Recommendations for environmental monitoring around seafloor exploitation sites: Drilling, Mining, Decommissioning

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There are yet no international regulations or even an international consensus on how exactly the activities of the offshore oil, gas and mining industry should be monitored. Variations in seabed depth, topography, fauna and ambient oceanographic conditions found at each potential exploitation site compound the problem, making it difficult for one set of regulations or guidelines to be applicable for all situations. Fig.1 presents one example.

With experience from several international projects on environmental monitoring of drilling operations and on planned deep sea mining operations I recommend a two-way approach by combining A: laboratory experiments with numerical modeling to characterize the hydrodynamic behavior of particles/pollutants which are resuspended during industry operations with B: in-situ robotic monitoring prior (≥ 1year), during and after these the industry operations.

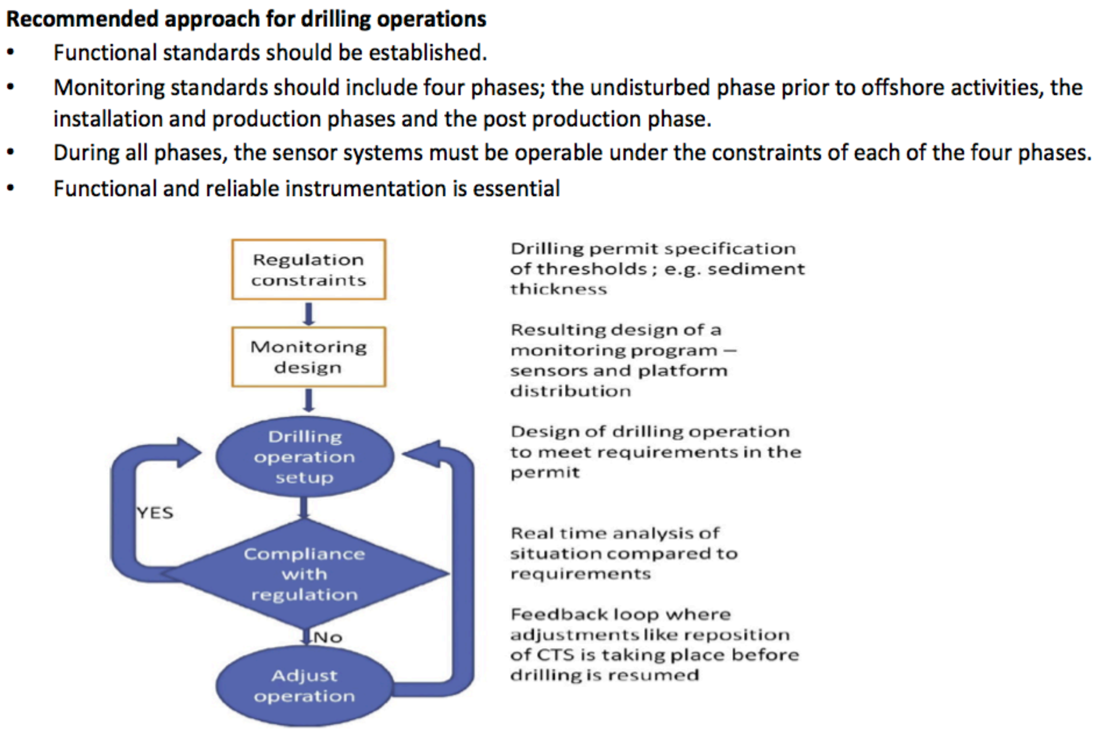


Fig. 1 Example for drilling operations (Godo, Klungsøyr, Meier, Tenningen, Purser,Thomsen, L. (2014)

A Laboratory work

The following characteristics of the surface sediments and processes should be determined: u_{*cri} (critical shear stress) and u_{*dep} (critical depositional stress), Ws (settling velocity), particle size spectrum and D_{50} (median particle size), sediment blanketing, aggregation rate under low and elevated turbulence using shear tanks, water column simulators and flumes. The data collected are then fed into a hydrodynamic model to localize fallout areas of the different aggregated size fractions.

Key species from the exploitation site should be investigated in their behavior following blanketing events, that is the massive fallout of particles onto the benthic communities. Ex-situ experiments can be carried out with species which occur in both shallow and deep sea environments like cold water corals. For species which only occur in the deep sea, surrogate species from shallow waters with similar feeding behavior or in-situ observations during such exploitation activities can be used. Animal behavior (using HD cameras) and oxygen demand under stress are two parameters which can be determined to support subsequent ecosystem modeling (Fig.2).

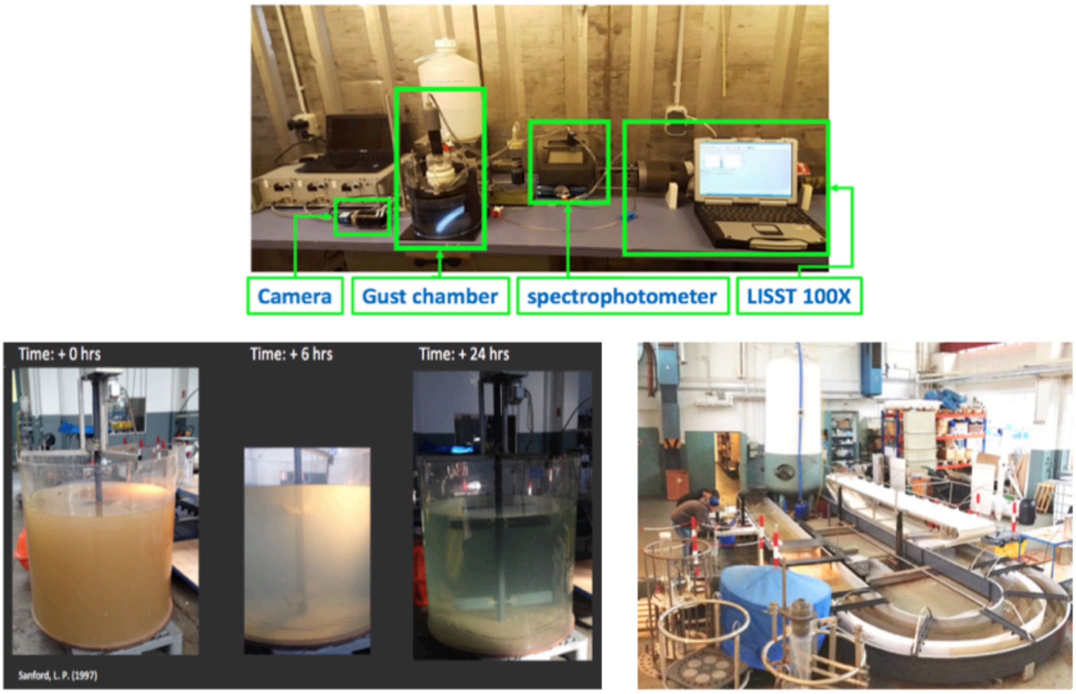


Fig. 2. Laboratory setup in OceanLab at Jacobs University to determine particle characteristics, using benthic (Gust) chambers, water column simulators (1000 l) and a 14 m seawater flume

B Field work

Baseline study prior to and after offshore exploitation activities

For baseline studies prior to industry operations and for environmental monitoring during and after operations we recommend to use a combination of stationary lander and mobile robots (crawlers) which are in use since 2010 (Fig.3).

A baseline study on benthic community structure, species richness is required prior to drilling, for comparison with post drilling assessments. Multivariate analysis of fauna at various survey points around the exploitation site are recommended. It is important to be able to predict the dispersal paths of material following release to the ocean. These predictions should be based on the results from the laboratory analyses and on the hydrodynamic conditions assessed at the site during the monitoring period before industry operations commences. Commonly, Acoustic Doppler Current Profilers (ADCPs) located on the stationary lander (central station) and on the mobile robot record current conditions for a period of time.

We recommend to deploy 1 -2 autonomous crawlers (Fig.8) equipped with sensors to determine flow characteristics, particle behavior, turbidity, fluorescence (chlorophyll), oxygen demand (benthic chamber or micro profiler), (3D) cameras for faunal analyses and 3D mapping of the seafloor. Regular time-lapse sampling of bio- and environmental data over a period of ≥1 year can then quantify biodiversity status and key species presence, if conducted at the appropriate spatial scales. A bioacoustics sensor is recommended for the central station to study the bentho-pelagic fauna including fish and mammals.
These mobile robots perform transect analyses over several kilometers (Fig.8). On demand they can be supported by central stations (junction boxes) which allow to recharge the batteries and transfer the data onto an additional central data storage (Fig.5).

During exploitation

Scientific research projects such as ONC Canada or LoVe Norway have shown that 24/7 access to sensing equipment over cabled infrastructures is possible, even at several thousands of meters depth. Such scientific cabled observatories can be accessed remotely by researchers over the internet, often with users downloading high volumes of data in seconds, analyzing HD video streams or controlling remote operated equipment and manipulators. We recommend to install such cabled infrastructure which allows authorities and operational centers to permanently monitor the environment and rapidly react to disturbances. Once installed the sensors and crawlers (ONC) can easily be recovered for maintenance and exchanged using regular ships, thus avoiding expensive ROV operations for recovery and redeployment (METAS).

The robots are either tele-operated or monitor the environment autonomously during transects from one junction box to the next, where they transfer the data and recharge the batteries.

More especially, this approach allows multidisciplinary teams from different continents to investigate in parallel short- and long-term events and processes at the same time, interact with the sampling procedure by changing the observational missions, change the instrument/sensor deployments and data collection strategies, and interrogate a progressively large digital database. AUVs and docking station can be developed at a second stage of the project.

This technology can also easily be deployed at shallow water decommissioning sites in the North Sea (Fig.7), where existing/remaining infrastructure above sea surface can serve as communication and energy hub for tele-operations with crawlers equipped with specific analyzing technologies (Raman-spectroscopy, manipulators)

For nearshore areas the robot can be controlled via a surface buoy and WLAN. The robots are small enough to allow deployment from small vessels or even helicopters if needed (Fig.6). This technology can also be used to control crawlers for cable inspection, thus avoiding difficult ship-connected ROV operations under strong currents.

For each of the activities mentioned above the seafloor robots allow a cost- and energy efficient monitoring procedure in the range of 1 – 2 km, with the ability to extend operations to 10 or more kilometers when using autonomous operations and additional X-nets equipped with power to provide energy.

Fig. 3 Crawler technology, operational at the Ocean Networks Canada cabled observatory since 2010 for 12 – 18 months deployments at 900 m water depths in Barkley Canyon

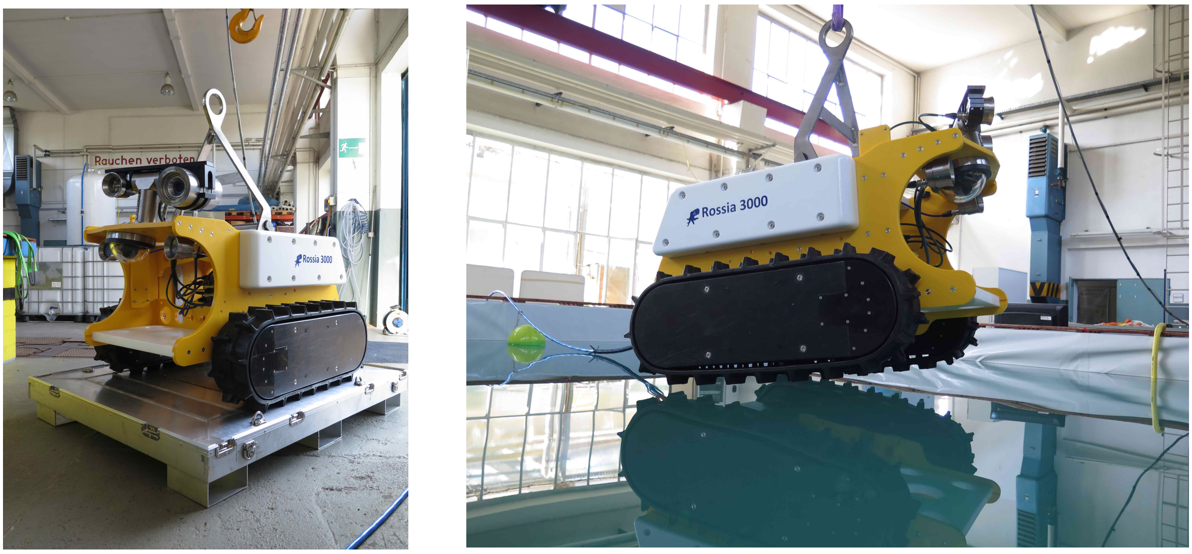


Fig. 4. New crawler robots (iSeaMC) for tele-operated or autonomous operations from 10 – 5000 m water depths. Dimensions: 120 x 100 x 90 cm /L/W/H), 250 kg in air, 30 kg in water, 5 – 10 sensors, benthic chamber (operational in 2018).

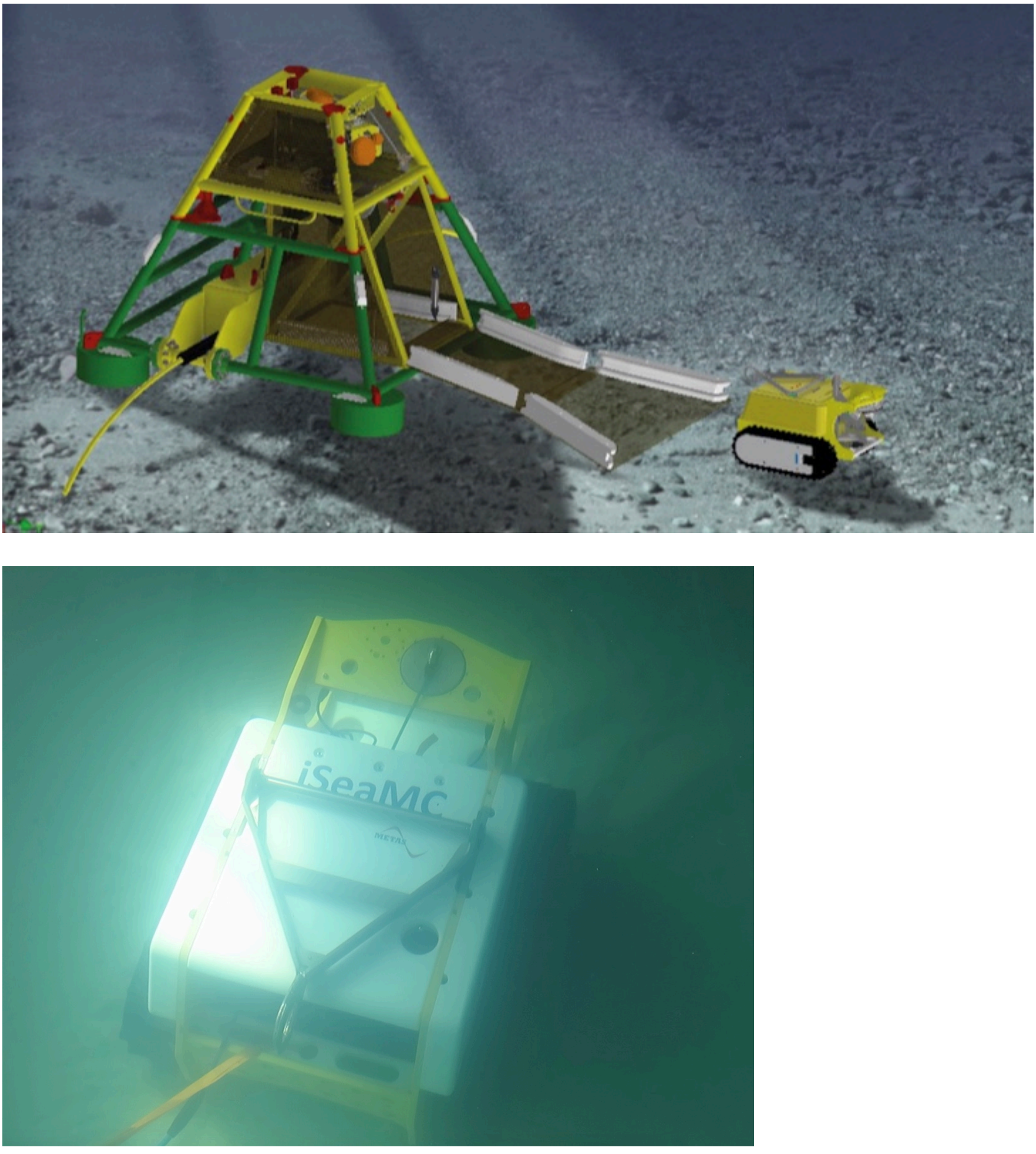


Fig. 5. Cabled observatory with the METAS X-Net system with garage for a tele-operated or fully autonomous crawler from iSeaMC. The sensors installed in the X-Frame (yellow part) and crawler is serviced and maintained via a specially designed launch and retrieval tool (METAS), which does not need ROV operations (operational in 2020).

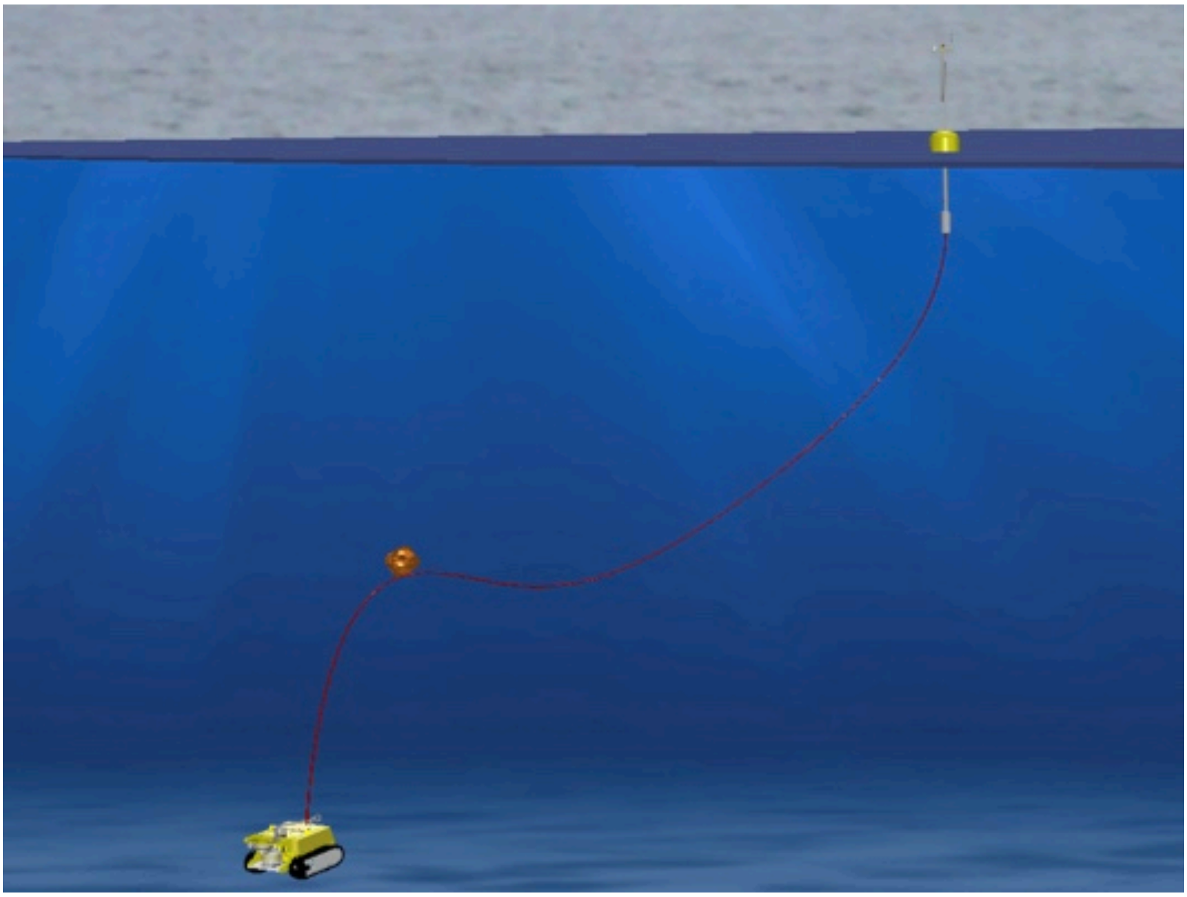


Fig. 6. Crawler control via surface float for deployments in coastal areas from ships. The crawler can be deployed from a vessel of opportunity. Test cruise in November 2019. The WLAN connection can be extended to several kilometers in water depth down to 200 m.

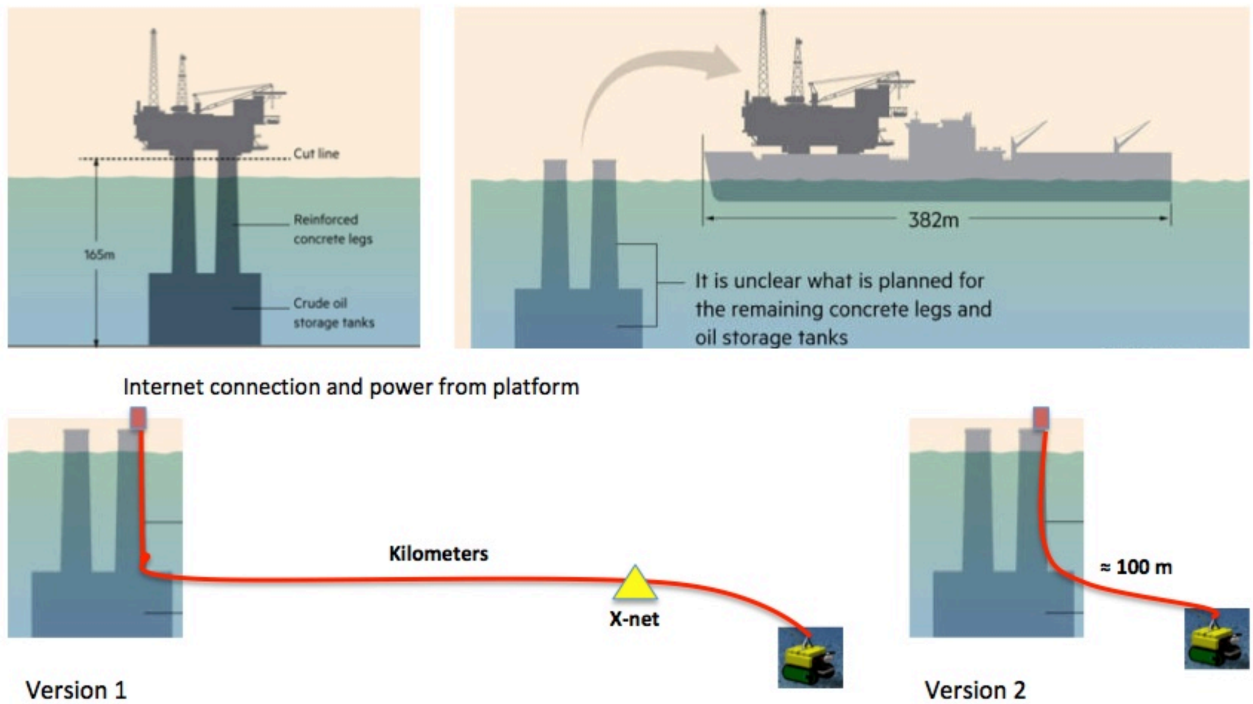
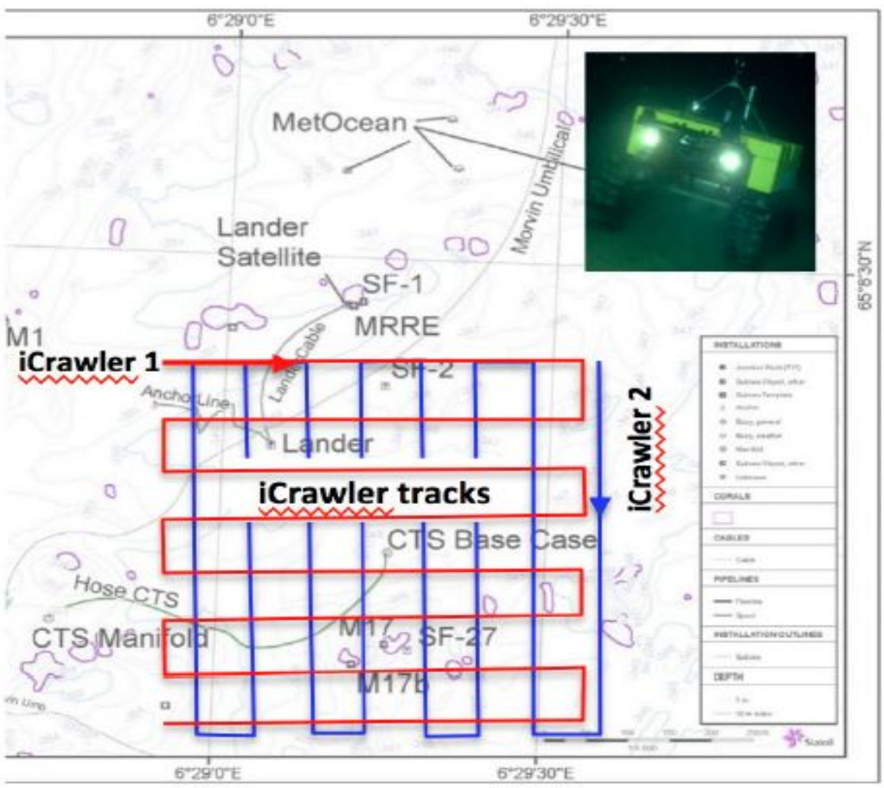


Fig. 7. Suggestion for environmental monitoring of decommissioning sites. Tele-operated crawlers are controlled via infrastructure which remained at the site during the decommissioning process. (Modified from Shell)

Example of future monitoring operations: A baseline study will be provided with one robot 1 – 0.5 years before drilling operations, followed by detailed monitoring during the 3-6 weeks drilling process and 1 mission after the end of drilling. During exploration, 1 – 3 robots can monitor the environment and can be regularly maintained via ROVs.



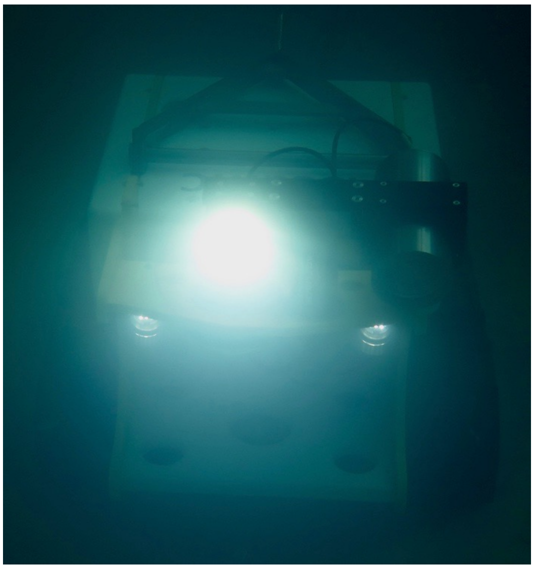


Fig. 8. Example for autonomous operations (by 2020). The system can then also be used for environmental monitoring at deep sea mining sites (> 4 km water depth)

Comparison Crawler / AUV, Glider / ROV

Crawler (typically monitoring areas of 0.1 to 1 km^2 size)

Safety

- simpler technology in terms of complexity, costs, and robustness, less personal intensive
- missions can be transferred via internet onto the ship before deployment
- can safely be switched off, energy efficient,
- qualifies for longterm operation both regarding robustness and energy efficiency

Stability

- solid base from which to work and sample. Sensor data can be taken accurately. Sensors can be placed more precisely than with ROVs.
- a robotic arm (on demand) allows direct access into complex habitats such as reefs (teleoperated mode)

Repeatability

- not affected by current flow conditions and can return to resample locations easier
- less personal bias in sampling.
- at cabled observatories, experts can drive and analyze via internet

Sensor load (120 kg payload)

- crawlers are routinely equipped with 6 sensor ports, though with the stable tracked design, more can be carried if required.
- sensors and profilers can precisely penetrate the seafloor; by mounting such systems at the front of a crawler, undisturbed areas can be profiled for oxygen, pH, methane, CO_2, etc. In the context of oil and gas drilling, cores to gauge drill cutting depth coverage can be easily taken, either for in situ camera observations or for transport back to a base station for retrieval and later analysis
- very detailed transect analyses with laser guided habitat mapping.

Fig. 9. Comparison between crawlers and AUVs, ROVs

Relevant references from the author

Thomsen, L., Aguzzi, J., Costa, C., De Leo, F., Ogston, A., & Purser, A. (2017). The Oceanic Biological Pump: Rapid carbon transfer to depth at Continental Margins during Winter. *Scientific reports*, *7*(1), 10763.

Doya, C., Chatzievangelou, D., Bahamon, N., Purser, A., De Leo, F.C., Juniper, S.K., Thomsen, L. and Aguzzi, J., (2017). Seasonal monitoring of deep-sea megabenthos in Barkley Canyon cold seep by internet operated vehicle (IOV). *PloS one*, *12*(5), p.e0176917.

Danovaro R.[1,2*], Aguzzi, J.[3*], Fanelli E.[4*], Billett D.[5], Gjerde K.[6], Jamieson A.[7], Ramirez-Llodra E.[8], Smith C.R.[9], Snelgrove P.V.R.[10], Thomsen L.[11], Van Dover C. (2017) Towards a global ecosystem-based strategy for the deep ocean. *Science* 355, 6324, pp. 452-454

Chatzievangelou, D., Doya, C., Thomsen, L., Purser, A., & Aguzzi, J. (2016). High-Frequency Patterns in the Abundance of Benthic Species near a Cold-Seep–An Internet Operated Vehicle Application. *PloS one*, *11*(10), e0163808.

Brandt, A., Gutt, J., Hildebrandt, M., Pawlowski, J., Schwendner, J., Soltwedel, T., & Thomsen, L. (2016). Cutting the Umbilical: New Technological Perspectives in Benthic Deep-Sea Research. *Journal of Marine Science and Engineering*, *4*(2), 36.

Thomsen, L., et al. Temporal and spatial benthic data collection via mobile robots: Present and future applications. In: *OCEANS 2015-Genova*. IEEE, 2015. S. 1-5

Aguzzi, J., Doya, C., Tecchio, S., De Leo, F. C., Azzurro, E., Costa, C., ... L.Thomsen& Catalán, I. A. (2015) Coastal observatories for monitoring of fish behaviour and their responses to environmental changes. *Reviews in Fish Biology and Fisheries*, 1-21.

Person, R., Favali, P., Ruhl, H. A., Beranzoli, L., Rolin, J. F., Waldmann, C., ... & Thomsen, L. (2015). From ESONET multidisciplinary scientific community to EMSO novel European research infrastructure for ocean observation. In *SEAFLOOR OBSERVATORIES* (pp. 531-563). Springer Berlin Heidelberg.

Godø O R, Klungsøyr J, Meier S, Tenningen E, Purser A, Thomsen L (2014). Real time observation system for monitoring environmental impact on marine ecosystems from oil drilling operations. Marine pollution bulletin 84.1 (2014): 236-250.

Ballent, A., S. Pando, A. Purser, M. F. Juliano, and L. Thomsen (2013). "Modelled transport of benthic marine microplastic pollution in the Nazaré Canyon." Biogeosciences 10, no. 12

Pando, S., M. Juliano, R. Garcia, Jesus Mendes, and L. Thomsen (2013). "Application of a Lagrangian transport model to organo-mineral aggregates within the Nazaré canyon." Biogeosciences Discussions 10, no. 1, 447-481.

Purser, A., Thomsen, L., Barnes, C., Best, M., Chapman, R., Hofbauer, M., & Wagner, H. (2013). Temporal and spatial benthic data collection via an internet operated Deep Sea Crawler. Methods in Oceanography, 5, 1-18.

Larsson, A., Oevelen, D., Purser, A., Thomsen,L. (2012) Tolerance to long-term exposure of suspended benthic sediments and drill cuttings in the cold-water coral Lophelia pertusa, Marine Pollution Bulletin, in press, 10.1016/j.marpolbul.2013.02.033.

Thomsen L, Barnes C, Best M, Chapman R, Pirenne B, Thomsen R, Vogt J. (2012) Ocean circulation promotes methane release from gas hydrate outcrops at the NEPTUNE Canada Barkley Canyon node, Geophys. Res. Lett., 39, L16605, doi:10.1029/2012GL052462.

Pabortsava K, Purser A, Wagner H, Thomsen L (2011) The influence of drill cuttings on the physical characteristics of phytodetritus. Marine Pollution Bulletin. 62, 2170-2180.doi:10.1016/j.marpolbul.2011.07.002

Ruhl H, Andre M, Beranzoli L, Cagatay N, Colaco A, Cannat M, Danobeitia J, Favali P, Geli L, Gillooly M, Greinert J, Hall P, Huber R, Karstensen J, Lampitt R, Larkin K, Lykousis V, Mienert J, Miranda J, Person R, Priede Puillat I, Thomsen L, Waldmann C (2011) Societal need for improved understanding of climate change, anthropogenic impacts, and geo-hazard warning drive development of ocean observatories in European Seas. Progress In Oceanography 91 (1), 1-33.doi:10.1016/j.pocean.2011.05.001

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