evaluate the detection pipeline for detection and identification of marine mammals (in particular seals). In close collaboration with IMR.
- Utilize the hierarchical structure of the benthic habitat annotations to obtain more consistent classification across multiple taxonomy levels for nature type identification and

mapping (simultaneously use all annotated data to train the model). In close collaboration with NIVA.

- Transform the annotations of all previously collected drone data (incl. Ølbergholmen in 2021 and Frisk-Oslofjord 2020) to the same class structures and implement support for annotation files from several surveys.
- Implement support for hyperspectral data.

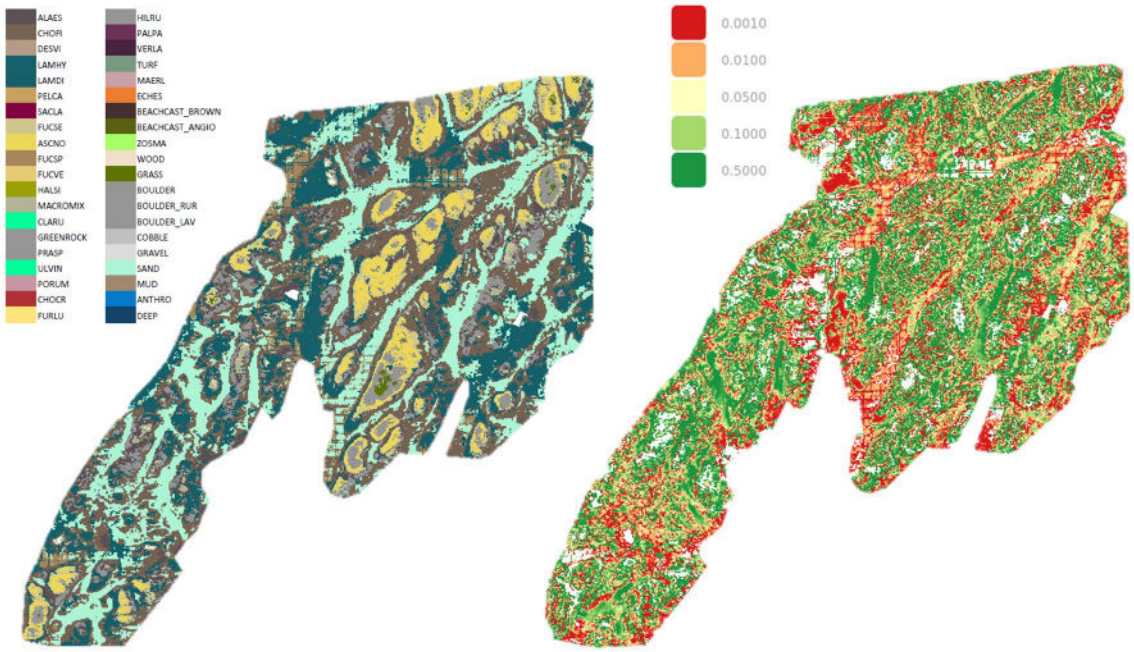


Figure 4. Example of classification map of the finest granularity (left) and corresponding confidence map (right) obtained from the drone data collected in the KELPMAP project.

4.5 Drone data validation and groundwork

In 2023, the SeaBee data validation teams collected ground truth data in the field for the four specific SeaBee applications at several locations. Some campaigns were funded as part of the SeaBee project and others by associated projects using the SeaBee infrastructure.

4.5.1 Benthic habitats

Field campaigns for benthic habitats were completed to map kelp forests north of the island Vega in Nordland (KELPMAP, NEA), to map the seaweed *Ascophyllum nodosum* (grisetang) for commercial harvest on the coast of Finnmark (ASCOMAP, RFF) and to map nature types in connection with the environmental monitoring program of the inner Oslofjord in the inner Oslofjord (IO23, Fagrådet for Indre Oslofjord). Furthermore, a time series of drone images were collected monthly between March and November at Ølbergholmen, outside Larvik. Here, the focus has been on eelgrass habitat (ZosMap, SeaBee). During each visit to Ølbergholmen, we followed the same flight route at three different elevations: 20 m, 60 m, and 100 m. In June and September, we also included a flight of 40 m altitude. During all flights, both multispectral imaging (MSI) and RGB images were collected. A RGB orthomosaic created from ~500 RGB images is shown in Figure 5. In June and September, the drone image collection was combined with collection of ground truth data of eelgrass and other habitat types in the area, through manual observations and snorkeling, as well as an uncrewed surface vehicle (USV, Otter, Maritime Robotics, Norway). The USV collected sonar data for bathymetry and habitat classification (Figure 6), underwater video/photo and surface water concentrations of chlorophyll, organic matter, and inorganic particles, temperature, and salinity data.

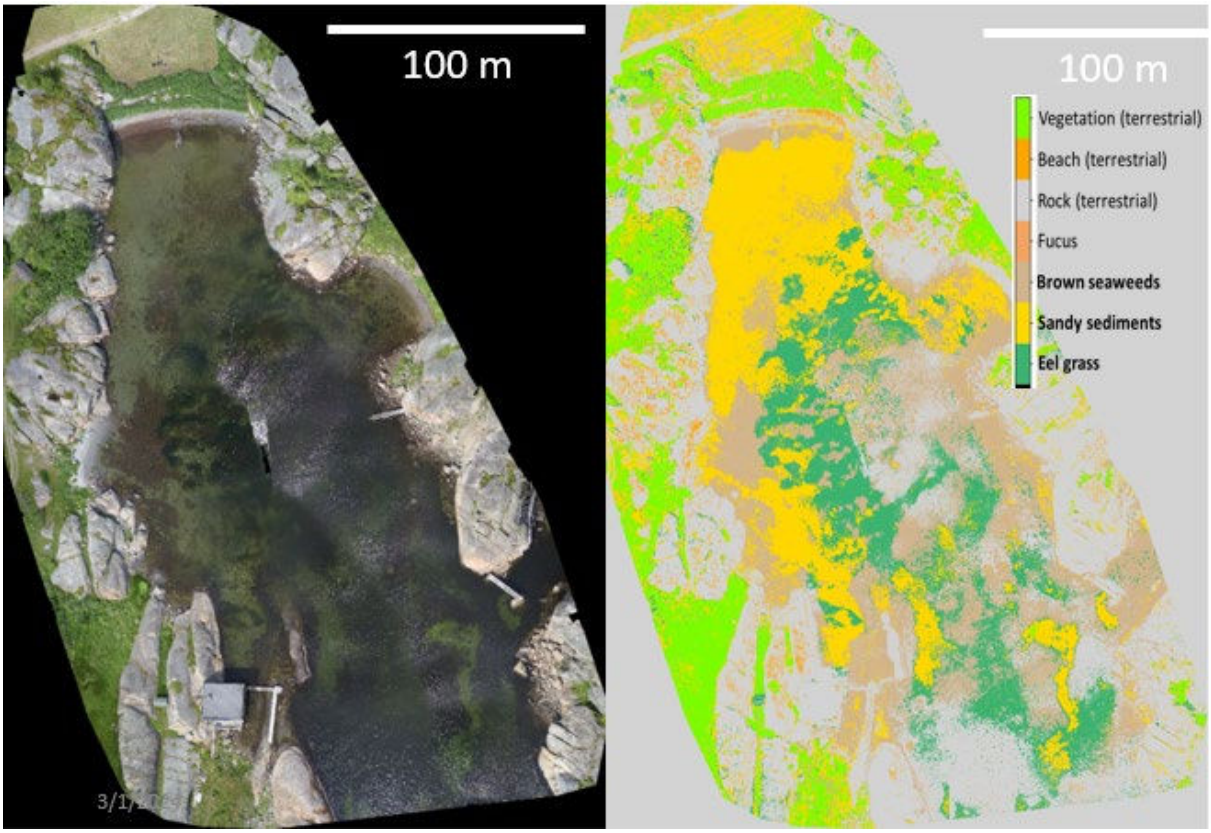


Figure 5. Drone generated RGB-based orthomosaic and habitat classification of the field site near Ølbergholmen outside Larvik. At this site, a large part of SeaBee's drones and sensors have been tested and methods have been developed. The image to the left is an orthomosaic from ~500 RGB images, while the image to the right shows a habitat classification map.

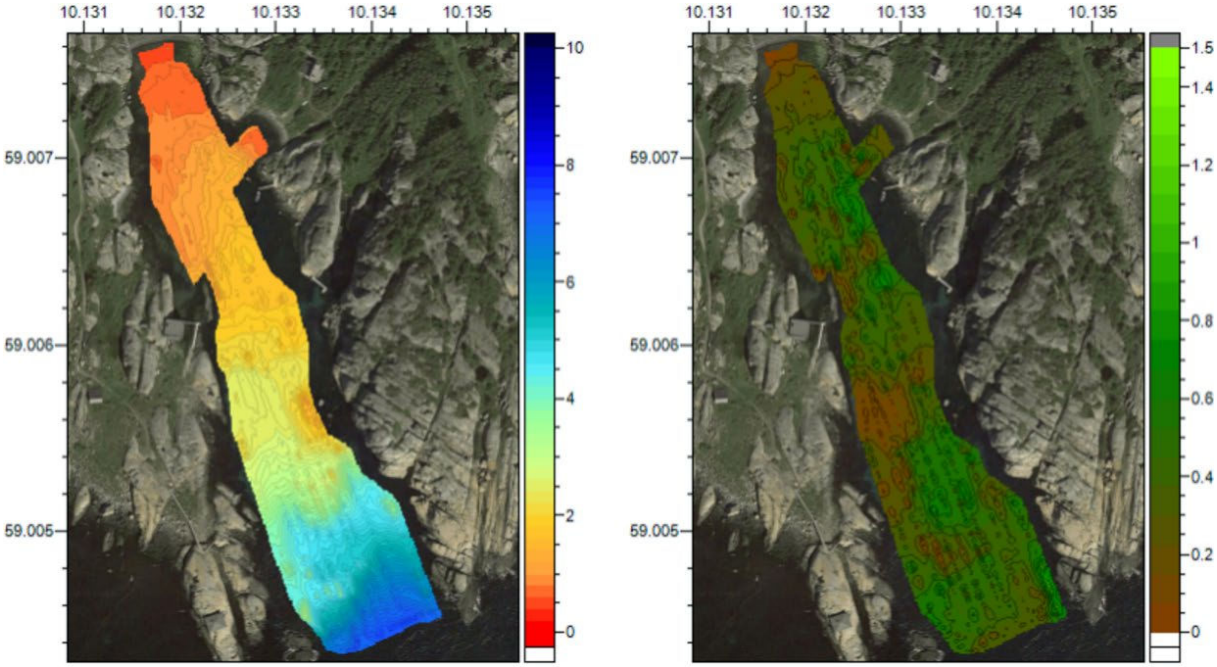


Figure 6. Example of data collected from an acoustic sensor onboard an uncrewed surface vehicle (USV, Otter from Maritime Robotics, Norway), at Ølbergholmen, Larvik, September 2023. Left: Bathymetry [m]. Right: Plant canopy height above bottom [meters above seabed]. Map units: Decimal degrees.

The collected ground truth data were used to train and validate drone products like habitat classification maps. Furthermore, data are used to develop applications for measuring seagrass coverage and distribution, plant biomass, carbon content, and health status using flying and surface drones, which is the focus of two master student projects to be completed in May 2024. The time series consisting of monthly drone images and habitat maps will provide valuable insights into how coastal habitats and species in the littoral and sublittoral zones change throughout the seasons. Pictures from the fieldwork and ground data collection is shown in Figure 7.

Figure 7. Photos from eelgrass data collection during field work outside Larvik in June 2023.

In October 2023, we used SeaBee surface and underwater drones with Underwater Hyperspectral Imagers inside and outside Hopavågen (South of Trondheimsfjorden outlet, depth range 0-5 m), to identify and map biogeochemical objects of interest (OOI) for ground truthing in the field, and to provide *in vivo* spectral reflectance per image pixel of different species of invertebrates, algae, and sediments (Figure 8). We also measured spectral reflectance of selected organisms in the lab, to provide a spectral reflectance database of biogeochemical OOI for supervised classification purposes. This approach is now part of the NTNU MSc/PhD course *Enabling technology for marine science*. Several students in the course collected specimens for further measurements in the lab. The same approach was used in January and February 2024 using aerial drones, surface drones, and hand picking/snorkeling to provide a spectral database and identification overview of OOI´s in different habitats. MSc, PhD candidates and post docs at NTNU are involved in this work.

Figure 8. The SeaBee USV-UHI during mapping in Hopavågen in October 2023. Photo: Geir Johnsen.

4.5.2 Seabird identification

As described under *Data handling and visualization*, SeaBee drones (DJI MAVIC 3 equipped with a RGB camera) were used in NINA's annual seabird survey in May 2023, amounting to 440 drone missions, around 100 000 images, and 47 km^2 of surveyed area in two weeks (Figure 9). The goal of the survey was to count seabirds in colonies, mostly focusing on open-nesting species, like gulls and cormorants (Figure 10). Using drones allowed large-scale, non-intrusive bird counts with a higher degree of accuracy and repeatability than using traditional methods. NINA's field campaign was the first large-scale test of SeaBee's data handling infrastructure, with drone images uploading directly to the SeaBee data server directly from the field, at the end of each day. This not only saved time in the field but allowed for more efficient mapping and monitoring of large geographic areas with better data quality, and options for on-the-go adjustments of drome data sampling protocols and methods.

Figure 9. Map of missions flown to quantify colonies of breeding seabirds. Fieldwork by two teams at NINA during June 2023.

4.5.3 Marine mammal identification

The regular monitoring of coastal seals (harbour and grey seals) along the Norwegian coast was continued in 2023, with the collection of drone-based images of known seal haul-out sites. Fieldwork for harbour seals was carried out in Aug-Sep 2023 during the annual moult, while fieldwork for grey seals was carried out in Oct-Nov 2023 during the annual breeding season. The images will be incorporated into the SeaBee data pipeline in the same way as the seabird data (preliminary work has been initiated to accomplish this task). In addition, the automated seal detection system for ice-breeding seals (Figure 10), developed by NR in collaboration with IMR, was tested for the first time on aerial images collected in the Greenland Sea in March 2022. The system was validated against traditional manual seal counts and was shown to perform very well. While the initial project was not directly connected to SeaBee, the system is now being modified to allow detection and classification of coastal seals, for future implementation within the SeaBee infrastructure.

Figure 10. Three SeaBee use cases where object detection has been applied: harbor seals, lesser black-backed gull, and marine litter.

4.5.4 Ocean color

In May 2023, we evaluated the methods for detection ocean colour from images, using a controlled environment at NIVA's field research station. Both the MicaSense Altum PT multispectral and the Specim AFX10 hyperspectral cameras, mounted on a DJI Matrice 300 RTK and a DJI Matrice 600 Pro drone, respectively, were flown over an outdoor tank (50 m^3 volume, ca.5.5 m diameter) filled with seawater from the Oslo fjord (Figure 11). The water was manipulated to modify its optical properties through addition of phytoplankton cultures, lignin and kaolin, and water samples were analysed on a benchtop spectrophotometer as reference. We also collected multispectral and hyperspectral drone images from transects across the Oslo fjord outside the Solbergstrand field station, at matching times with the passing of a FerryBox system installed onboard the MS Colour Fantasy and Satellite (Sentinel 2-3, Landsat 8-9) observations. Water samples for chlorophyll a, and turbidity were collected simultaneously with the drone observations. The images were analysed by examining the correlation between reflectance measurements at relevant wavelengths with the corresponding discrete measurements of chlorophyll a, and turbidity.

Figure 11. A flying drone (DJI Matrice 600 Pro) with an onboard hyperspectral sensor (Specim AFX10) flown over a 50 m3 tank containing manipulated sea water (foreground) and the Oslo fjord (background) in May 2023. Photo by Sabine Marty.

4.6 Communications, dissemination, and impact

For SeaBee's CDI team, the main activities in 2023 were implementation of the Plan for Exploitation and Dissemination in main communication channels (website, social media, news). The deliverables D6.1, D6.2, D6.4 and D6.5, have been completed.

In 2023, the website was updated monthly (108 fixes during 2023) with a focus on improving performance, updating content to better match target audiences, and embedding the GeoNode visualization platform. The home page, "What We Do" and "News" were the most visited pages in 2023 (1357 views combined, Table 2), and we had 876 new users in 2023 from around the world (Figure 12).

In 2023, we established a LinkedIn page to complement the X social media channel and for reaching out to research professionals who are more commonly on LinkedIn (Twitter became X in 2023 which has changed the channel dramatically, therefore focus was placed on LinkedIn). It has received a good level of engagement (Table 2, Figure 13). The SeaBee YouTube channel was also updated. 14 short, teaser videos were added covering Infrastructure highlights (from WP leads) and drone footage, which were also shared on X and LinkedIn.

Table 2. Metrics from SeaBee communication channels for 2023 (website and social media channels)

Channel	Visitors, users, followers	Posts, views	Impressions, sessions, plays	Comment
Website	876 new users in 2023 (893 total)	4793 views of website (all pages) 12 news, 2 press releases posted, and updates on applications, equipment and publications	1403 sessions (806 engaged sessions – group of user interactions on website)	Google Analytics was updated in April 2023, so data from May onwards is presented differently. Total users cover new and returning users.
X / Twitter	314 followers (up 20 from 2022)	72 posts	11200 impressions	Twitter became X in 2023, which impacted the reach as target groups are not as well represented on this channel anymore.
LinkedIn	141 followers (up 141 from 2022)	27 posts, 338 profile views	6348 impressions	Began in February of 2023, and has seen promising growth and activity throughout the year
YouTube	20 subscribers (up 6 from 2022)	14 new videos, 9193 views of all videos	621 plays	There are 20 videos in total, most viewed are 'What we do and how it works' (added 2022, 578 views) and 'The Complete Package' (added 2023, 221 views)

Twelve news items were prepared and published on the website, highlights focused on progress of the data storage and analysis platform, use of SeaBee infrastructure in Applications, and in-depth information on pilots, technology, and machine learning used in SeaBee.

Relevant links:
https://seabee.no/
https://geonode.seabee.sigma2.no/droneViz/
https://twitter.com/SeaBeeNorway
https://www.youtube.com/@seabeeresearchinfrastructu4578/videos
https://www.linkedin.com/company/seabee-research/

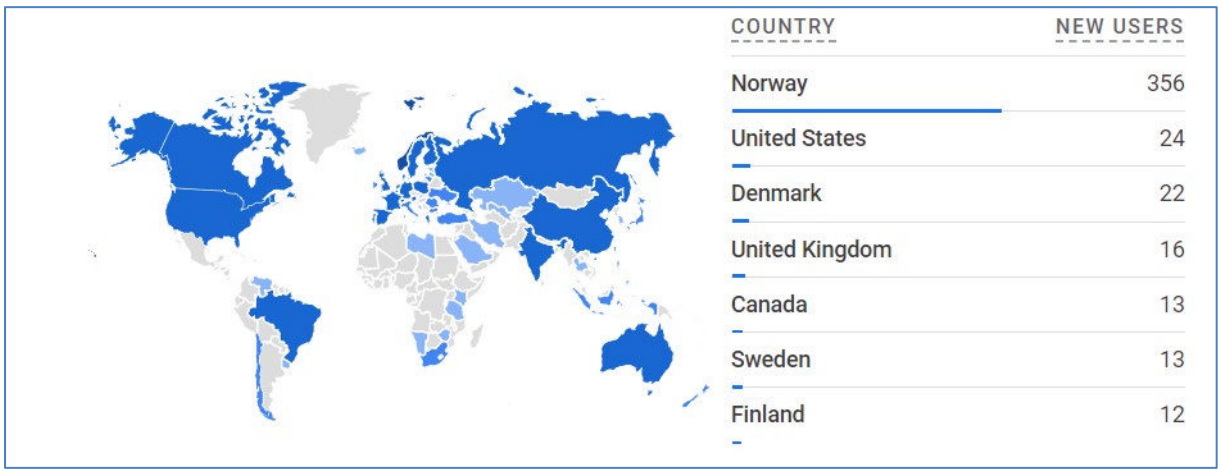


Figure 12. Screenshot from the SeaBee website analytics (www.seabee.no) showing new users (600 of 876) by country from May to December 2023. (January to April was not available in this format due to Analytics updates).

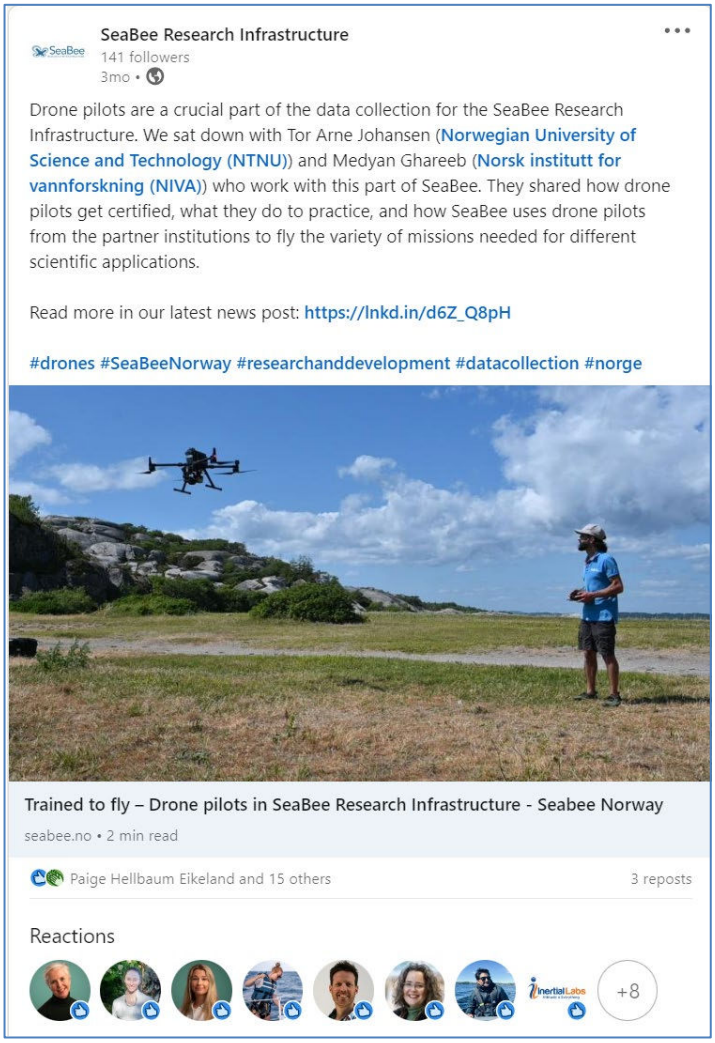


Figure 13. Screenshot of engaging LinkedIn post in November 2023, sharing a news item about SeaBee drone pilots, which created 548 impressions, 16 reactions and 12 link clicks.

4.6.1 SeaBee Impact

In 2023, we defined the intrinsic value and potential external impacts of SeaBee for the target audiences (research and management groups). This work sets the stage for documenting and measuring the extent of SeaBee impact on our target audiences and wider society. In 2024, two working groups will be established to document and measure the intrinsic value and impact of the infrastructure.

5 Project management

The SeaBee management group at NIVA has remained intact through 2023 and consists of Kasper Hancke (lead), Hege Gundersen (co-lead), Liv Lang-Ree (project support) and Karoline Slettebø (economy). In total, the SeaBee team engages around 40 researchers, engineers, data scientists, drone pilots, and project support members, employed at the six partner institutions and two industry partners. In addition, several MSc and PhD students and post docs are involved in SeaBee.

Throughout 2023, the SeaBee management group has focused on securing an efficient, transparent, and inclusive project management, for both the research- and industry partners. Core activities have been to provide well-organized information to project partners, facilitating good communication between work packages, oversee project results and communications, and securing a high quality of SeaBee deliverables. Monthly meetings within the SeaBee steering committee has facilitated efficient collaboration. Dedicated meetings with work package leaders and team members has provided an arena to deliberate on project plans, track progress, and address challenges that arise. The SeaBee annual meeting in Bergen, 25-27. October 2023 created an inclusive environment for the entire SeaBee team to meet and present results and ideas from the previous year and discuss future plans and possibilities. SeaBee's scientific advisory board participated in the annual meeting and delivered well-structured feedback on the project's progress and achievements, along with a list of constructive suggestions for future progress. On 15. November, a proposal was submitted to the Research Council of Norway's call for Research Infrastructures for a further continuation and further development of the infrastructure from 2025 to 2030, named SeaBee2.

During 2023, SeaBee has actively collaborated with and contributed to several research projects, environmental monitoring programs, and industry projects. These include providing drones, sensors, and other equipment, sharing data, and offering expertise and solutions related to SeaBee outcomes. In more detail, SeaBee is closely involved in two Horizon EU research projects, at least two national R&D projects, several R&D and monitoring programs by the Norwegian Environment Agency (NEA), and an industry-lead R&D project on sustainable use of marine resources. In total, SeaBee has contributed a value of at least 2,671 kNOK to national and international research and development projects. Table 3 provides a list of core collaboration projects, however minor contributions to research projects, student projects and teaching etc. is not included.

Table 3. List of projects that SeaBee collaborates with and contributes with equipment, data, know-how or other services to in 2023.

Name of project	Source	SeaBee's approximate part of budget (kNOK)
International research projects		
OBAMA-NEXT	HEU	658
NAUTILUS	HEU	N/A
National research projects		
MASSIMAL	RCN	129
SABICAS	RCN	45
National R&D projects		
KELPMAP	NEA	662
National monitoring programs		
IO2023	Fagrådet Indre Oslofjord	100
NINA seabird monitoring	NEA	800
Industry		
ASCOMAP	RFF and Polar Algae	277
SUM		**2,671**

6 SeaBee publications

The list below presents publications reported to Cristin for the period from 1. March 2023 to 29. February 2024. Downloaded 29.02.2024. Table 4 presents an overview of publications related to SeaBee reported in Cristin.

Table 4. List of all publications and results associated with the SeaBee infrastructure (RCN ID #296478, Cristin project ID #2572443), per year and type of publication. Data downloaded from the Cristin database per 29. February 2024.

Publication type	2017	2018	2019	2020	2021	2022	2023	2024	Total
PhD thesis							1		1
Master theses				1		6	1		8
Peer reviewed publications						2	3		5
Scientific reports				1	1	2	2		6
Scientific talks and posters	2	2	6	10	13	10	25	6	74
Popular science articles and briefs		4		1				1	6
Interviews	2	1	6	11	3	6	2		31
Webpages			2	2			2		6
Software							5		5
Total	**4**	**7**	**14**	**26**	**17**	**26**	**39**	**7**	**142**

PhD and MSc theses

Løvås HS. 2023. Optical techniques for hyperspectral imaging of the seafloor. Doctoral thesis, NTNU, 2023:267.

Woldstad TJ. 2023. Self-organizing maps for fusion of spectral images. Master thesis, NTNU, 72 pp.

Scientific peer-reviewed publications

Løvås HS, Hasler OK, Langer DD, Sørensen AJ. 2023. Coregistration of hyperspectral imagery with photogrammetry for shallow-water mapping. IEEE Transactions on Geoscience and Remote Sensing 2023 (0196-2892) Vol. 61.

Williamson DR, Moreira FG, Majaneva SK, Dallolio A, Halvorsen DØ, Hasler OK, Oudijk AE, Langer DD, Johansen TA, Johnsen G, et al. 2023. Monitoring algal blooms with complementary sensors on multiple spatial and temporal scales. Oceanography 2023: 1042-8275. Vol. 36.

Li Y, Xie L, Gundersen H, Ge Z, Hancke K. 2023. Quantifying seaweed and seagrass beach deposits using high-resolution UAV imagery. Journal of Environmental Management 331. doi.org/10.1016/j.jenvman.2022.117171

Scientific reports

Albretsen J, Arneberg P, […], Gundersen H, Hancke K, et al. 2023. Status of the environment in Norwegian marine areas. Report from the Advisory Group on Monitoring 2023. 172 pp. (In Norwegian with English summary)

Salberg A-B, Liu IY, Gundersen H, Hancke K. 2023. Mapping kelp forests using multi-spectral drone images and convolutional meural networks. Norwegian Computing Center report note BAMJO/12/23. 27 pp.

Scientific talks and posters

Gundersen H, Hancke K. 2024. Seagrass mapping using drones and machine learning - distribution and ecological status. Presentation at OBAMA-NEXT annual meeting in Delft, 05-07.02.2024.

Hancke K, Gundersen H, Azhar M, Stæhr P. 2024. Remote sensing methods for benthic mapping and monitoring. OBAMA-NEXT workshop on RS methods. OBAMA-NEXT annual meeting, Delft, 08.02.2024.

Gundersen H, Hancke K. 2024. Coastal vegetation mapping - upscaled from drones to satellites. Presentation at OBAMA-NEXT annual meeting in Delft, 05-07.02.2024.

Gundersen H, Hancke K. 2024. Collection of ground-truth data and image annotation. OBAMA-NEXT workshop on RS methods. OBAMA-NEXT annual meeting, Delft, 08.02.2024.

Gundersen H, Molværsmyr S, Hancke K. 2023. Population estimates of seabirds based on drone images and object recognition. Presentation for the OBAMA-NEXT Practitioners Advisory Board, 23.10.2023. Online meeting.

Hancke K. 2023. Havets opptak av CO2 gjennom blå skog og taredyrking; muligheter og utfordringer. Invited talk at "Den store karbonløsningsdagen", Bjerknes Center, University of Bergen. 23.08.2023.

Van der Zande D, Borja A, Gundersen H, Creach V, Lavigne H, Massant J, Azhar M, Stæhr PAU, Hancke K, Carstensen J. 2023. Observing and mapping marine ecosystems - next generation tools. Improving the efficiency of observation technologies to monitor the marine ecosystems and their biodiversity. Presentation at EC-ESA Earth System Science Initiative Joint Workshop, Rome, Italy, 23.11.2023.

Hancke K, Gundersen H. 2023. Quantification of habitat carbon sequestration. Presentation for the OBAMA-NEXT Practitioners Advisory Board, 23.10.2023. Online meeting.

Gundersen H, Hancke K. 2023. Available data at OBAMA-NEXT Learning Site 3 at Møre Coast. Presentation at the HEU project OBAMA-NEXT kick-off in Mallorca. 26.01.2023.

Hancke K, Gundersen H. 2023. Drones for mapping benthic habitats and the SeaBee infrastructure. Presentation at the HEU project OBAMA-NEXT kick-off in Mallorca. 25.01.2023.

Gundersen H, Viitasalo M. 2023. OBAMA-NEXT WP3: Assessing existing and new data sources for benthic habitats. Presentation at the HEU project OBAMA-NEXT kick-off in Mallorca. 24.01.2023.

Hancke K, Hagen AG, Johansen TA, Garrett J, Salberg A-B, Kalbekken K, Sample JE, Kvile KØ, Bekkby T, Little L, Poulsen RN, Ghareeb M, Buls T, Ødegaard ØT, Gundersen H. 2023. Drones for mapping benthic habitats and the SeaBee infrastructure. Oral presentation at the GeoHab conference, Saint-Gilles-Les-Bains, La Réunion Island, 10.05.2023

Salberg A-B, Liu I, Jensen A, Reksten JH, Garrett J, Sample J, Gundersen H, Hancke K. 2023. SeaBee - Norwegian infrastructure for drone-based research, mapping, and monitoring in the coastal zone. Oral presentation at the Norwegian Artificial Intelligence Research Consortium (NORA) annual conference, Tromsø, 5-6. June 2023.

Skjelvareid M, Blix K, Rinde E, Hancke K, Hoarau GG. 2023. Shallow water habitat mapping using UAV hyperspectral imaging. 13th International Temperate Reefs Symposium, 08.01.2023-12.01.2023.

Skjelvareid M, Blix K, Hoarau GG, Rinde E, Hancke K. 2023. Mapping seagrass and rockweed habitats using UAV hyperspectral imaging and machine learning. GeoHab 2023, 08.05.2023-12.05.2023.

Popular science, briefs, and other outreach

Gundersen H. 2024. Marin kartlegging og restaurering: globalt rammeverk, lokal handling. NBFN frokostseminar: Topp trender for blå skog i 2023. Hotel Bristol, Oslo. 14.02.2024.

Jacobsen K-O, Molværsmyr S. 2024. Mapping of breeding seabird populations with drone. SEAPOP workshop, 22.01.2024-23.01.2024.

Molværsmyr S. 2023. Landsdekkende hekkekartlegging av sjøfugler med drone. Havvind- og miljøseminar 2023-11-01. NINA

Skjellum SF, Seifert I, Gundersen H, Nesheim I. 2022. Naturbaserte løsninger. Presentasjon på NORAD avdelingsmøte, Oslo, 24.08.2022

Molværsmyr S. 2023. Ny teknologi i overvåkning av sjøfugl. IT-Forum; 2023-03-22. NINA

Ghareeb M, Gundersen H, Hancke K. 2023. The SeaBee project and mapping of the coast and aquatic environments with uncrewed aerial vehicles. Presentation at Tekna Fagtreff seminar on sensors for monitoring of water quality. Røverstaden, Oslo, 13.11.2023

Berg PR, Gundersen H, Hancke K. 2023. The SeaBee infrastructure for mapping and monitoring coastal habitats. Presentation for Indian and Norwegian stakeholders (Mdir, IMR, NCCR, Norwegian Embassy, Indian government). Bangaram, Lakshadweep, India. 17.02.2023.

Berg PR, Gundersen H, Hancke K. 2023. Seagrass restoration and the SeaBee drone infrastructure. Meeting with the INECO project, National Centre for Coastal Research (NCCR), Chenai, India. 28.11.2023.

Gundersen H. 2023. Kartlegging, overvåking og restaurering av Blå skog i 2022. Presentasjon på frokostseminar «Blå skog topp 10 trender fra 2022», arrangert av NBFN. Hotel Bristol, Oslo 01.02.2023

Thrane J-E. 2023. NIVA is frontrunner in the tech race - Modern and innovative methods for environmental monitoring, NIVA institute seminar at Holmenkollen, Oslo, 27-28.03.2023

Harvey T, Marty S, Sørensen K, Hancke K, Gundersen H. 2023. Drone and satellite activities for water applications at NIVA. Invited presentation for Faggruppe Satellittdata, Helsfyr, 24.03.2023.

Ødegaard ØT, Frigstad H. 2023. Verktøy for overvåking - fra elv til hav. Foredrag på jubileumsarrangementet "NIVA Sør 40 år", Grimstad, 27.04.2023.

Gundersen H, Kvanneid AJ. 2023. Kystsonen i Agder - verdier og vern. Foredrag på jubileumsarrangementet "NIVA Sør 40 år", Grimstad, 27.04.2023.

Hagen AG. 2023. Drones for mapping and monitoring benthic communities. Talk at AZTI summer school 2023 on Innovative and practical tools for monitoring and assessing multiple human pressures affecting biodiversity in marine systems. Aquarium of San Sebastian, Spain, 5-7. June 2023.

Kalbekken K, Hancke K, Gundersen H. 2023. SeaBee - Bruk av droner for miljøovervåking og kartlegging i kystsonen. NIVAs miljøovervåkingsdag 23.05.2023.

Gundersen H, Poulsen RN, Buls T, Christie H, Ghareeb M, Salberg A-B, Slettebø K, Hancke K. Mapping kelp forests using flying drones and machine learning: A case study from Norway. Oral presentation at the GeoHab conference, Saint-Gilles-Les-Bains, La Réunion Island, 09.05.2023

Haugland BT, Haugan P, Duinker A, Fagerli CW, Haldorsen ST, Little L, Lutz S, Gundersen H, Borgersen G, Slotsvik GN. 2024. Top ten trends from 2023. Norwegian Blue Forests Network (NBFN) report. Launched at www.nbfn.no 14.02.2024.

Sample JE, Leirvik KN, Bhakta D. 2023. Technical documentation for the SeaBee data platform.

Sample JE, Molværsmyr S. Drones to the rescue (Sigma2 news article about the SeaBee national infrastructure project).

Products (code, software, websites etc.)

Sample JE, Leirvik KN. 2023. seabeepy: a Python package to support SeaBee workflows.

Sample JE, Leirvik KN, Bhakta D, Molværsmyr S, Salberg A-B, Reksten JH. 2023. The SeaBee GitHub Organisation: code infrastructure for the SeaBee project.

Leirvik KN, Bhakta D, Sample JE. 2023. SeaBee's GeoNode data portal: a website for exploring and visualising SeaBee data products.

Bhakta D, Leirvik KN, Sample JE. 2023. SeaBee's geovisualisation website: an interactive map application for exploring SeaBee missions and data.

Løvås HS. 2024. gref-hsi: An open-source Python codebase for georeferencing pushbroom hyperspectral imagery. Available online: https://github.com/havardlovas/gref-hsi

Interviews

Wikøren PE. 2023. NINA med landsdekkende sjøfuglkartlegging. Dronetelling er skånsomt. Intervjue av Sindre Molværsmyr i www.uasnorway.no, 30.03.2023.

Sample, J. 2023. SeaBee: Machine learning in the coastal zone. Oral talk at Arendalsuka, Grid-Arendal arrangement "AI to address climate change, biodiversity loss, and pollution". Arendal, 15.08.2023.

NIVA
Norsk institutt for vannforskning

NINA
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Kunnskap for en bedre verden

NR Norsk Regnesentral
NORWEGIAN COMPUTING CENTER

HAVFORSKNINGS INSTITUTTET

GRID ARENDAL
A UNEP Partner

TIEPOINT

SPECTRO FLY