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SEABEE'S DRONE AND SENSOR INFRASTRUCTURE

Norwegian Infrastructure for Drone-Based Research, Mapping and Monitoring in the Coastal Zone

Report

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Abstract
SeaBee is the Norwegian Infrastructure for drone-based research, mapping, and monitoring in the coastal zone. The infrastructure uses three main types of drones: aerial, water surface, and underwater drones. These drones act as platforms for various sensors such as RGB cameras, multispectral, hyperspectral, LiDAR systems, single-beam echosounders, submersible fluorometers, and sensors that measure conductivity. Together, they serve distinct purposes. In addition to the drones, SeaBee also has handheld sensors such as spectroradiometers, infrared cameras, and GNSS sensors that help verify the data collected by drones. The equipment is stored in operational nodes referred to as drone garages, in Oslo and Trondheim. These nodes are also used as facilities to train drone pilots, payload operators, and maintain and calibrate equipment.

Keywords: Drones, Hardware, UAV, UUV, USV, RGB, MSI, HSI, LiDAR
Emneord: Droner, Utstyr, UAV, UUV, USV, RGB, MSI, HSI, LiDAR

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Foreword

This report describes the development and current status of the hardware part of the SeaBee research infrastructure project over the past five years, a national research infrastructure dedicated to drone-based research, mapping, and monitoring in the coastal zone. SeaBee is led by the Norwegian Institute for Water Research (NIVA) in collaboration with the following partners: the Norwegian University of Science and Technology (NTNU), the Norwegian Institute for Nature Research (NINA), the Norwegian Computing Center (NR), the Institute of Marine Research (IMR), and Grid Arendal. Additionally, SeaBee includes industry partners SpectroFly Aps and TiePoint AS.

SeaBee is funded by the Research Council of Norway from 2020 to 2025 (project ID#296478) and has developed an advanced drone and sensor infrastructure to support ecological and environmental research. As of July 1, 2025, SeaBee transitions to its operational phase, making its resources available to research, management, and commercial clients and stakeholders for a minimum period from 2025 to 2030, with aspirations for further extension.

This report gives an overview of the SeaBee hardware, detailing the various drones and sensors used, their applications, and the operational capabilities established. The infrastructure includes aerial drones, water surface drones, and underwater drones, each equipped with various sensors such as RGB cameras, multispectral (MSI)-, hyperspectral (HSI)- and, thermal sensors, LiDAR systems, as well as acoustic and ground-based sensors for environmental data collection. These technologies enable extensive environmental assessments and support a wide range of scientific studies.

SeaBee's operational nodes in Oslo and Trondheim, referred to as drone labs or garages, serve as hubs for storage, maintenance, calibration, and training. These facilities ensure skilled handling and precise operation of the equipment, supporting SeaBee's mission to provide high-resolution environmental data for informed decision-making.

We extend our gratitude to the Research Council of Norway for their support and to all our partners for their contributions to the successful establishment of this infrastructure. We look forward to the continued improvement of environmental research and monitoring through the innovative use of drone technology.

Oslo, 30th June 2025

Summary

SeaBee utilizes three main types of drones: aerial drones, water surface drones, and underwater drones. Each type serves distinct purposes in ecological and environmental research. Aerial drones are used for large-scale mapping and monitoring from above, sea surface drones operate on water to collect data on marine environments, and underwater drones explore below the surface to gather information on aquatic ecosystems. These aerial drones are equipped with various sensors, including RGB cameras for true-color imaging, multispectral (MSI) sensors for capturing data across multiple wavelengths, hyperspectral (HSI) sensors for detailed spectral analysis, and laser-emitting LiDAR sensors which provide topography and bathymetry data. Water surface drones are equipped with single-beam echosounders, submersible fluorometers, optical sensors and sensors that measure conductivity and temperature. Lastly the underwater drones have RGB sensors, and navigation and positioning sensors. In addition to the sensors carried by the drones, SeaBee also utilizes handheld sensors such as spectroradiometers, infrared cameras, and GNSS positioning sensors to support and validate drone data collection. The combination of different drone types and sensors allows for comprehensive environmental assessments and supports a wide range of scientific studies and applications.

SeaBee's drone infrastructure includes various Unoccupied Aerial Vehicles (UAVs) such as the DeltaQuad EVO, Mugin 2 Pro VTOL, and DJI Matrice models. VTOL drones like the DeltaQuad EVO and Mugin 2 Pro are designed for remote and constrained environments, eliminating the need for traditional runways. These drones can carry multiple sensors and have extended flight endurance. In addition to the aerial drones, the SeaBee utilizes water surface drones such as the Martime Robotics Otter, and underwater drones such as the Blueye and FIFISH.

SeaBee has established operational nodes in Oslo and Trondheim, referred to as drone garages. These facilities are used for storage, maintenance, and calibration of drones and sensors. They also serve as training centers for drone pilots and payload operators, ensuring skilled handling and precise operation of the equipment. In addition, SeaBee has hardware positioned at partner institutions in Bergen, Grimstad and Tromsø. Overall, SeaBee is fully operational in all of Norway and internationally as well. Being able to complete drone missions and data collection from Lindesnes to Grense Jakobselv, and from inshore freshwater to coastal waters.

Abbreviation	Meaning
ROV	Remotely Operated Vehicle
UAV	Unoccupied Aerial Vehicle
UUV	Unoccupied Underwater Vehicle
USV	Unoccupied Surface Vehicle
VTOL	Vertical Takeoff and Landing
RGB	Red, Green, Blue (true-color camera)
MSI	Multispectral Imaging sensors
HSI	Hyperspectral Imaging sensors
RTK	Real-Time Kinematic (Positioning)
GNSS	Global Navigation Satellite System
IR	Infrared
VLOS	Visual Line of Sight
BVLOS	Beyond Visual Line of Sight
CTOL	Conventional Takeoff and Landing
FTS	Flight Termination System
SORA	Specific Operations Risk Assessment

Introduction to the SeaBee hardware infrastructure

Drones are often referred to as unoccupied, uncrewed, or unmanned vehicles, and sometimes remotely operated vehicles (ROVs). We recommend using the gender-neutral terms unoccupied or uncrewed vehicles (UVs) in scientific and management context.

SeaBee uses unoccupied arial vehicles (UAVs) for aerial data collection, unoccupied surface vehicles (USVs) for sea surface data collection and unoccupied underwater vehicles (UUVs) for underwater data collection.

The sensors used on SeaBee’s UAVs include true-color Red, Green, Blue (RGB) cameras, multispectral imaging (MSI) sensors, hyperspectral imaging (HSI) sensors, and laser-emitting LiDAR sensors. RGB cameras capture images in red, green, and blue wavelengths, providing visual data that are developed to look like what the human eye sees. MSI sensors capture data across multiple wavelengths, allowing for the analysis of vegetation health and other environmental factors in more detail. HSI sensors provide even more detailed spectral information, enabling the identification of specific materials and conditions and creating full range “optical signatures” of objects in nature types of interest. LiDAR sensors use a high-frequency active emitting laser pulse to create detailed topographical and bathymetric maps, offering precise measurements of surface and underwater features. The imagery from these sensors is then uploaded to NIVA’s Geo-node data platform, where the images are stitched together to create maps ranging from tens of square meters to several square kilometers.

USVs within SeaBee’s infrastructure primarily use acoustic sensors such as single-beam echosounders for bathymetric measurements and underwater hyperspectral imaging sensors to identify aquatic organisms and substrates. Additionally, these platforms may be equipped with optical sensors for monitoring water quality parameters, such as turbidity, chlorophyll concentrations, and dissolved organic matter.

SeaBee’s UUVs feature high-resolution RGB cameras for detailed visual inspection and monitoring of underwater environments. These vehicles may also integrate additional instrumentation, such as temperature, conductivity, and navigational sensors, facilitating comprehensive ecological assessments beneath the water's surface.

Table 1 provides an overview of SeaBee's hardware inventory, including the types and quantities of drones and sensors, their carrying capacities, and operational range capabilities. This comprehensive inventory highlights the extensive resources available within the SeaBee infrastructure, supporting a wide range of environmental applications. Table 2 summarizes the strengths, weaknesses and the applications of various types of equipment used by SeaBee.

By utilizing a diverse fleet of drones and advanced sensor technologies, the SeaBee project aims to provide comprehensive environmental assessments and support ongoing scientific studies.

Table 1. SeaBee hardware inventory; an overview of quantum, carrying capacity and approximate operational range capacity.

Category	Units	(#)	Approx range (km)	Carrying capacity (kg)
Drones	VTOL drones	4	75 (with 2 sensors)	3
Drones	Large rotor UAVs	3	15 (with one sensor)	6
Drones	Medium rotor UAVs	6	5	4
Drones	Small rotor UAVs	>10	4	0 - 0,5
Drones	Medium USV	2	74	30
Drones	Small ROV	3	11 (tether range 0.25m)	
Drone sensors	RGB camera	>10		
Drone sensors	MSI imaging	>5		
Drone sensors	HSI imaging	2		
Drone sensors	Thermal	3		
Drone sensors	LiDAR	2		
Drone sensors	Acoustics	1		
Drone sensors	Optical in-water	4		
On-ground sensors	Handheld on-ground sensors	>10		
Organizational units	Drone garages	2		
	Geographical representation	5		
Pilots	UAV pilots	>11		
	USV & UUV pilots	>8		

Table 2. List of SeaBee equipment used for various data sampling applications and their usefulness.

Equipment Type	Application	Advantages	Disadvantages
Rotor Unoccupied Arial Vehicles (UAVs) (e.g., DJI MATRICE 350 RTK)	Detailed mapping of nature type (habitats), objects (animals and litter), water quality, and features above and below water	Adjustable flight speed/stand-still Slower speed allows higher spatial resolution in images Large payload capacity Low and high altitude Vertical take-off and landing	Limited areal coverage
Fixed-wing UAVs (e.g., DeltaQuad Evo VTOL)	Large scale mapping of nature types, objects and features	Energy efficient, larger aerial coverage Long distance	Smaller payload capacity Large landing zone (unless equipped with VTOL) Susceptible to wind direction Fixed flight speed Risk of smearing at low altitudes
Unoccupied Surface Vehicles (USVs) (e.g., Maritime Robotics Otter)	Environmental monitoring, e.g. water quality assessments (optical, physical, and chemical), nature type mapping, and underwater imaging	Operate on water surfaces Ideal for surface and immediate subsurface data collection Autonomous or remote operation Zero-emission options available	Limited by sea state Slower data collection compared to aerial vehicles Limited spatial coverage
Unoccupied Underwater Vehicles (UUVs) (e.g., Blueye X3)	Underwater exploration and monitoring, e.g. subsurface imaging and mapping	High maneuverability Can operate at significant depths	Complex operation and navigation high Limited battery life

	Optical, physical, and chemical measurements	Suitable for detailed underwater surveys	Data collection can be affected by water turbidity Lacks accurate positioning
Red, green, and blue (RGB) sensors (e.g., SONY RX1RM2 42MP)	Annotation and study site overview Simple habitat classification	True colors (optimized for the human eye) High pixel resolution	Low spectral resolution and low sensitivity for species and habitat recognition Not radiometrically correct (overlap between colors) Pixel values are represented with a digital number, not surface reflectance
Multispectral imagery (MSI) sensors (e.g., MicaSense Altum 5band)	Advanced/ detailed habitat mapping and classification Pixel-wise thematic mapping	Several images at specific wavelengths Radiometrically correct color sensing Enable comparison with spectral reflectance libraries	Less suitable for annotation due to false-color images, lower pixel resolution, increased complexity
Hyperspectral imagery (HSI) sensors (e.g., Specim AFX10)	Species detection, detailed habitat classification and identification	High spectral resolution Can reconstruct true-color images	Low light sensitivity Low pixel resolution Requires complex data handling and analyses Heavy weight Expensive
Green LiDAR (e.g., YellowScan Navigator)	Topo-bathymetric mapping of coastal environments Underwater vegetation mapping	Able to penetrate water Effective for mapping seabed and riverbeds Measures water column and submerged vegetation	Heavy weight Susceptible to water clarity Higher cost due to complex technology

			Less effective in turbid waters Expensive
Red LiDAR (e.g., YellowScan Explorer)	Topographic mapping Forest canopy assessment	Light weight Effective for terrestrial mapping Good penetration of forest canopies Widely used and well-developed technology	Cannot penetrate water, limited to land use, affected by atmospheric conditions like fog and dust
Handheld low-resolution GNSS (e.g., handheld Garmin Montana 700)	Ground-truthing	Inexpensive Pocket size Robust (water/splash proof) Immediate response time when taking a position	Low spatial accuracy (~2 m), i.e., ground-truth data can only be used as guidance
High precision GNSS (e.g., Leica GS18 T RTK Rover)	Ground-truthing	High spatial accuracy (< +/-2 cm) Programmable, ground-truth data can be used as annotation directly	Requires correction signals (RTK) Expensive Large size Not fully waterproof Sometimes long response time for taking positions (when low signal coverage/quality)

1. SeaBee Hardware Infrastructure

1.1 Aerial Platforms

There are three main types of flying drones that are used for coastal habitat classification, animal surveying and a range of other SeaBee relevant applications. These are fixed-wing drones, rotor drones, and vertical take-off and landing (VTOL) drones. The latter combines the benefits of the first two systems and uses rotors to lift a fixed-wing drone vertically for take-off and landing. These drone types serve somewhat different purposes, and their use depends on the scope of the campaign. Rotor drones are easily maneuvered, can fly at low speed, and stand still in the air. Fixed-wing drones on the other hand, are more energy efficient and typically have longer flight times. Therefore, they are often used for long- distance missions. However, most fixed-wing drones require a take-off and landing zone, which can be hard to find when working in the coastal zone and remote areas. VTOL drones combine the two, which particularly makes landing easier. Table 1 summarizes the applications, advantages and disadvantages of the different drones.

1.1.1. DeltaQuad EVO VTOL

Figure 1. DeltaQuad EVO VTOL. Photos: Kasper Hancke (left) and Anders Gjørwad Hagen (right).

1.1.1.1. About platform

The DeltaQuad EVO is a VTOL UAV that merges efficiency and extended range of fixed-wing aircraft with the adaptability of quad or multi-rotor drones. For SeaBee, this means that as our operational range and coverage expand, the takeoff and landing zones remain consistent. These zones are often compact and hard to access, especially during survey missions at remote coastal locations. The cumbersome launch and recovery gear typically required for conventional take-off and landing (CTOL) vehicles is challenging to transport, making VTOL drones a superior choice for such environments.

1.1.1.2. Applications

The DeltaQuad Evo features dual payload bays with a maximum payload capacity of 3 kg. It boasts a claimed range of up to 270 km and a flight time of 4.5 hours. With RTK tagging, it can carry dual payloads, doubling the data collection capability compared to typical rotor vehicles, regardless of range. This vehicle's range far exceeds that of SeaBee quadcopters, as its battery life (with dual sensors) is effectively four times longer. However, the DeltaQuad Evo is less flexible for smaller tasks due to its bulkier design and longer setup time. It requires a minimum turning radius of 100 meters, unlike the zero turning radius of quadcopters. This can lead to increased unwanted data collection during turns, especially on smaller, more complex maps. Additionally, fixed-wing and VTOL UAVs need to maintain higher speeds (over 15 meters per second) to achieve lift, which can be a drawback for sensors that require slower speeds, making quadcopters more suitable for such tasks

Table 3. Table showing SeaBee's DeltaQuad EVO VTOL Drone Inventory.

Count	Purchase Year	Platform name	Type	Subtype
2	2023	DELTAQUAD EVO VTOL DRONE Seabee	UAV - Unoccupied Aerial Vehicle	VTOL fixed wing

1.1.1.3. Performance of platform

Performance examples

- Maximum take of weight (MTOW): 10 Kg
- Maximum payload: 3 Kg.
- Nominal flight time: Claimed up to 4,5 hours. From field experience we are finding that it can fly for about 60 minutes with a dual payload, and 75 minutes with a single payload.

Flight statistics

- Number of Flights: 17
- Flight time: 05:00:29
- Range: 270 km
- Flight patterns

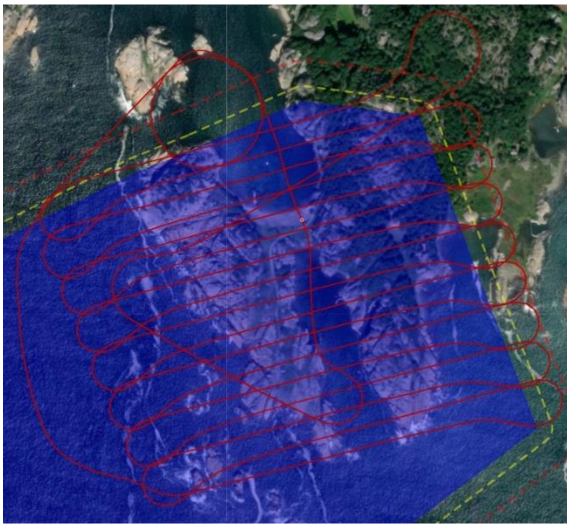

Figure 2. DeltaQuad EVO VTOL Flight Pattern Example. Photo: Medyan Ghareeb, Drone Logbook.

1.1.1.4. Sensor configurations and performance impacts

Table 4. DeltaQuad EVO VTOL sensor configurations, and typical maximum flight time for the various configurations.

Typical Mission	Sensor configuration	Flight time	Comment
RGB + MSI benthic habitat	Sony RGB & Altum PT	1.5 hrs	
IR + MSI	Wiris PRO & Altum PT	1.5 hrs+	RGB not possible
RGB	Sony RGB	2.0 hrs+	Dual battery
MSI	Altum PT	2.0 hrs+	Dual battery
MSI	MicaSense Rededge red/blue	2.0hrs	Approx. 30% less resolution than PT, 5 bands per camera
MSI (10 band)	MicaSense Rededge Red and Blue	1.5hrs	Approx. 30% less resolution than PT but dual band

1.1.1.5. Possible future upgrade

A performance upgrade would be to include the LiDAR YellowScan Mapper system for the DeltaQuad EVO, so far only red LiDAR systems are compact enough for the EVO. But following trends in technology we speculate that it will be possible in the future to equip green lidar systems compact enough to be carried by the DeltaQuad EVO.

Direct Geo Referencing (DG) is a new technology that promises to change the way we carry out mapping surveys. Rather than relying on multiple overlapping images to give cm precision data on our RGB and MSI maps DG, using highly sensitive INS sensors, can reduce the overlap required from 80% to less than 20%. This practically means much less data to process, up to a factor of 4.

The parachute system for the EVO is already specified but not certified. It is planned to use a system that was already tried and tested in the legacy 'map' platform by Drone Rescue systems. DeltaQuad are planning testing of this system with the EVO in 2025.

Flight Termination System (FTS): Independent system to cut the power to the aircraft in the event of an emergency (fly away for example). Drone rescue systems have supplied this to the DeltaQuad MAP.

Independent FTS and Parachute systems for the EVO and/or Tundra will allow the platform to operate in the CLASS 6 category under PDRA 01 and 02. This basically means missions over areas where an incident can result in collateral damage (population density of over 25 persons/km^2).

1.1.2. Mugin 2 Pro VTOL

Figure 3. Mugin 2 Pro VTOL. Photo: muginuav.com.

1.1.2.1. About platform

The Mugin 2 Pro VTOL excels in several areas. Its carbon fiber construction ensures durability and a reduced weight, making it robust yet agile. The platform can carry up to 6 kg of payload, accommodating a variety of sensors and equipment. Its VTOL capability adds to its versatility, enabling it to be deployed in diverse environments. Additionally, it offers impressive endurance, with flight times reaching up to 1.5 hours when using electric propulsion. Its main advantage over the DeltaQuad Evo is that it can hold a larger payload.

1.1.2.2. Applications

Within the context of the SeaBee infrastructure, the Mugin 2 Pro VTOL is particularly valuable for long-distance environmental monitoring. Its ability to cover extensive areas makes it ideal for monitoring coastal and marine environments. Equipped with advanced sensors, it can collect high-resolution data over large bodies of water, providing critical insights into marine ecosystems.

For instance, the UAV can be used to monitor water quality by deploying MSI and HSI sensors to detect pollutants and assess the coverage of aquatic vegetation. It can also be employed in mapping and tracing coastal and terrestrial wildlife, using RGB and thermal imaging sensors to observe and document animal behavior and population dynamics over time, e.g. birds and seal populations.

SeaBee partner NTNU, have monitored seals populations using the Mugin 2 Pro VTOL, where they have also used thermal sensors which have been useful not only in locating the seals but also in revealing their stress levels. Where stressed seals display higher temperatures around the nose and eyes.

Table 5. SeaBee's Mugin 2 Pro VTOL Inventory.

Count	Purchase Year	Platform name	Type	Subtype
2	2021	Mugin 2 Pro VTOL Seabee NTNU	UAV - Unoccupied Aerial Vehicle	VTOL fixed-wing

1.1.2.3. Performance of platform

- Performance examples
- Maximum take of weight (MTOW): 25 Kg
- Maximum Payload: 6 Kg
- Nominal flight time: 70 minutes with sensors.

Table 6. Sensor configuration and performance impacts on Mugin 2 Pro VTOL.

Typical Mission	Sensor configuration	Flight time	Comment
Mugin 2 001	Sony ILX-LR1 full format RGB kamera and FLIR Vue Pro thermal camera.	70 minutes.	This Mugin has been used to count seals in Tarva in 2022 and 2024 for IMR. Furthermore, it was used to count birds in Frohavet in the spring of 2024 with NIVA. Finally, it was used on the research vessel PIA in the fall of 2024 to count whales (IMR).
Mugin 2 002	Micasense RedEdge-P Dual Multispectral camera and NTNU's V4 Hyperspectral Camera	70 minutes.	It was flown in the fall of 2024 in Mausundsvær, and in Trondheimsfjord spring 2025, to test out the sensors effectiveness in detecting "ocean colour".

1.1.2.4. Possible future upgrades

There are plans to upgrade the Mugin 1 with a new thermal sensor to replace the FLIR camera. The replacement will be a user-friendly thermal camera, such as those produced by Workswell. The Mugin 2 currently has a Micasense RedEdge-P Dual multispectral sensor installed, along with the V4 hyperspectral camera developed by NTNU. This combination of sensors needs further testing before it is ready for operational use.

1.1.3. DJI Matrice 300/ 350

Figure 4. DJI Matrice 350. Photo: DJI.com.

1.1.3.1. About platform

The SeaBee DJI 3-series drones are the workhorses for collecting RGB and 5-band MSI data. With a payload capacity of up to 2.7 kg, they are typically loaded with approximately 1 kg payloads and used for missions covering less than 0.5 km². These platforms are highly flexible, capable of taking off and landing in tight spots or difficult areas and provide efficient coverage with minimal unneeded data from the area. While the drones can be equipped with dual payloads, RTK tagging is only available for one sensor at a time. Due to the post-processing demands of accurately GNSS tagging the secondary payload data, we prefer to fly with one payload at a time unless there is a very small window of opportunity for flight.

1.1.3.2. Applications

The SeaBee DJI Matrice 300 and 350 are used for MSI and RGB mapping of smaller regions. The main strengths of the DJI Matrice are its smaller size and shorter setup time compared to fixed-wing drones. It is ideal for mapping smaller areas. With a payload capacity of up to 2.7 kg, it is well-suited for MicaSense multispectral sensors and RGB sensors. However, it cannot accommodate heavier sensors such as the YellowScan LiDAR or the Specim AFX10 Hyperspectral sensor.

While it is possible to fly multiple sensors on a DJI Matrice 300/350, it currently cannot RTK tag data from both sensors simultaneously. This requires manual tagging after data collection, which is inefficient. Additionally, flying with two sensors significantly reduces flight time. These factors have led to the practice of flying one sensor at a time and using the DeltaQuad Evo for operations where two sensors are essential. For smaller operations, the Matrice 300/350, like other quadcopters, has a smaller turning radius compared to the 100m turning radius of the DeltaQuad Evo.

Table 7. SeaBee's DJI Matrice 300/350 Inventory.

Count	Purchase Year	Platform name	Type	Subtype
2	2023, 2024	DJI MATRICE M300 QUAD PPK UAV - Seabee	UAV - Unoccupied Aerial Vehicle	VTOL rotor quad
4	2023, 2024, 2025	NIVA DJI MATRICE M350 RTK QUAD PPK UAV - Seabee	UAV - Unoccupied Aerial Vehicle	VTOL rotor quad

1.1.3.3. Performance of platform

- Performance examples
- Maximum take of weight (MTOW): 9.2 Kg
- Maximum Payload: 2.7 Kg.
- Nominal flight time. 55 minutes no payload,
- Other specs
- Number of Flights: 199
- Flight time: 50:12:18
- Flight patterns

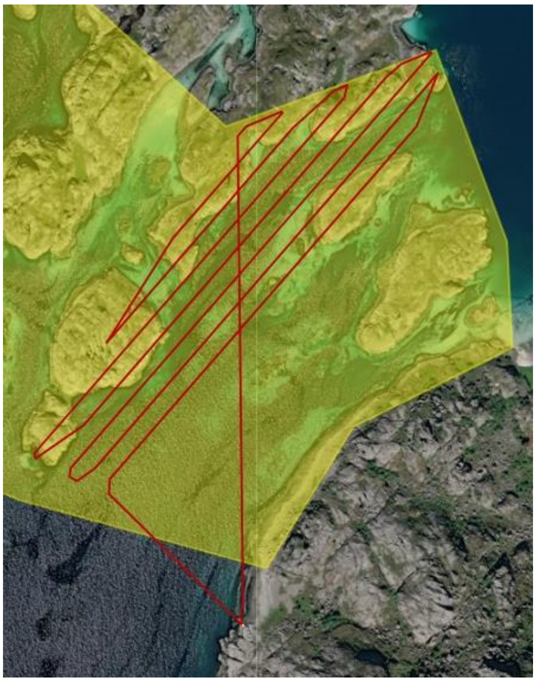

Figure 5. DJI Matrice 300 Flight Pattern Example. Photo: Medyan Ghareeb, Drone Logbook.

Table 8. Sensor configuration and performance impacts on DJI Matrice 300/350.

Typical Mission	Sensor configuration	Flight time	Comment
MSI	Altum PT, RedEdge, and RedEgde-P	30 minutes	From 100% to 20% battery life.
RGB	Zenmuse P1	30 minutes	From 100% to 20% battery life.
RGB + MSI	Zenmuse P1 + Altum PT	20 minutes	Only one of the sensors receive GNSS data. Faster to fly the drone twice with two different sensors.

1.1.3.4. Possible future upgrades

The main upgrades planned for the Matrice 300/350 include Flight Termination Systems (FTS) and parachutes. These enhancements will improve safety and provide greater flexibility in mission planning for Specific Operations Risk Assessments (SORAs). Direct Georeferencing will be considered if technology advances to meet our required accuracy standards.

1.1.4. DJI Matrice 600

Figure 6. DJI Matrice 600. Photo: DJI.com.

1.1.4.1. About platform

The DJI Matrice 600 is a hexacopter designed for a variety of industrial and commercial applications. Unlike the quadcopters, it has six propellers. The biggest advantage that the Matrice 600 has over the Matrice 300/350 is that it can carry a 6 Kg payload compared to the 2,7 Kg payload of the Matrice 300/350. The platform integrates DJI's A3 flight controller and Lightbridge 2 video transmission technology, providing reliable and high-quality performance.

1.1.4.2. Applications

The Matrice 600 is particularly suited for short-distance environmental monitoring and data collection. Its ability to carry multiple sensors makes it ideal for comprehensive environmental assessments, including coastal and marine monitoring. The 6 kg payload makes it well suited to carry the heavier Specim AFX10 Hyperspectral sensor which weighs 2.1 kg alone and 4.8 kg with a Gremsy T7 gimbal. The M600 was first deployed in August 2022 and has since been utilized for mapping coastal regions, primarily in the Runde/Remøy area in 2022 and Hopavågen in Trøndelag in 2024. Additionally, it was deployed to compare AFX10 data with satellite imagery in experimental basins at NIVAs research station Solbergstrand.

Table 9. SeaBee's DJI Matrice 600 Inventory.

Count	Purchase Year	Platform name	Type	Subtype
1	2021	DJI MATRICE M600 PRO QUAD UAV Seabee	UAV - Unoccupied Aerial Vehicle	VTOL rotor quad

1.1.4.3. Performance of platform

- Maximum take of weight (MTOW): 15.1 Kg
- Maximum Payload: 6 Kg.
- Nominal flight time. 40 minutes no payload
- Dimensions: 1668 mm x 1518 mm x 759 mm (Propellers, frame arms and GPS mount unfolded)
- Flight number: 26
- Flight time with 5.5kg payload (AFX10): 17 minutes
- Flight patterns: Flexible but normally used in lawn-mower or waypoint modes

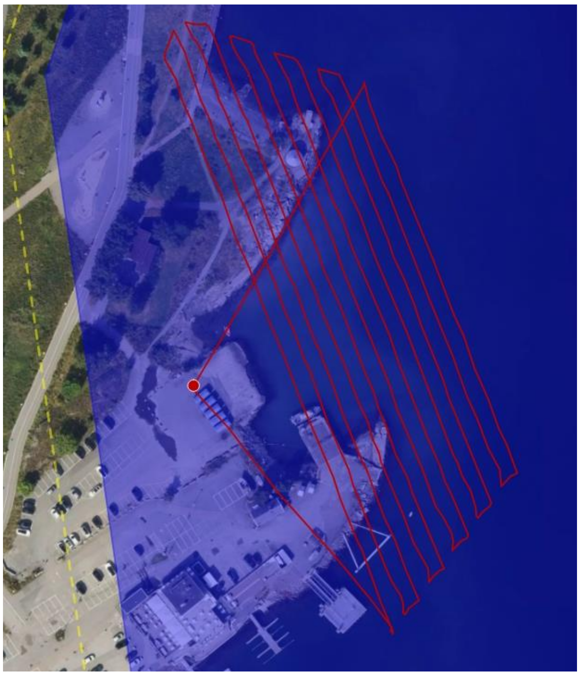

Figure 7. Flight pattern example DJI Matrice 600. Photo: Medyan Ghareeb, Drone Logbook.

Possible future upgrades

Currently there are no plans for future upgrades of the DJI M600. The M600 is discontinued.

1.1.4.4. Sensor configuration and performance implications

The DJI M600 has predominantly been used in conjunction Specim AFX10 Hyperspectral.

1.1.5. Hexadrone Tundra 2 Endurance

Figure 8. Hexadrone Tundra 2 Endurance. Photo: Trygve Heide/NIVA.

1.1.5.1. About platform

The Tundra 2 is a heavy weight quadcopter produced by the French company Hexadrone. It has an IP rating of IP54, and can fly in winds up to 12 m/s. Hexadrone has also developed various drone arms, which make it adaptable for different purposes. By combining the drone with the different arms, the drone becomes specialized for flying in urban environments, flying longer distances, or carrying heavier payloads.

1.1.5.2. Applications

While the Tundra 2 can serve various purposes, SeaBee specifically purchased it for carrying the YellowScan Navigator (5.5 kg). This green LiDAR has the potential to provide topographic and bathymetric data (up to 2 Secchi depths). It has multiple applications and can be used in both coastal and freshwater environments. Due to the heavy weight of the sensor and the diverse tasks the drone needs to perform, the Tundra 2 is a suitable choice.

Table 10. SeaBee's Hexadrone Tundra 2 Inventory.

Count	Purchase Year	Platform name	Type	Subtype
2	2024	HEXADRONE TUNDRA-2 QUAD COPTER UAV Seabee NIVA	UAV - Unoccupied Aerial Vehicle	VTOL rotor quad

1.1.5.3. Performance of platform

- Maximum take of weight (MTOW): 15 kg.
- Maximum Payload: 6 kg.
- Nominal flight time. 1 hour with a light sensor.
- Dimensions: 786 x 786 x 513mm (LxWxH)

1.1.5.4. Possible future upgrades

SeaBee's two Tundra2's are currently awaiting an electronics stack upgrade to the 'Tundra 2.1'. This upgrade will make the Tundra 2.1 compatible with a parachute and Flight Termination System (FTS).

The new electronics stack is required for MoC 2511/2512 approval with the DRS system and subsequent C5/C6 certification. C5/C6 certification provides more flexibility and allowances when planning and executing missions. For example, STS missions are permitted with a C6 category vehicle and 1+1km BVLOS (Beyond Visual Line of Sight). This certification simplifies mission planning.

The parachute system: the Tundra is waiting for the parachute system certification and expected to be ready for purchase in mid-2025. Hexadrone are currently finalising compliance for the Tundra so that it can operate in a classified category, this included integration of a parachute and flight termination system.

Independent FTS and Parachute systems for the Tundra will allow the platform to operate in the CLASS 6 category under PDRA 01 and 02. This basically means missions over areas where an incident can result in collateral damage (population density of over 25 persons/km^2).

1.1.5.5. Sensor configuration and performance implications

Currently, the only sensors carried by the Tundra 2 are the LiDARs: Navigator and Explorer. However, future plans include developing gimbals and adapters to accommodate our SONY ILX LR1 sensors. This will enable drone pilots to perform both LiDAR mapping and capture high-quality, high-resolution RGB images with a single drone. The SONY ILX is a very light sensor (less than 1kg with gimbal), allowing for an estimated flight time of one hour with the Tundra 2, which exceeds the current flight time of our M350.

1.1.6. DJI Mini

Figure 9. DJI Mini. Photo: DJI.com.

1.1.6.1. About platform

The DJI Mavic Mini series include models from version 1 to 4, with that in common that they weigh only 249 grams or less. Due to this it is regarded as safer for the public than the larger drones and can be flown recreationally without a drone license. However, the pilot still needs to be registered at Flydrone.no, the portal for pilot register at the Civil Aviation Authority Norway (CAA). For deploying in SeaBee operations, the internal infrastructure protocols require the pilots to hold at least a A1/A3 drone pilot certificate. Regardless of its small size it has a decent 4K camera and can film in 8 bit 4:2:0 and has a 48-megapixel camera for still photography (version Mini 3 and 4). The DJI Mavic Mini 3 and 4 also has more than 38-minute flight time with its regular batteries and can use a more powerful battery which gives it 51 minutes flight time, these batteries are however heavier and bring the drone to over the 250-gram limit which makes it fall into stronger regulation. The main advantage of the Mavic Mini 3 and 4 are the flexibility of its small size, and its ease to launch and use.

1.1.6.2. Applications

The main application of the DJI Mavic Mini's has been to document the work that SeaBee is doing. As it is a relatively cheap drone, and easy to fly, it suits well for this function. Another useful application for the DJI Mavic Mini is that it serves well as a training drone. Its small size reduces the consequences in case of human errors. From a training perspective it is a DJI product, and its software is not completely different from the larger drones that have both a higher cost and larger consequence if anything were to happen.

Table 11. SeaBee's DJI Mini Inventory.

Count	Purchase Year	Platform name	Type	Subtype
2	2020	DJI Mavic Mini	UAV - Unoccupied Aerial Vehicle	VTOL rotor quad
2	2021, 2023	DJI Mavic Mini 3	UAV - Unoccupied Aerial Vehicle	VTOL rotor quad
1	2024	DJI Mavic Mini 4	UAV - Unoccupied Aerial Vehicle	VTOL rotor quad

1.1.6.3. Performance of platform

- Maximum take of weight (MTOW): < 249 g
- Maximum Payload: Should not take additional payloads
- Nominal flight time. 34 minutes (with Intelligent Flight Battery). 45 minutes (with Intelligent Flight Battery Plus*)
- Dimensions: Folded (without propellers): 148×94×64 mm (L×W×H)
  Unfolded (with propellers): 298×373×101 mm (L×W×H)

1.1.6.4. Sensor configuration and performance implications

No additional payloads are added to the DJI Mini's.

1.1.6.5. Possible future upgrades

It is unlikely that we will make future upgrades to the already purchased drones. However, newer models with improved specifications may be purchased.

1.1.7. DJI Mavic 3 Pro Cine

Figure 10. DJI Mavic 3 Pro Cine. Photo: Trygve Heide/NIVA.

1.1.7.1. About platform

The DJI Mavic 3 Pro Cine is a compact drone capable of filming in Apple ProRes and color sampling at 10-bit 4:2:2. It features three RGB sensors: a Hasselblad camera with a 24mm, 4/3 CMOS sensor; a medium telephoto camera with a 70mm, 1/1.3" CMOS sensor; and a telephoto camera with a ½" CMOS sensor. The DJI Mavic 3 Pro Cine has a flight time of 43 minutes and a maximum hovering time of 37 minutes. Its main advantages are its small size and ease of use, making it very useful for documentation and as a medium-sized drone for practice before using larger, more expensive drones.

1.1.7.2. Applications

The primary use of the DJI Mavic 3 Pro is for documentation and as a training drone for pilots. It is larger than the Mavic Mini, relatively easy to fly, and serves as a good steppingstone from the mini to larger, more expensive drones.

Table 12. SeaBee's DJI Mavic 3 Pro Cine Inventory.

Count	Purchase Year	Platform name	Type	Subtype
1	2025	DJI Mavic 3 Pro Cine	UAV - Unoccupied Aerial Vehicle	VTOL rotor quad

1.1.7.3. Performance of platform

- Maximum take of weight (MTOW): 963 g
- Maximum Payload: Should not take additional payloads
- Max flight time. 43 minutes (in ideal conditions)
- Dimensions: Folded (without propellers): 231.1×98×95.4 mm (L×W×H). Unfolded (without propellers): 347.5×290.8×107.7 mm (L×W×H)

1.1.7.4. Sensor configuration and performance implications

No sensor configurations have been made to the Mavic 3 Pro Cine.

1.1.7.5. Possible future upgrades

There are no future upgrades planned.

1.1.8. DJI Mavic/Matrice Thermal/Enterprise

Figure 11. DJI Mavic 2 Thermal Enterprise. Photo: DJI.com.

1.1.8.1. About platform

The DJI Mavic Enterprise series is designed for professional and industrial applications, offering advanced features that surpass those of the standard Mavic Pro. Following the Mavic 3 Enterprise, DJI rebranded the series to Matrice 4. Unlike the standard models that focus on RGB sensors at different focal lengths, the Enterprise models incorporate specialized sensors, enhancing their suitability for enterprise tasks beyond photography and filmmaking. The series includes two main versions: the standard Enterprise, which excels in mapping and surveying, and the Thermal Enterprise, equipped with a thermal sensor for tasks requiring thermal imaging. Additionally, DJI released the Mavic 3 with a Multispectral Sensor, also known as the M3M.

SeaBee's Mavic 2 Enterprise Thermal features a thermal camera with a resolution of 640×512, a visual camera with 48 MP effective pixels, and omnidirectional obstacle sensing for safe navigation. SeaBee's M3M Enterprise, also known as the M3M, includes a multispectral camera and an RGB camera. The M3M captures four bands: green, red, red edge, and near-infrared (NIR), and collects solar irradiance for consistent data capturer. The Matrice 4E in the SeaBee toolbox features a laser rangefinder, a 20 MP wide-angle camera, a 48 MP medium-sized telephoto camera, and a 48 MP telephoto camera.

1.1.8.2. Applications

The Mavic 2 Enterprise Thermal has been primarily used for marine mammal research in Northern Norway by the Institute of Marine Research. Its thermal sensors effectively detect temperature differences, making it useful for spotting whales and seals in environments where these animals are difficult to identify. The M3Mis used for environmental monitoring. The Matrice 4E is applied for detailed 3D mapping.

Table 13. SeaBee's DJI Mavic Enterprise / Matrice Inventory.

Count	Purchase Year	Platform name	Type	Subtype
1	2021	DJI Mavic 2 Thermal Enterprise	UAV - Unoccupied Aerial Vehicle	VTOL rotor quad
2	2024	DJI Mavic 3 Enterprise MSI and RGB (M3M)	UAV - Unoccupied Aerial Vehicle	VTOL rotor quad
2	2025	DJI Matrice 4 RTK	UAV – Unoccupied Aerial Vehicle	VTOL rotor quad

1.2 Unoccupied surface vehicles in SeaBee

Unoccupied Surface Vehicles (USVs) are autonomous or remotely operated vehicles designed to operate on the surface of the water. These vehicles are essential tools in marine research, providing valuable data for maritime surveillance, environmental monitoring, and oceanographic studies. USVs come in various shapes and sizes, each suited to different tasks and environments. They can be equipped with a range of sensors, including acoustic sensors for bathymetry, optical sensors for water quality assessments, and hyperspectral sensors for detailed imaging. USVs offer the advantage of zero-emission operation, making them environmentally friendly alternatives to traditional boat surveys. Their ability to operate autonomously or under remote control allows for efficient data collection in both coastal and freshwater areas.

1.2.1. Maritime Robotics Otter

Figure 12. Maritime Robotics Otter. Photos: Øyvind Tangen Ødegaard/NIVA.

1.2.1.1. About platform

The Otter USV is engineered for data collection in shallow, sheltered, coastal and freshwater areas. Under optimal conditions, it can operate its two electric propellers for up to 20 hours using its four battery packs. The electric propulsion system offers a zero-emission alternative to traditional boat surveys.

1.2.1.2. Applications

SeaBee has two Maritime Robotics Otters, one equipped primarily for acoustic bathymetry measurements (the Bathy Otter) and one primarily for underwater hyperspectral imaging (the HSI Otter). The Bathy Otter is fitted with a single-beam Biosonics MX200 echosounder, which produces a sound beam at 8.5 degrees conical, allowing it to measure bathymetry, estimate substrate type of submerged aquatic vegetation and provide bathemetry data (0,5 to 100 m range). This makes it a great complementary tool to the flying drones with RGB MSI and green LiDAR sensors. This approach has been tested in various conditions, from coastal environment to rivers with less turbulence.

The Hyperspectral version (HSI Otter) is fitted with an ECOTONE underwater HSI sensor. The otter travels across the water surface while the HSI sensor scans the seabed. The sensor is then able to pick up the different spectral reflections that are emitted by different organisms. Through this the organisms can be identified. The HSI Otter is in addition equipped with optical sensors for data collection of the optical properties of the water, i.e. a TriOS VIPER bean attenuation meter.

Table 14.SeaBee's Maritime Robotics Otter Inventory.

Count	Purchase Year	Platform name	Type	Subtype
2	2021	Maritime Robotics Otter	USV Unoccupied Surface Vehicle	Catamaran shape Electric propulsion

1.2.1.3. Performance of platform

- Weight with batteries: 85 kg
- Maximum Payload: 30 kg
- Endurance. 20 hours at 2 knots
- Dimensions: 2000 mm x 1080 mm x 1065 mm

1.2.1.4. Possible future upgrades

- Docking system with charging capability, for example standardized to fit in the boat slips of a typical leisure boat marina.
- Situational awareness system: 360˚ camera/LIDAR system on top of the vehicle. Off-the-shelf option: Maritime Robotics SeaSight.
- Winch for water column profiling. interfaced towards the vehicle's sonar. Off-the-shelf option: Maritime Robotics AutoCast winch. Approx. 110 m depth range, 100N lift capacity.
- Multi-beam echosounder for bathymetry mapping.

1.2.1.5. Sensor configuration and performance implications

The vehicle's top speed according to spec is about 3 m/s, with a typical operational speed at 1-3 m/s.

Current payload on the "Bathy Otter":

- Biosonics MX aquatic habitat mapping 200kHz single-beam echosounder
- Turner C3 Submersible Fluorometer (Chlorophyll a, CDOM, turbidity)
- Valeport MiniCT (conductivity & temperature)
- Dual GoPro Hero10 cameras (submerged, downward looking & above-surface downward looking for thruster monitoring)
- Forward-looking navigation POE IP camera
- GNNS/RTK positioning system
- *AIS System: A standard ship identification system*

Current payload of the "HSI Otter" TriOS Viper

- Forward-looking navigation POE IP camera
- GNNS/RTK positioning system
- *AIS System: A standard ship identification system*

1.3 Unoccupied Underwater Vehicles (UUV's) in SeaBee

Unoccupied Underwater Vehicles (UUVs) are remotely operated vehicles designed to function below the water's surface. These vehicles are essential for marine research, performing tasks such as seabed mapping, environmental monitoring, and underwater infrastructure inspection. UUVs come in various forms, including remotely operated vehicles (ROVs), which are controlled by operators from the surface. They can be equipped with a range of sensors, including high-definition cameras for detailed imaging, sonar systems for navigation and mapping, and environmental sensors for measuring water quality parameters. UUVs offer the advantage of high maneuverability and the ability to operate at significant depths, making them great for detailed underwater surveys.

1.3.1. Blueye Pioneer

Figure 13. Blueye Pioneer. Photo: blueyerobotics.com.

1.3.1.1. About platform

The Blueye Pioneer, developed by Blueye Robotics in Norway, is a versatile and user-friendly remotely operated vehicle designed for underwater exploration and inspection. It features a high-definition tilt camera, allowing for detailed inspections and effective navigation in challenging underwater conditions. With a depth rating of 150 meters and a robust design, it is suitable for tasks in aquaculture and marine research.

1.3.1.2. Applications

The Blueye ROV has been employed in several environmental and marine biology studies. For instance, in the evaluation of macroalgae conditions and registration of the water depth defining the lower growth limit of macroalgae and seagrass. With its high-quality camera, it enables researchers to capture detailed imagery used for assessing, for instance health indicators and distribution of these species across different seafloor environments and depths.

Moreover, the Blueye Pioneer was used in environmental impact assessments and played a role in surveying the seabed and assessing marine habitats. Detailed investigations of the sea floor topography and biological communities have been conducted, particularly focusing on areas potentially impacted by construction activities. The ROV's capabilities facilitated a thorough examination of the site's marine biodiversity and helped in mapping out areas that required environmental protection measures. The data collected supported the development of mitigation strategies to minimize adverse effects on the marine ecosystem during and after the development phase.

Table 15. SeaBee's Blueye Pioneer Inventory.

Count	Purchase Year	Platform name	Type	Subtype
1	2023	Blueye Pioneer	UUV Unoccupied Underwater Vehicle	Electric propulsion

1.3.1.3. Performance of platform

- 8.6 kg (with saltwater ballast).
- Dimensions: 485 x 257 x 354 mm (LxWxH).
- Endurance: Approximately 2 hours.
- Speed: 3 knots.
- Sensor resolution: FHD: 1980x1080 25/30FPS.
- LED lights: 3300 lumens.
- Max depth: 150 meters.

1.3.1.4. Possible future upgrades

The Blueye Pioneer is our workhorse UUV but is becoming a legacy platform. It will continue duties as an underwater camera drone, but no upgrades are planned for the vehicle.

1.3.1.5. Sensor configuration

The Blueye Pioneer has inbuilt sensors such as the HD camera sensor, temperature, navigation sensors and tilt and yaw capabilities.

1.3.2. Blueye X3

Figure 14. Blueye X3. Photo: blueyerobotics.com.

1.3.2.1. About platform

Blueye X3 was released after the Blueye Pioneer and has an improved battery life, where the operation time is 5 hours compared with the 2-hour operating time of the Blueye Pioneer. It also comes with 3 ports compared with the one port option offered by Pioneer. These extra ports can be used to connect manipulators or grippers, sonars and other sensors, as well as positioning systems which can be used to track the ROV's location while underwater.

1.3.2.2. Applications

The Blueye X3 opens new projects at greater depths, that require longer battery life, and more guest ports. This would allow the newer version to have an advantage in areas that are more complex to navigate in. For example, with the additional ports you can attach additional cameras, lights and other sensors to the X3 which allow for more data collection in areas where maneuverability may be limited.

Table 16.SeaBee's Blueye X3 Inventory.

Count	Purchase Year	Platform name	Type	Subtype
1	2025	Blueye X3	UUV Unoccupied Underwater Vehicle	Electric propulsion

1.3.2.3. Performance of platform

- 8.6 kg (with saltwater ballast).
- Dimensions: 485 x 257 x 354 mm (LxWxH).
- Endurance. Between 2 and 5 hours.
- Speed: 3 knots.
- Sensor resolution: FHD: 1980x1080 25/30FPS.
- LED Lights: 3300 lumens.
- Max depth: 305 meters.

1.3.2.4. Possible future upgrades

In its planned configuration the INS sensors of the X3 can keep accuracy within one meter for approximately 15 minutes underwater. After that time the X3 must return to base and 're-set' its home point. An upgrade is planned by Blueeye whereby the drone itself is equipped with a GNSS antennae. When position accuracy decreases to a point that is unacceptable the vehicle needs only to surface, re-lock and then dive again. This upgrade is planned for Q3 2025.

1.3.2.5. Sensor configuration

The X3 has inbuilt sensors such as the HD camera sensor, temperature, navigation and positioning sensors. With multiple guest ports it can support additional sensors such as multibeam sonars, additional cameras, as well as manipulators and grippers.

1.3.3. FIFISH V6

Figure 15. FIFISH V6. Photo: qysea.com.

1.3.3.1. About platform

The FIFISH V6 is developed by QYSEA, plays a role in enhancing underwater research and data collection. Its 360° omnidirectional movement and compact design make it highly maneuverable, allowing it to navigate complex underwater environments with ease. However, having this maneuverability makes it less user friendly when compared with the Blueye. The FIFISH is equipped with a 4K UHD camera and powerful 4000-lumen LED lights, the FIFISH V6 can capture high-quality imagery and video, even in low-light conditions. This capability is essential for detailed inspections and monitoring of underwater ecosystems, infrastructure, and marine life. The FIFISH V6's VR head tracking controls provide an immersive piloting experience, enabling researchers to conduct precise and efficient underwater missions.

1.3.3.2. Applications

The FIFISH V6 drone has been used to collect high-resolution images and data of kelp forests and other marine habitats. This data is then analyzed and validated against ground truth data collected manually by researchers. This data helps monitor and assess the health of marine ecosystems, identifying different species and habitats.

Table 17. SeaBee's FiFish V6 Inventory.

Count	Purchase Year	Platform name	Type	Subtype
1	2022	FiFish V6	UUV Unoccupied Underwater Vehicle	Electric propulsion

1.3.3.3. Performance of platform

- 4.6 kg.
- Dimensions: 383 x 331 x 143 mm (LxWxH).
- Endurance: 1 hour in current and 6 hours in still water.
- Port number: 1 guest port.
- Speed: 3 knots.
- Sensor resolution: 4K UHD: 25/30 FPS and FHD: 1980x1080 25/30/50/60/100/120 FPS.
- LED lights: 6000 lumens.
- Max depth: 100 meters.

1.3.3.4. Possible future upgrades
There are no future upgrades planned.

1.3.3.5. Sensor configuration
In addition to the 4K inbuilt RGB sensor, the FIFISH V6 has sensors that are used to measure depth, temperature and the GPS position of the controller. It also has a removable claw that is used to take samples.

1.4 Sensors in SeaBee

SeaBee is equipped with a diverse array of sensors, each serving distinct functions for various applications. These include color imaging sensors such as RGB sensors, spectral imaging sensors like Multispectral and Hyperspectral sensors, infrared sensors and thermal sensors that detect infrared and thermal infrared wavelengths, light detection and ranging (LiDAR) sensors that emit laser pulses to measure distance, and high precision positioning sensors like Real-Time Kinematic (RTK) instruments.

1.5 RGB Cameras

1.5.1.1. About sensor
RGB sensors are commonly found in DSLR cameras, video cameras, and smart phones. They capture images that resemble what the human eye perceives, making these sensors very useful for creating beautiful pictures in nice colour. Due to high consumer demand, these sensors are rapidly developing with respect to pixel resolution and light sensitivity, resulting in continuing launch of improved models. They are often cheaper than Multispectral Imaging (MSI) and Hyperspectral Imaging (HSI) sensors, as they cater to the consumer market.

1.5.1.2. Applications
RGB sensors have been used in SeaBee's context for both simple habitat classification and providing an overview of the study site, which is useful for annotation. The main advantage of these sensors is that they offer a representative overview that resembles what the human eye sees.

Table 18. SeaBee's stand-alone RGB Sensor Inventory. In addition to these listed are the built-in RGB sensors on the smaller UAVs, the USVs, and the UUVs.

Count	Purchase year	Model	Type	Subtype
4	2022, 2023, 2024	DJI ZENMUSE P1 35mm 45MP RGB	RGB Sensor	Full-Frame Sensor
1	2021	SONY RX1_RM2 42MP RGB CAMERA	RGB Sensor	Full-Frame Sensor
1	2023	SONY A7R IV 61MP RGB CAMERA	RGB Sensor	Full-Frame Sensor
2	2025	SONY ILX LR1 62MP	RGB Sensor	Full-Frame Sensor

1.5.1.3. DJI Zenmuse P1 35mm 45MP RGB

The Zenmuse P1, produced by DJI, is designed for use with the DJI Matrice 300/350 RTK. It weighs approximately 800 g and has an effective pixel count of 45 MP. It features a prime lens with a focal length of 35 mm. When capturing data, it stores photos, GNSS raw observation data, and an image log file. Additionally, it has a detachable DJI Skyport mount.

1.5.1.4. Sony RX1R II 42MP RGB Camera

The Sony RX1R II is a compact camera with a 35mm Zeiss fixed lens. It has a 42.4 megapixel full-frame CMOS sensor. Weighing 480g, it was the lightest RGB sensor that has been used by SeaBee for mapping and monitoring before the Sony ILX (see below).

1.5.1.5. Sony A7R IV 61 MP RGB Camera

Sony A7R IV has a 35 mm full frame CMOS sensor that has 61 megapixels. It has a high-speed continuous shooting of up to 10 frames per second with autofocus tracking. The camera has an ISO range between 100 and 32000 but can be expanded to 50 and 102 400 ISO.

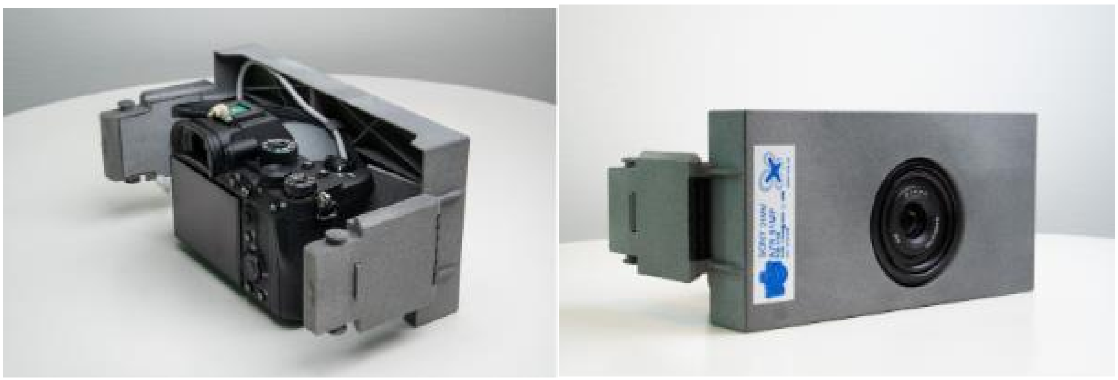

Figure 16. Sony A7R IV inside DeltaQuad EVO casing. Photos: Trygve Heide/NIVA.

1.5.1.6. Sony ILX LR1 62 MP RGB Camera

The ILX LR1 is basically a stripped-down and low weight (243 g) version of the Sony A7R IV that is specialized for the usage with drones. It also has 61 effective megapixels, making it a very powerful yet light weight tool for RGB mapping

Figure 17. Sony ILX LR1 on DJI Enterprise X Port Gimbal. Photos: Trygve Heide/NIVA.

1.6 Multispectral MSI sensors

Figure 18. Altum PT MSI Camera. Photos: Medyan Ghareeb/NIVA.

1.6.1.1. About sensors

Multispectral Imaging (MSI) sensors are essentially filtered RGB cameras. Their task is to separate different wavelengths of light representing different colors entering the lens into distinct, quantifiable groups, meaning there is minimal energetic overlap from other bands (e.g. the blue band is only sensitive to light at 450 to 500 nm). This allows objects or materials to display unique optical "finger prints," which can be measured and used to feed algorithms for identifying types of terrestrial and benthic coverages through machine learning. These sensors are typically used on medium-sized drones. Smaller compact drones with multispectral capabilities like the DJI M3 do not provide the same resolution and clarity as larger drones.

1.6.1.2. Applications

Benthic habitat mapping has been the primary use for multispectral sensors in SeaBee. We typically map areas of 0.1 to 10 km^2, to observe variations in habitat characteristics and growth patterns.

Table 19. SeaBee's MSI Sensor Inventory.

Count	Purchase year	Model	Type	Subtype
1	2022	MICASENSE REDEDGE PT Multispectral Camera - EVO Seabee	Sensor	MSI
3	2020, 2023	MICASENSE ALTUM PT Multispectral Thermal Camera	Sensor	MSI
1	2023	MICASENSE REDEDGE P Dual Camera System (10 BAND MSI (5x2))	Sensor	MSI
1	2024	MICASENSE REDEDGE_P BLUE MSI CAMERA	Sensor	MSI
1	2023	MICASENSE REDEDGE P 'red' 1of2 DUAL Seabee	Sensor	MSI

1.6.1.3. Data examples

Figure 19. MSI 'false colour' composite orthoimages. Photos: Medyan Ghareeb/NIVA.

The MSI sensors in SeaBee infrastructure

1.6.2. Rededge-P

The Rededge-P is a compact multispectral imaging (MSI) sensor, weighing 315g, that SeaBee includes in its toolbox. Despite its small size, it features five multispectral bands with a 1.6MP resolution and a panchromatic sensor with a 5.1MP resolution. Additionally, it offers full integration with our DJI M300/350 platform via Skyport.

Figure 20. MicaSense Rededge-P. Photos: Trygve Heide/NIVA.

1.6.3. Altum PT

The MicaSense Altum-PT, weighing 460g, is larger than the Rededge-P but represents a significant upgrade. It features five multispectral bands (blue, green, red, red-edge, and near-infrared) with a 3.2MP resolution, a thermal band with a 320x256 resolution, and a panchromatic band with a 12MP resolution. The thermal band enables heat detection, which is useful for monitoring heat-emitting organisms that are well camouflaged. The panchromatic sensor produces a higher resolution greyscale image compared to the multispectral bands and enables an improvement of the image quality across all of the spectral bands. The Altum-PT offers full integration via Skyport with our DJI M300/350 Platform and partial integration with our EVO platform through position data (RTK capability).

Figure 21. MicaSense Altum-PT mounted for use in DeltaQuad EVO instrument bay. Photos: Trygve Heide/NIVA.

1.6.4. Micasense Dual Camera System

The MicaSense Dual Camera System essentially combines the regular RedEdge-P with the RedEdge-P Blue. Each sensor has their own spectral band sensitivity, can be used independently, but when combined, they provide ten multispectral bands. The system prioritizes maximizing multispectral coverage, and as a result, the panchromatic band is not included in the combined setup. The total weight of the sensors, including cables, is 508.8 grams, making it suitable for applications requiring broader spectral ranges for detailed analysis.

Figure 22. MicaSense Dual Camera System. Photo: micasense.com.

Table 20. SeaBee's MSI Sensor Specifications.

Specifications	Dual Camera System	RedEdge-P	Altum-PT
Bands	10 Bands	6 Bands	7 Bands
Thermal?	No	No	Yes
Weight (including DLS2 and cables)	508.8g	315 g	460g
Sensor resolution	1280 x 960 px	1456 x 1088 px	2064 x 1544 px
Ground Sample Distance at 120m	8 cm/px (MS bands)	7.7 cm/px (MS bands) 3.98 cm/px (PAN)	5.28 cm/px (MS bands) 2.49 cm/px (PAN)

1.6 Infrared sensors

Infrared sensors offer capabilities that extend beyond the visible spectrum. These sensors detect infrared radiation, which is emitted by all objects based on their temperature. In environmental monitoring these sensors can be used to detect heat signatures of wildlife, helping identify species that are well camouflaged by their surroundings.

1.6.5. Workswell Wiris Pro

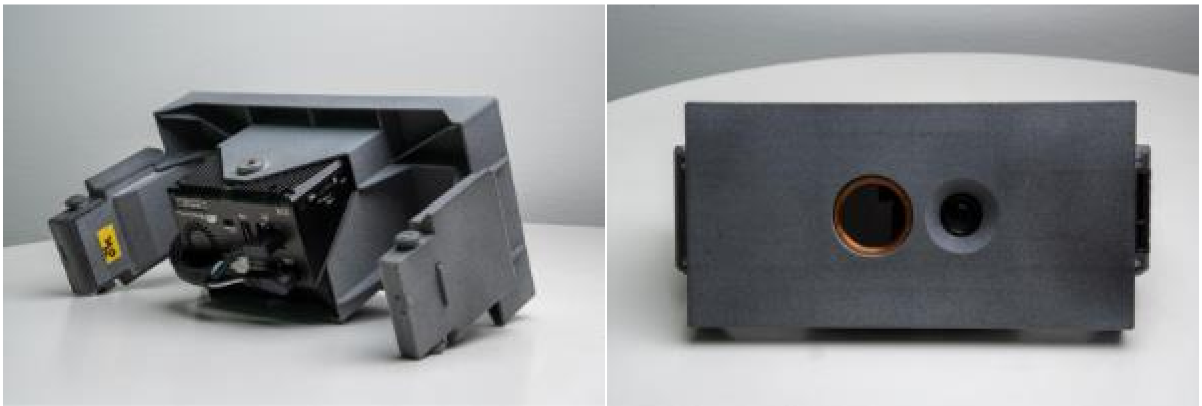

Figure 23. Workswell Wiris Pro Infrared Camera mounted for use in DeltaQuad EVO instrument bay. Photos: Trygve Heide/NIVA.

1.6.5.1. About sensor

The Wiris Pro uses an infrared (IR) sensor to capture thermal images. This is done through the sensors ability to detect infrared radiation that is emitted by objects. The Wiris Pro is able to measure temperatures up to 1,500 °C and down to - 40°C. The camera has a resolution of 640 x 512 pixels, an accuracy of +/- 2 °C and a spectral range of 7.5 – 13.5 μm.

1.6.5.2. Applications

With the ability to register thermal radiation, the Wiris Pro has multiple applications for SeaBee. Thermal cameras have previously been used to locate camouflaged bird species as well improving the detection of marine mammals and being able to recognize stress levels in seals, which display elevated temperatures around the nose and eyes.

Table 21. SeaBee's Wiris Pro Sensor Inventory.

Count	Purchase Year	Model	Type	Subtype
1	2023	WIRIS PRO INFARED CAMERA	Sensor	Infrared

1.7 Hyperspectral HSI sensors

Hyperspectral Imaging (HSI) sensors are advanced tools that capture and analyse a wide spectrum of light across numerous narrow wavelength bands. Unlike traditional cameras that capture images in just three primary colours (red, green, and blue), HSI sensors can detect hundreds of spectral bands, providing detailed information about the composition and properties of the observed objects.

1.7.1. Specim AFX10

Figure 24. Specim AFX10. Photo: specim.com.

1.7.1.1. About sensor.

Hyperspectral sensors (HSI) are invaluable when the spectral range and resolution from multispectral sensors (MSI) isn't sufficient. While MSI setups typically capture four to ten bands, the Specim AFX10 HSI sensor can register 224 spectral bands. Hyperspectral sensors typically, like the Specim AFX10 function like scanners (like a paper scanner in the office, rather than like an image camera), measuring a full spectrum of light across the visible and non-visible range of light. The Specim AFX10 has a spectral sensitivity range from 400 to 1000 nm with a spectral resolution at 5.5 nm.

1.7.1.2. Applications.

Hyperspectral sensor data allows for identification of materials or species that MSI sensors might not distinguish and can appear similar in visible light. In SeaBee's context, HSI sensors have primarily been used for high resolution benthic habitat mapping from both AUVs, USVs, and UUVs. Due to the complex nature and large amount of data collected by HSI sensors data processing often requires dedicated efforts and filtering as well as computational power to generate applicable products

Table 22. SeaBee's Specim AFX10 Inventory.

Count	Purchase Year	Model	Type	Subtype
1	2021	Specim AFX10	Sensor	HSI

1.8 LiDAR

LiDAR (Light Detection and Ranging) sensors work by emitting laser pulses at a specific wavelength and measuring the time it takes for these pulses to bounce back after hitting an object. This makes LiDAR sensors "active sensors" in contrast to imaging sensors that are regarded as "passive sensors". The process involves sending out thousands of laser pulses per second, which reflect off surfaces and return to the sensor. By calculating the time delay between the emission and reception of each pulse, the sensor can determine the distance to the object with high precision. Data can then be used to create detailed 3D maps of the environment above and below water. LiDAR sensors are capable of capturing fine details of terrain, vegetation, and structures, making them applicable for coastal bathymetric and topographic mapping.

1.8.1. YellowScan Navigator

Figure 25. YellowScan Navigator. Photo credit: Trygve Heide/NIVA.

The YellowScan Navigator emits a green laser pulse (at 532 nm) which is capable of penetrating water, as opposed to red laser light. Due to this the Navigator functions as a bathymetric LiDAR system designed for both underwater and terrestrial mapping. The green laser penetrates water bodies corresponding to approximately 1 to - 2 secchi depths. The system includes an SBG Quanta Micro IMU for precise positioning and an embedded low-resolution RGB camera for true-color data colorization of the resulting point cloud. Typical flight heights are 30 to 100 meters.

1.8.1.1. Applications.

The YellowScan Navigator is used for a variety of environmental and industrial applications. It has the potential in tracking coastal erosion and sediment movement, river mapping, monitoring, flood hazard assessment, and biomass studies of above and underwater vegetation with centimeter-level precision. SeaBee has applied it for measuring biomass and organic carbon stocks in seagrass meadows, for river hydro morphology monitoring and coastal and freshwater bathymetry mapping.

1.8.2. YellowScan Explorer

Figure 26. YellowScan Explorer. Photo credit: Trygve Heide/NIVA.

The YellowScan Explorer is a versatile LiDAR system designed for UAVs with a red-light emitting laser (1556 nm). It operates at altitudes up to 300 meters and offers a system precision and accuracy of 2 cm. The system is lightweight, weighing 1.8 kg without the battery.

1.8.2.1. Applications.

The YellowScan Explorer´s light weight allows it to be used with a larger range of drones, as well as have less impact on the flight time when compared with the Navigator. It has a red laser that does not penetrate water and is therefore restricted to mapping terrestrial environments onshore. It has been used for topographic mapping, forestry, and infrastructure inspection, providing high-quality 3D data for detailed analysis.

Table 23. SeaBee's LiDAR Inventory.

Count	Purchase Year	Model	Type	Subtype
1	2024	YellowScan Navigator	Sensor	Green LiDAR
1	2024	YellowScan Explorer	Sensor	Red LiDAR

1.8.2.1. Data examples:

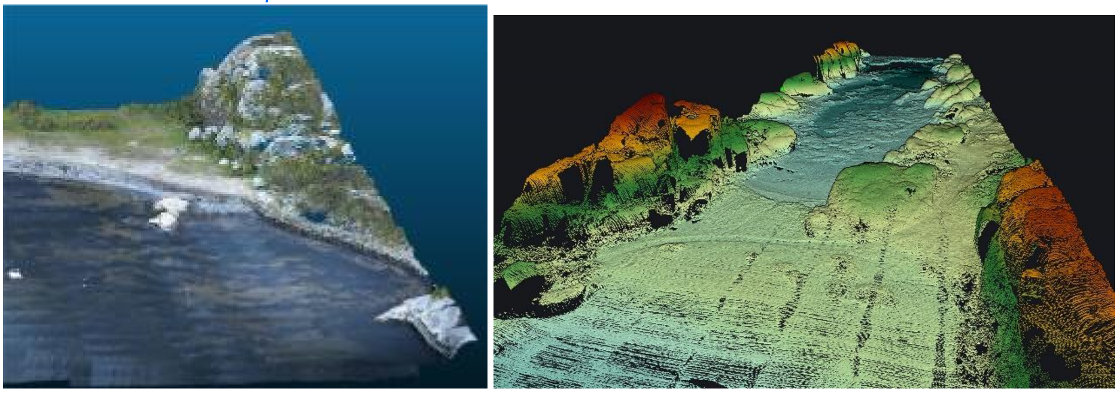

Figure 27. YellowScan Navigator LiDAR (LiDAR) colourised (left). Photos: Charles Patrick Lavin and Kasper Hancke/NIVA.

1.9 Sensors Mounted on Unoccupied Surface Vehicles (USVs)

1.9.1. BioSonics MX Echosounder OEM Version

Figure 28. Turner C3 Submersible Fluorometer. Photo: biosonicsinc.com.

1.9.1.1. About the sensors

The BioSonics MX200 Echosounder OEM Version for Unmanned Surface Vehicles (USVs) is mounted on the SeaBee "Bathy Otter" USVs. It is an acoustic sensor designed for underwater measurements. It operates with a transmit power of 105 Watts RMS and can measure depths from 0 to 100 meters with an accuracy of 1.7 cm ± 0.2% of depth. The echosounder supports GPS integration and features interfaces like Ethernet for system control and RS232 for GPS input. It is ideal for applications such as bathymetry, and also has an application for aquatic plant mapping and substrate type analysis.

1.9.2. Turner C3 Submersible Fluorometer

Figure 29. Turner C3 Submersible Fluorometer. Photo: turnerdesigns.com.

1.9.2.1. About the sensors

Fluorometers, like the Turner C3 Submersible Fluorometer, measure the intensity and wavelength of fluorescence emitted by substances in water after being excited by a specific spectrum of light. The C3 can be configured with up to three optical sensors, covering a range from deep ultraviolet to infrared. It is used for applications such as measuring chlorophyll a, Colored Dissolved Organic Matter (CDOM), and water turbidity.

1.9.3. ValePort miniCT

Figure 30. ValePort miniCT. Photo: valeport.co.uk.

1.9.3.1. About the sensors

The ValePort miniCT is a compact sensor designed for precise measurement of conductivity and temperature in marine environments. It features a digital inductive conductivity sensor with a range of 0-80 mS/cm and an accuracy of ±0.01 mS/cm. The temperature sensor, operates within a range of -5 to +35°C with an accuracy of ±0.01°C. The sensor is integrated with the Maritime Robotics Otter.

1.9.4. TriOS Viper

Figure 31. TriOS Viper. Photo: trios.de.

1.9.4.1. About the sensors

The TriOS Viper measures beam attenuation and transmission coefficients within the 360 nm to 750 nm wavelength range, allowing for detailed assessment of the water column beam attenuation. It uses five selected, energy-efficient LEDs as the light source, ensuring long service life and stable measurement data. The TriOS Viper is versatile and can be used in various media, available in multiple path lengths and housed in either stainless steel or titanium. Typical applications for VIPER include monitoring water quality, measuring the color of aqueous solutions. The sensor is integrated in the Maritime Robotics Otter.

1.10 Various handheld sensors

1.10.1. SpectraPen LM 510

Figure 32. SpectraPen LM 510. Photo: psi.cz.

1.10.1.1. About the sensors

The SpectraPen LM 510 is a handheld portable spectroradiometer designed for research applications. It measures incident irradiance in radiometric or photometric units and is calibrated for visible light in the range of 340-790 nm and near-infrared light in the range of 640-1,050 nm. The device is particularly useful for rapid measurements of spectral light quality, monitoring artificial lighting, and quantifying light radiation.

1.10.2. FLIR Vue Pro Thermal

Figure 33. FLIR Vue Pro. Photo: flir.eu.

1.10.2.1. About the sensors

The FLIR E8 Pro is a high-performance infrared camera that has a range of -20°C to 550°C with an accuracy of ±2°C or ±2% of the reading. This high level of accuracy and broad thermal range make it a good tool for ground truthing thermal data, which involves validating remote sensing data with on-the-ground measurements to ensure accuracy and reliability

1.10.3. LEICA GS18

Figure 34. Leica GS18 I GNSS RTK. Photo: leica-geosystems.com.

1.10.3.1. About the sensors

The Leica GS18 I GNSS RTK rover is highly effective for ground truthing due to its centimeter-level accuracy, typically within 1-2 centimeters as well as tilt compensation. It is commonly used by experts, such as marine biologists or ecologists, who identify species and record their GNSS positions. This process validates remote sensing data with precise on-the-ground measurements, ensuring the accuracy and reliability of data collected from sources like drones or satellites.

1.10.4. Reach RS2

Figure 35. Reach RS2. Photo: emlid.com.

1.10.4.1. About the sensors

The Reach RS2 GNSS RTK receiver is effective for ground truthing due to its centimeter-level accuracy, typically within 1-2 centimeters, although it lacks tilt compensation. It is commonly used for validating and calibrating data from drone-carried sensors. This process is conducted by drone specialists, marine biologists, or ecologists, who identify species and record their GNSS positions.

2. Infrastructure nodes

2.1 SeaBee lab – NIVA in Oslo

The NIVA SeaBee lab, is located on the second floor of the NIVA building at Økernveien 94, Oslo, Norway. The room, approximately 20 m² in size, is designed to accommodate ample space for a drone with a 2.4 m wingspan to be displayed for training and engineering as well as calibration and storage for SeaBee equipment. It has a wide door and equipped with access control via a code on the door handle. The SeaBee lab houses the Bathy Otter, Multiple UAVs and UUVs.

The lab's layout includes a large table for drone assembly, a desk/workspace for 2-3 people, and shelves or cabinets for storage. The lab is equipped with a powerful computer for data processing and handling large datasets using programs such as Pix4D. The lab is near researchers, as well as to an elevator and parking lot, which is essential for frequent equipment movement. Activities in the room involve technical work on drones and sensors, optical/electronic calibration, data downloading and processing, and storage of equipment. The workspace is used daily to several times a week by up to three users, including drone pilots, technicians, and project-based workers. The lab also serves as a showroom for showcasing infrastructure and equipment to partners, research customers, colleagues, and students.

Figure 36. Photograph of Kasper Hancke (SeaBee project coordinator) and Medyan Ghareeb (SeaBee chief pilot) in the NIVA SeaBee Lab with a DeltaQuad EVO VTOL drone. Photo: Anders Gjørwad Hagen/NIVA.

2.2 SeaBee LAB - NTNU

The NTNU SeaBee lab is a well-equipped facility featuring desk space, a screen, and ample storage for equipment. It houses various UAVs, including two Mugin 2 Pro VTOLs and the Matrice 600, along with sensors such as the AFX10 and the bathymetry version of the Maritime Robotics Otter. The Otter is equipped with advanced sensors like the TriOS Viper, Valeport Mini, and C3 Submersible Fluorometer. The lab also includes a dedicated desk where engineers, scientists, and pilots can examine and mount equipment, facilitating detailed technical work and research.

Figure 37. Photograph of the NTNU SeaBee Lab during a presentation. Photo credit: Kasper Hancke/NIVA.

3. Training drone pilots

In total, 11 UAV pilots and nine USV and UUV pilots are currently operative as part of the SeaBee infrastructure. These are located at the institutions involved as described below. Six drone pilots from NIVA are now educated for A1/A3 Open operations, one pilot is trained for STS (specific) operations. From NTNU, two pilots are trained for specific operations. In NINA (available for SeaBee), one pilot is trained for A1/A3. Within IMR, currently two pilots are trained for A1/A3 being part of SeaBee.

Table 24. Describes the number of pilots in SeaBee and level of training.

Institution	No. of pilots	License level
NIVA	6	Open A1/A3
NIVA	1	Specific
NINA	1	Open A1/A3
NTNU	2	Open A1/A3 and Specific
HI	2	Open A1/A3

3.1 Courses and training of pilots and payload operators

Keeping pace with the regulatory landscape has been one of our focuses. As drone technology and availability has spread so has the need for keeping pilots up-to date with the regulatory environment and current with their qualifications. Another important area is keeping pilots current with a drone flight at least every 3 months.

To keep pace with regulatory advances we have found that having a representative attending conference such as the UNMANNED NORDIC and the like annually has helped us keep track of any updates to procedures as well as better workflows to make fulfilling regulatory requirements more efficient. For example, the use of the NINOX application.

The European Union Air Safety Agency (EASA) provides up-to-date information regarding piloting and the necessary protocols that should be followed for any given scenario, pilots are encouraged to regularly check easa.com for updates

Our project partner TIEPOINT is focused on training Pilots and give us up-to date information as well as the opportunity to train.

For payloads pilots are encouraged to thoroughly read documentation concerning the operation of specific payloads to ensure that the best quality data can be collected. Experience with a particular sensor in close collaboration with the researchers that use the data as well as the data pipeline specialists is encouraged to get the best possible data from instruments. For instruments that need specialist software and skill for handling the data, for example the LIDAR and hyperspectral sensors specialist training is provided by the manufacturers of these sensors.

3.2 Integration of sensors

3.2.1. RGB Sensors

The DJI Zenmuse P1 (45MP RGB, 35mm lens) is specifically designed for DJI's Matrice 300/350 RTK and mounts directly via DJI's SkyPort gimbal system, providing full stabilization, power, and control integration. The M350 supplies power and handles all communication through this port, enabling seamless control via DJI Pilot. In contrast, third-party RGB cameras such as the Sony RX1RM2 (42MP), Sony A7R IV (61MP), and Sony ILX-LR1 (61MP) require custom mounts or gimbals. On the M350, these cameras are typically mounted using a Gremsy T3/T7 or similar gimbal, providing 3-axis stabilization, with power supplied either via the UAV's PSDK ports or separate batteries. The ILX-LR1 is designed for industrial UAV integration, supporting remote triggering and power (12-24V DC) via USB-C or GPIO, making it more UAV-friendly than the A7R IV or RX1RM2, which require camera control via Sony's Imaging Edge or third-party trigger modules.

For the DeltaQuad Evo VTOL, the P1 is not compatible due to its dependence on the SkyPort system. Instead, fixed nose- or belly-mounted configurations are used. The Sony ILX-LR1 is best suited for the Evo, designed for integration with UAVs and weighing only 243g. It supports remote triggering and full API control, powered directly from the airframe's avionics. The RX1RM2 (507g) and A7R IV (665g body) require custom mounts and careful weight balancing within Evo's payload bay. Data is stored internally on SD cards for all Sony models, with image triggering managed via flight controller signals (e.g., MAVLink commands or GPIO triggers) tied to mission waypoints. The Evo allows integration with PPK GNSS modules for precise geotagging, especially when using cameras like the ILX-LR1 designed for mapping missions.

3.2.2. Multispectral Sensors

The Micasense multispectral cameras are deployed using either multirotor or fixed-wing UAVs, depending on the application requirements. Multirotor UAVs are suitable for detailed imaging over small areas, while fixed-wing UAVs are used for long, straight transects with fewer options for tight overlap and flight patterns. The cameras are mounted on DJI drones using a skyport damping bracket to absorb vibrations and allow quick release. The DLS2 irradiance reference sensor is installed on the highest position of the drone to avoid shadowing.

On the DeltaQuad EVO, payloads are swappable without tools, integrated into the bottom panels. The multispectral cameras are powered by the drone's batteries through the DJI skyport connector, with the M300 drone featuring an embedded power converter. Data is stored internally on high-speed CF express type B memory cards. The cameras can be triggered automatically based on altitude and overlap settings or externally through the drone's skyport, with configurable GPIO pins for external triggering.

3.2.3. Hyperspectral Sensors

The SeaBee AFX10 hyperspectral camera is exclusively deployed on the DJI Matrice 600 Pro due to its weight and UAV payload restrictions. It is mounted using a Gremsy T7 3-Axis Digital Gyro-Stabilised Gimbal, which provides precise stabilization through a heated and temperature-controlled IMU sensor. The gimbal corrects pan, roll, and tilt angles to maintain nadir orientation, with rapid updates for smooth footage. The AFX10 camera is attached to the gimbal using tapped holes and offers quick plug-and-play installation.

The AFX10 camera is powered by the UAV's batteries, with a voltage range of 10 to 30 VDC. It interfaces with multiple devices through various ports, including flight controllers and remote controls. Data is stored internally and downloaded via FTP using a network cable. The camera's acquisition is triggered internally by Specim software, configured via ethernet connection before deployment, and records data during flight, associating frames with IMU records for geolocation.

3.2.4. LiDAR

The YellowScan Navigator bathymetric LiDAR is mounted on the Hexadrone Tundra 2 using the TR-LOCK quick-release interface and a vibration-damped bracket. This setup ensures nadir orientation and minimizes roll and pitch impacts on data quality. The LiDAR's 44° field of view is unobstructed, and vibrations are kept low. The system is made rugged for coastal operations with waterproof connectors and corrosion-resistant materials.

The Navigator is powered by either its LiPo battery or the Tundra 2's power supply, drawing 120 W. The TR-LOCK interface provides plug-and-play connectivity with Fischer IP68-rated connectors. Data is logged onboard to USB storage devices, and GNSS corrections are applied post-flight using PPK processing. The system operates based on GPS timestamping and can be integrated with UAV MAVLink commands or GPIO triggering if needed.

4. Conclusion

Over the past five years, the SeaBee research infrastructure has successfully established a national drone and sensor platform designed to support ecological and environmental research, mapping, and monitoring in aquatic environments. Led by the Norwegian Institute for Water Research (NIVA) and funded by the Research Council of Norway (2020–2025), SeaBee addresses critical societal challenges related to climate change, biodiversity loss, and ecosystem management. This is by providing advanced drone and sensor technology for collecting relevant and high-resolution environmental data to support data-driven decision-making.

The infrastructure has been developed through a comprehensive requirement assessment, which has guided the specification and acquisition of commercial and custom-built drones and sensors. These systems have been integrated into an operational capacity with the capability to support a wide range of environmental applications. Hardware configurations and capabilities have been continuously refined to align with the evolving demands of the scientific and policy communities.

SeaBee operates from two fully functional drone infrastructure nodes located at NIVA in Oslo and at NTNU in Trondheim. These sites serve as logistical and technical nodes for operations, storage, maintenance, and calibration of drones and sensors. Additionally, they function as national training and education centers, supporting capacity-building and workforce development in environmental science and technology.

The infrastructure now comprises a fully operational fleet of drones and sensors, with documented specifications and readiness to meet ongoing and future research needs. The establishment of “drone garages” at both nodes ensures sustained logistical support and efficient operational workflows at nationwide scales. This report represents the successful completion of an efficient physical drone infrastructure detailing available drone systems and sensor specifications.

Looking ahead, SeaBee will continue to support universities, research institutions, public authorities, and private stakeholders through a user-based funding model and strategic already-ongoing collaborations with Horizon Europe (HEU) and national and regional programs. Future development will focus on scaling-up of drone operations, integrating next-generation sensors, and advancing collaborations with other infrastructure platforms and research programs. Ongoing training and feedback mechanisms will ensure continuous adaptation to emerging technologies and maintain operational excellence.

In summary, SeaBee has delivered a robust and future-ready drone infrastructure that strengthens Norway’s capacity for environmental research and monitoring. Its continued operation and further developments will play a vital role in meeting national and international climate and environmental goals.