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Table of contents

1. Executive Summary 4

2. Introduction 5

3. Main report 6

4. Conclusions 13

5. Annexes and references 14

1. Executive Summary

The objective of this task is to develop a new towed underwater video system (TUVS), called 'Pagure-2' in order to map habitats, describe biodiversity, and monitor ecological changes in coastal benthic ecosystems. For this purpose, we modified an existing TUVS ('Pagure') to expand the range of accessible benthic habitats, to get more stable footage on irregular rocky bottoms, and to investigate fragile ecosystems (e.g., marine protected areas) where impact has to be limited. Thus, the Pagure-2 is a more versatile tool capable of being deployed on two different configurations: a classical 'sledge' mode with skates, and a 'flying' mode that reduces contact with the sea floor. It is easily deployable on small (~25 m) coastal vessels as well as large research vessels and was designed to cope with a 10-500 m operating depth range and with all kind of sea conditions and currents. It is also simple to use opportunistically on different kind of scientific cruises (benthic survey, fisheries stock assessment, hydrology, etc…) and without any dedicated specialist staff.

The two first years of the project were dedicated to the design, the production and the tests (in experimental tank and at sea) of the TUVS Pagure-2.

The optical sensors (front video camera and vertical still camera) provide data of very good quality during several tests at sea in 2016. Additional side cameras were used to assess the balance of the system and its footprint on the bottom.

A laser line coupled to a small video camera allows assessing surface microtopography (including features created by burrowing animals). The steel-frame of the Pagure-2 has been designed to integrate sensors of important environmental parameters (like temperature, salinity, oxygen, turbidity) to help to better characterize the ecological status of benthic habitats. However, these complementary equipments cannot be bought and installed in the context of the JERICO-Next project.

At this stage, the TUVS Pagure-2 proved to be a relevant imagery tool to get comprehensive insights into the integrity of benthic habitats of European coastal areas. The flying mode deployment still needs to be tested at sea in order to improve the stability of the system during towing and the measure of the vertical camera's coverage. This less destructive configuration should be particularly relevant to study benthic biodiversity in protected areas where disturbance has to be limited (e.g., maerl and seagrass beds, rocky bottoms with large erected benthic species).

Numerous applications should come in the next years, such as investigations of areas adversely affected by invasive species (e.g., *Crepidula fornicata*), human activities (bottom-trawling, sand-mining, marine renewable energy development).

2. Introduction

Advances in imagery instrumentation are allowing coastal ecosystems to be investigated at increasing spatial and temporal resolution since the 1950s (Mallet & Pelletier, 2014). Underwater video and still cameras, deployed in numerous ways, have become increasingly useful to map habitats, describe biodiversity, and monitor ecological changes in benthic ecosystems. These tools allow covering large and remote areas (beyond safe diving depth) efficiently and with minimal ecological impacts (permitting repeated sampling in fragile habitats). Moreover, archiving of imagery data (videos, photos) allows for repeated analyses of the data whenever required.

International, European and national targets to assess human impacts at sea and protect ecosystems require investigating biodiversity over large spatial scale with cost-effective and easily deployable tools. Many human activities at sea justify an assessment of their potential ecological disturbance on the benthic compartment. The impacts of fishing gears (trawling and dredging) have been widely investigated by imagery since the 1970s (Machan & Fedra, 1975). Recent activities such as exploitation of marine renewable energies (offshore wind farm, tidal turbines) often select sites that are difficult to access (e.g., high energy environments) and not well described in terms of benthic biodiversity. Here again, underwater video has proven to be an efficient tool to do benthic surveys in such context (Sheehan et al., 2010).

Underwater imagery tool can also be used to quantify many descriptors of the DCSMM such as biological diversity, non-indigeneous species, commercial shellfish, seafloor integrity or marine litter.

IFREMER has a long experience in developing underwater video imagery for different marine compartment (zooplankton, deep ecosystems, coastal zones) and various scientific purposes. The institute has recently developped an underwater towed video system (called Pagure) in the context of the European PANACHE (Protected Area Network Across the Channel Ecosystem) project (Sheehan et al., 2014). In the course of the same project, the Pagure has been compared to two other towed video systems, all three designed to investigate benthic ecosystems of the European continental shelves (Sheehan et al., 2016). Lessons have been learned from these different performance, userbility, and degree of impact. Despite providing data of very good quality, the Pagure system showed a significant impact on the bottom and appeared limited to quite homogeneous soft bottoms since it may snag on rocky seabed. It should be noted that the Pagure was initially designed to target trawled (or trawlable) areas in view of monitoring the impact of dredging fishing activities.

Then, it appeared necessary to improve the system in order to expand the range of type of benthic habitats. The objective was to get stable footage on irregular and hard bottoms, or to investigate fragile benthic ecosystems (e.g., marine protected areas) where impact has to be limited. As a result, it has been decided to propose a more versatile version of the Pagure system that could be deployed either on a classical ‘sledge’ mode or on a ‘flying’ mode which should be more suitable for rocky or fragile environments.

3. Main report

Description and functioning of the gear:

The 'Pagure-2' underwater towed video system (UTVS) is a gear capable of being deployed easily and opportunistically on a wide range of scientific vessels (25 m to larger).
Like the previous version ('Pagure'), the system is designed to cope with a 10-500 m operating depth range and with all kind of sea conditions and currents. It is also simple to use without any dedicated specialist staff and its compacted design allow for boarding on every kind of scientific cruises (benthic survey, fisheries stock assessment, hydrology, etc…).

The main innovation of Pagure-2 is its flexible deployment mode. A new steel frame has been designed to support a new buoyancy system and easily removable skates. That strategy allows deploying the system on two different modes: i) the classical 'seldge' mode (with skates) or ii) the 'flying' mode (without skates) (Fig. 1).

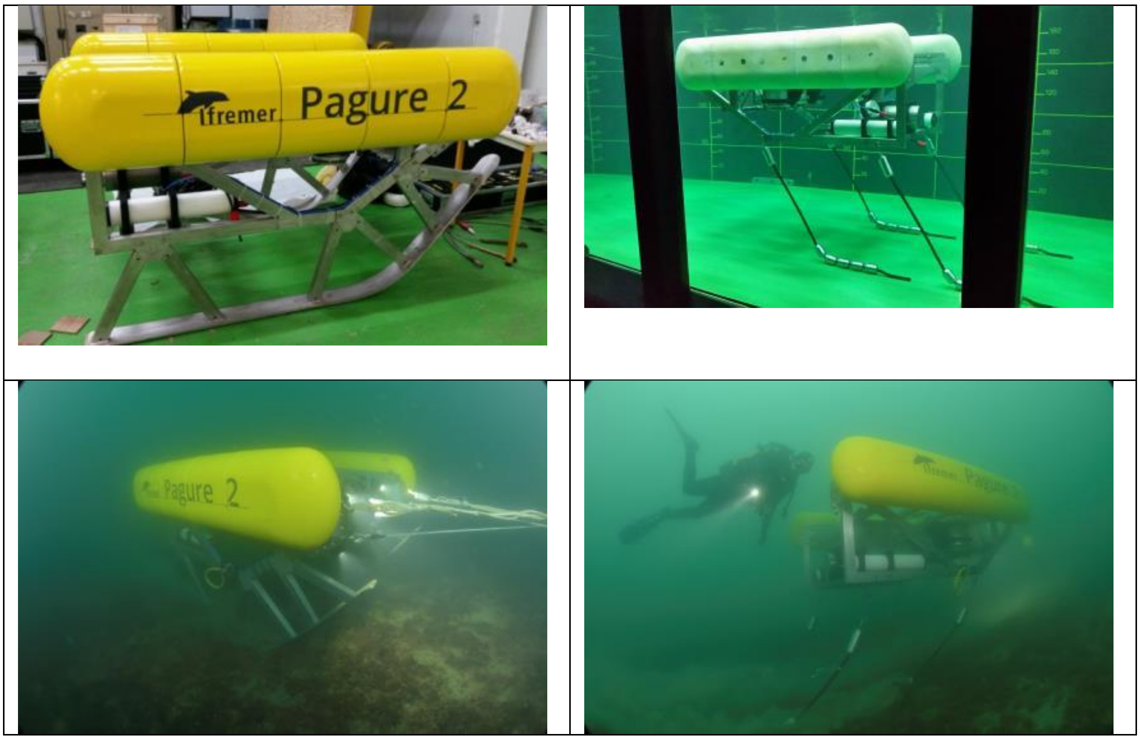

Figure 1: Views of the Pagure-2 on 'seldge' mode with its skates (left), on 'flying' mode with flexible ballasts (right), during tests at Boulogne-sur-Mer (top) and at sea in the bay of Brest (bottom) (© IFREMER, 2016).

The new buoyancy system is made of 10 independent floating modules made with syntactic foam (5 on each side of the sledge). This strategy significantly reduces the weight in water (30 Kg, when all modules are installed). When the skates are removed ('flying' mode), the weight in water may be further reduced depending on the number of weights attached on the flexible ballasts.

A video showing the functioning of the Pagure-2 TUV is available (only in French version) at this link: ftp://ftp.ifremer.fr/ifremer/com/montagePagure2SurThalia19Decembre.mp4

The optical characteristics are the same as those of the first version (Pagure) as they show good performance to provide accurate and well resolved imagery data on benthic biodiversity.
The camera (Panasonic HC-V700) is positioned 55 cm above the seabed (on sledge mode), and at an oblique 35° angle (adjustable from 0° to 60° to the horizontal). The camera is housed in a 600 m depth rated anodised aluminium chamber.

Two laser pointers (set 10 cm apart) are mounted above the video camera to allow size measurement of observed organisms and objects.

Table 1: Summary of the Pagure-2 specifications.

Operating depth	10 – 500 m
Size Size (without floating devices) Size (without skates)	1.80 m (L) x 1.00 m (H) x 1.80 m (W) 2.10 m (L) x 1.10 m (H) x 1.14 m (W) 1.86 m (L) x 0.65 m (H) x 1.14 m (W)
Mass	450 kg in air; 30 kg in water; (2 skates: 60 Kg in water)
Towing speed	0.7 – 1.2 knot
Floating	2 x (5 modules) Syntactic foam
Video camera	- HD Panasonic HC-V-700 (angled down 35°); 1920 x 1080 p, 50 fps; - GoPro-4 (coupled to laser line, and backward to assess impact on the bottom)
Photo camera	APN Canon G-15 (vertical view)
Lighting	4 LED-light (2 x 9000 lumens on top + 2 x 5000 lumens on bottom)
Laser	Front: 2 laser pointers (SeaLasers© 100; wavelength 532 nm green); down: 1 line laser
Batteries	- 1 x subCtech 90 Ah / 24V; - 2 x subCtech Li-Ion 25 Ah / 24V
Observation duration (for a single deployment)	3 h (limited by the video camera 32 Gb SD card capacity); batteries duration: 10 h

Type of collected data:

Video imagery:
Thanks to the wide field of the HD video camera, we can capture biodiversity data (visible mega- and macro-epibenthic organisms; flora, invertebrates and fish) and information on the physical characteristic of the visited benthic habitat (nature of bottom; anthropogenic footprints). Even the more dispersed taxa can be identified and counted by exploiting continuous video records. The two laser pointers allow estimating the size of the identified organisms (Fig. 2).

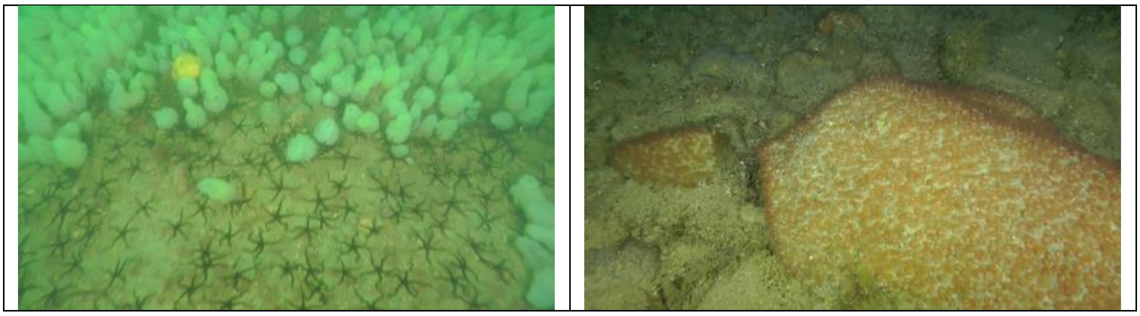

Figure 2: Examples of snapshots captured from videos recorded with the front oblique camera on during the Pagure-Next cruise in the Bay of Brest ('flying' mode; left) and during the CGFS cruise ('sledge' mode; right). NB: Laser points are hardly visible on these images (© IFREMER, 2016).

Still imagery:

Photography is used as a complementary tool to video to assess the density, coverage, size and ecological state (alive vs. dead) of the most frequent taxa. The better resolution of these photos allows a more precise identification of these taxa (with respect to the video records), especially for the smallest individuals (Fig. 3). This data acquisition is discontinuous and time lapse, sensibility of the optical sensor can be adjusted according to homogeneity of the habitat, darkness of the bottom type, turbidity of water, etc...

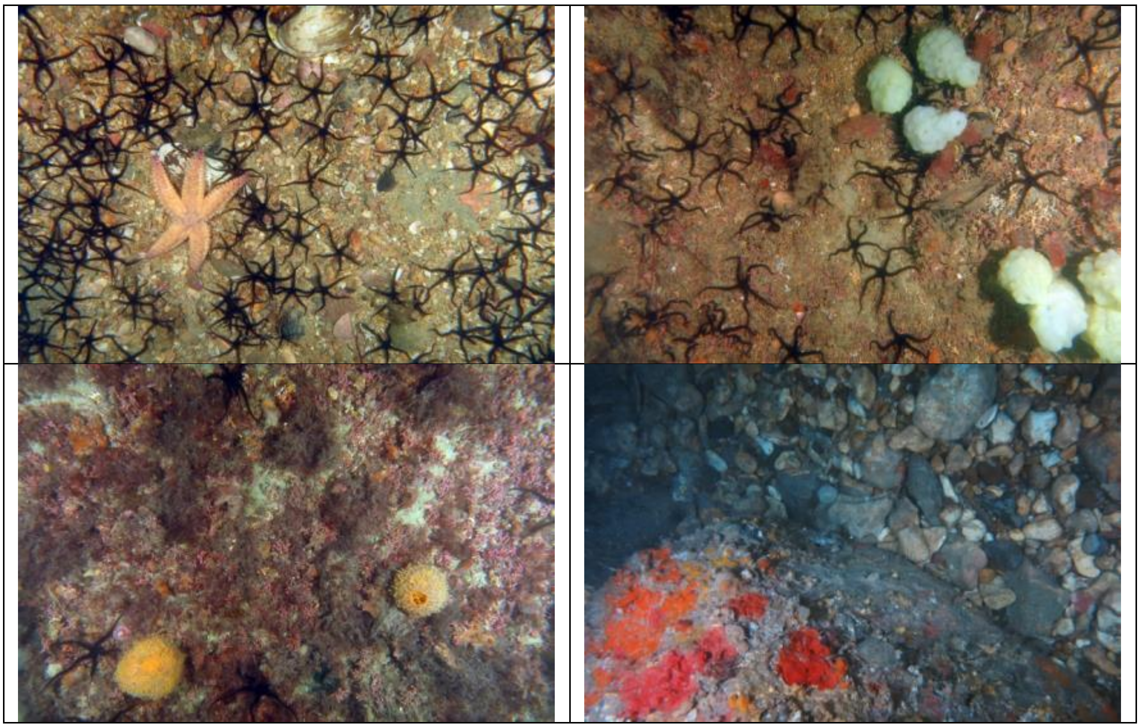

Figure 3: Examples of still images taken with the vertical camera ('sledge' deployment mode) during the Pagure-Next cruise in the Bay of Brest, showing the quality obtained on various benthic habitats (heterogeneous muddy; maerl bed; blocks and pebbles) (© IFREMER, 2016).

Tests at experimental facility and sea:

The Pagure-2 has been tested at the experimental tank of Boulogne-sur-Mer during summer 2016. Several immersions (for a total 3 days) were needed to test:
- the efficiency of the new floating system;
- the functioning of the sensors, batteries and connections;
- the position and the balance of the TUVS with current (to mimic the towing at ~ 1 knot) and with current and waves, especially on flying mode;
- the best attachment points for the towing cable and the weights (necessary for the 'flying' mode).

Soon after the experimental tests, the Pagure-2 has been deployed in several occasions, either for dedicated technical cruise or opportunistically during fisheries stock assessments:
- 37 dives during the CGFS cruise (September 23rd-October 14th, 2016), campaign of evaluation of the halieutic stocks in the eastern English Channel, only on 'sledge' mode;
- 27 dives during the Pagure-Next cruise, fully dedicated to tests with two deployment modes; in the bay of Brest, 5 days (October 16th-21th, 2016), at depth range 10-35 m, on different kind of bottoms (Fig. 1).
- Several dives during the EVOHE cruise (November-December 2016).

Forthcoming deployments at sea:
- EVOHE cruise (November-December 2017).

Footprint of the gear:

Besides permanent front and vertical cameras, additional side and backward cameras (GoPro) were temporary used to assess the balance of the system during towing and its physical impact on the seabed. Two successive video profiles were performed at a single shallow station in the Bay of Brest, first on sledge mode and then on flying mode to assess the relative footprint of each deployment mode. We choose a site with a mixed gravel and muddy sand sediment to detect easily the impact of the Pagure-2.
Divers took pictures of the footprints just after the passage of the TUVS and measured the wide and depth of these footprints with a plastic graduated scale (Fig. 4).

This preliminary comparison showed that the sledge mode generates a larger footprint (10 to 14 cm wide) than the flying mode (5 to 11 cm wide). Most often, the footprint of the flexible ballasts merged which generate a narrower trace (5 to 8 cm wide). However, the depth of the footprint seemed equivalent between the two deploying modes.
Of course, the footprint of the flying mode depends on the weight of the flexible ballast. This test was performed with four ballasts of 15 Kg each in order to reach a total weight in water equivalent to the sledge configuration. But the weight of these ballasts may be decreased.

Sledge mode	Flying mode (with 60 Kg of ballast)

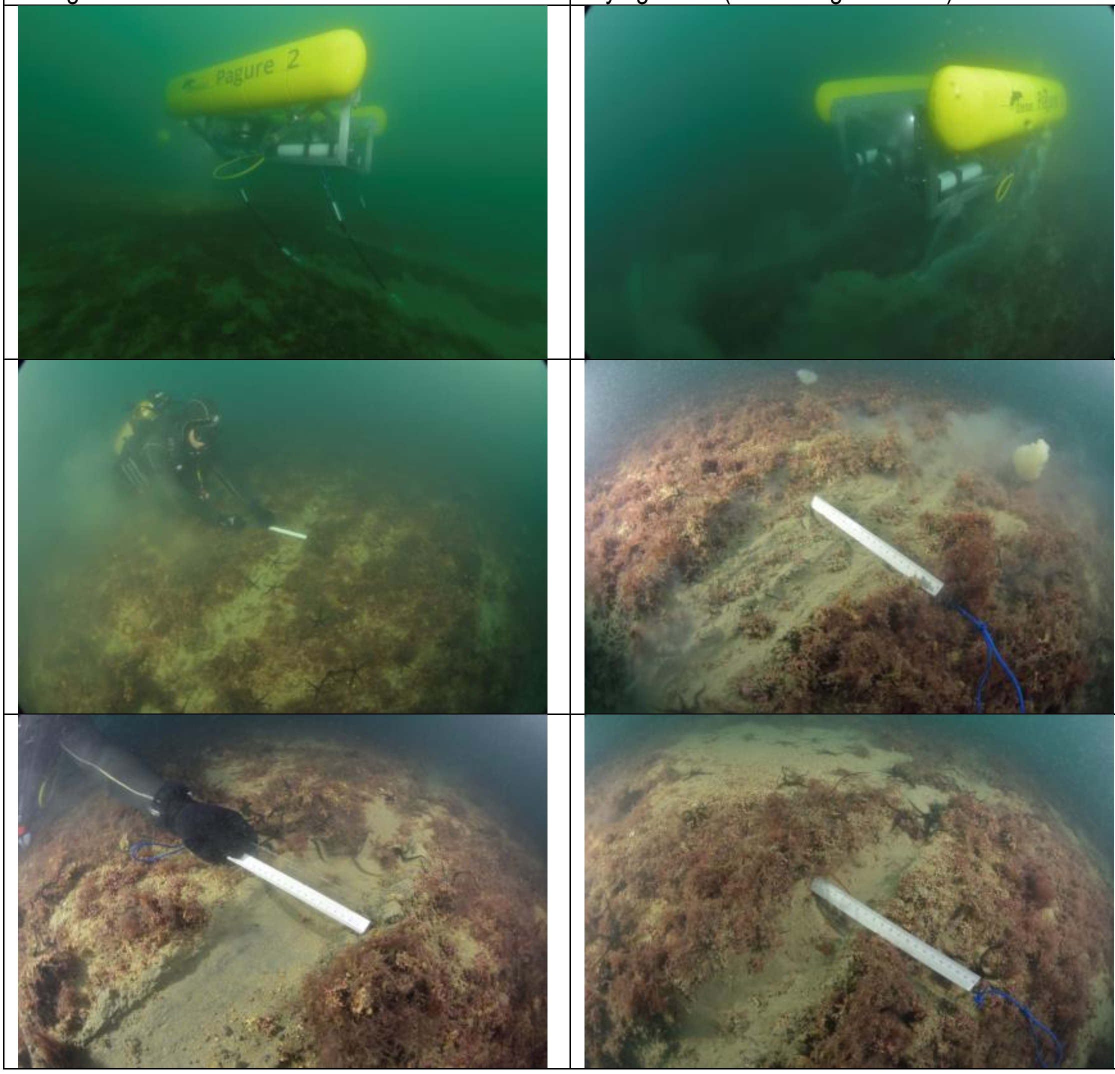

Figure 4: Footprints of the Pagure-2 deployed on sledge mode (left) and on flying mode (right) (© IFREMER, 2016).

Navigation recording:

The position of the Pagure-2 is recalculated from the GPS position of the vessel.
For deep investigations (> 50 m), a Marport system is installed on the frame of the video system to be informed of the landing and take-off time of the system.

Future evolutions:

Even though the flying mode of the Pagure-2 system gave so far satisfaction, and the 4 flexible ballasts allow varying the distance between the optical sensors and the bottom, improvements can be made regarding the stability of the system and coverage of the vertical still camera during data acquisition.
We have to do additional test-deployments to find the best combination of cable length, according to cable dimensions (material, diameter) and to the deployment depth.

Concerning the deployment flying-mode, additional work has to be done to properly determine the area covered by the vertical optical sensor, with respect to the deployment altitude (camera-bottom distance). Tests in experimental tank can allow establishing a correspondence between camera-covered area and the weight of the ballast (number of attached weights). However, in case of investigations of irregular bottoms, or during big swell in shallow (< 30 m) ecosystems, the altitude of the video-system may vary during a single transect. In such cases, a precise and real time evaluation of the scale would be needed. A laser system (equivalent to the one used with the front oblique camera) is not suitable as the laser points would not be visible because of the intensity of the camera flashes. So, others solutions have to be find.

In the near future, a better front camera is needed to replace the current one which is a commercial model that becomes obsolete (in terms of possibility of maintenance).

As initially presented in the proposal of this task, at the submission stage of JERICO-Next project, a valuable technical evolution would be to include additional sensors on the frame of the Pagure-2 system, in order to get data of important environmental parameters like bottom temperature and salinity (which can be very different from the surface layer in circalittoral areas), light available for benthic primary producers, cholorophyll *a* and turbidity. The steel frame and the floating system of the Pagure-2 have been designed in view of such technical evolution, and up to 10 kg (in water;) of additional sensors could be installed in the future.

Beyond the duration of the JERICO-Next project, and at a longer term perspective, an important and useful technical evolution could be to bring the video signal onboard with an additional numerical ombilic or with a electroporteur cable. Live video connection with the surface would help to select more efficiently the benthic habitats of scientific interest during exploration surveys, and to tune more precisely the deployment and towing parameters (towing cable length, speed of vessel, etc).

Finally, as for most of other underwater imagery approaches, a major challenge remains in the automatic treatment and interpretation of the video and photo data. As a large quantity of data can rapidly and easily be produced by a video system such as the Pagure-2 TUV, an automated or semi-automated treatment algorithm would be welcome to exploit in more standardized way biodiversity data originating from rich benthic habitats, to compare biodiversity changes over large temporal or geographical scale. Even if algorithms are still far from replacing human eye in the description of benthic taxonomic richness, recent advances have been made in automated imagery data processing and software can now perform preliminary, coarse benthic habitat classification (Aguzzi et al., 2011; Williams et al., 2012) and taxa counting (Romero-Ramirez et al., 2016). Preliminary results have been obtained with imagery data recorded with the 'Pagure' TUVS and exploitation of these data with software developed in the context of the JERICO project (Fig. 5).

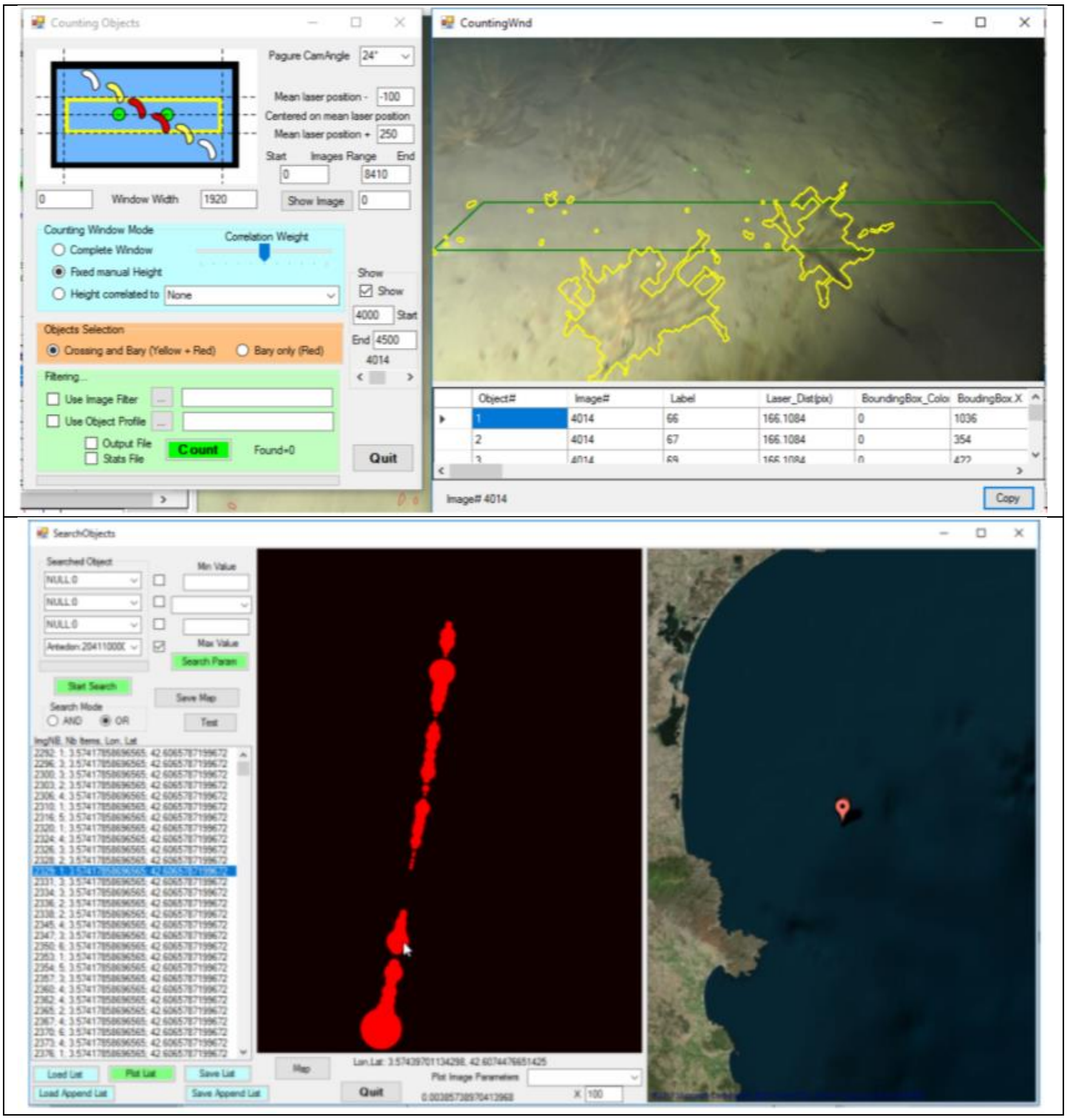

Figure 5: Examples of semi-automated treatment of videos recorded with the ‘Pagure’ in the Mediterranean Sea with the software AviNotes. Top: Detection and counting of benthic organisms; bottom: assessment of spatial variability of a benthic taxa based on geolocalised video snapshots (Guillerme, 2017).

4. Conclusions

The development of the new towed video system 'Pagure 2' and the first tests at sea have been successfully achieved on time.
A video is available on the JERICO-RI website: http://www.jerico-ri.eu/project-information/media/

The main innovation of the system is its flexible deploying mode, either on a sledge mode (with skates), or on a flying mode (without skates), the latter being well adapted for exploring irregular rocky bottoms and/or fragile benthic ecosystems.
Regarding the 'flying mode' of the system, there are still some tests to perform at sea in order to find the best combinaison of towing tuning.
The funding did not allow to install additional sensors to record important environmental parameters (temperature, salinity, light intensity, etc…) as mentioned in the proposal. However, the frame of the Pagure 2 has been designed in this sense, and this could be done later in other context of scientific projects.

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