Using a Remote Operating Vehicle (ROV) to estimate the population density of *Octopus vulgaris* at Krk Island, Croatia

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Abstract

This study investigates the use of small Remote Operating Vehicles (ROVs) to estimate the population density of *Octopus vulgaris* around Krk Island, Croatia. During this study 40 ROV dives were performed across ten locations. In total, seven octopuses were discovered in a total recording time of approximately 19 hours. Using these recordings and the area observed, the population density was 0.177 octopuses per 1000 m^2. This is similar to findings in studies applying different methods in the Mediterranean Sea. The study highlights the advantages of ROVs, including their ability to operate at great depths, for long durations and in different habitats. However, challenges remain like the difficulty in spotting octopuses in dens and further improvement of this method is required to obtain higher data quality and accuracy. The findings suggest that ROVs are a promising tool for octopus population studies.

1 Introduction

The Common Octopus (*Octopus vulgaris*) is the most common octopus species in the Mediterranean Sea [Jereb et al., 2016] and it is distributed in the Mediterranean Sea as well as in central and north-east Atlantic Sea [Jereb et al., 2016]. *Octopus vulgaris* has been reported to live in depth from 0 to 250 m depth, but can be found mostly shallower than 100 m [Jereb et al., 2016; Faraj and Bez, 2007; Belcari et al., 2002]. In the Mediterranean Sea *Octopus vulgaris* is a highly valuable food resource and the most important fished Cephalopod [Allcock et al., 2016; Jereb et al., 2016]. Octopuses are fished with different methods, like hand-jigs, pots, traps, trammel nets or bottom trawls [Allcock et al., 2016]. The commercial interest increased over years. In 1980, 1849 thousand tonnes of Cephalopods were consumed and in 2019, this number increased up to 3576 thousand tonnes [FAO, 2023]. Although the appetite for octopus is increasing, the rising average water temperatures due to climate change, lead to strong annual variability and long-term decline in octopus landings in the Mediterranean Sea [Vargas-Yáñez et al., 2009]. Nonetheless, no conservation measures for octopuses exist [Allcock et al., 2016]. Therefore, research and monitoring of octopus populations is essential to

determine whether climate change and harvesting have any significant impact on populations of octopuses.
To measure the population of octopuses different approaches are used. The most common one is trawling, with data from commercial fishing or special research cruises [Faraj and Bez, 2007; Belcari et al., 2002; Fonseca et al., 2002; Sobrino et al., 2020; Tsangridis et al., 2002; Quetglas et al., 1998]. Trawls are conducted on soft, sandy or muddy bottom [Quetglas et al., 1998] and in areas more distant from shore with maximum depths of 800 m [Belcari et al., 2002]. Often, octopuses are no target species in commercial trawls [Fonseca et al., 2002] and they may escape, because they can squeeze through small mesh sizes [Fonseca et al., 2002; Katsanevakis and Verriopoulos, 2006]. Trawling approaches may find less octopuses than there actually are, because of the size selectiveness. Other fishing methods to measure the population density of octopuses are traps and pots. Pots are made to catch octopuses. The annual catch of *Octopus vulgaris* made by pots from the Spanisch Mediterranean coast makes up 36.2 % from total [Sánchez and Obarti, 1993]. Traps are made of iron, in a circular shape and covered with a metallic mesh [Hernandez-Garcia et al., 1998]. They are used all year long, but octopuses are no target species for users of traps [Hernandez-Garcia et al., 1998]. Traps are also used in capture-recapture approaches to measure the population density of octopuses. Arechavala-Lopez et al. [2018] caught octopuses with traps and tagged them to recognize them later. This method can be used at very different bottoms, like mud, sand, cobblestones, gravel, seagrass, or rocks [Arechavala-Lopez et al., 2018].
In research, often, SCUBA diving is used to measure the population density of octopuses [Katsanevakis and Verriopoulos, 2004a, 2006; Oosthuizen and Smale, 2003; Guerra et al., 2014, 2015; Leite et al., 2009]. Fixed transects are dived by two or more divers and observed or video-recorded [Katsanevakis and Verriopoulos, 2004a, 2006; Guerra et al., 2014; Leite et al., 2009]. Another SCUBA diving based method is to do roving dives to cover a larger number of areas [Leite et al., 2009]. The maximum depth of SCUBA diving is 21 to 40 m, because of depth-time and with that decompression limits [Katsanevakis and Verriopoulos, 2004a,a; Guerra et al., 2014, 2015; Leite et al., 2009].
In the here described study, a small Remote Operating Vehicle (ROV) was used to

film the population of *Octopus vulgaris*. ROVs are unmanned submersibles which are connected to a pilot via a cable [Liu, 2022; Sward et al., 2019]. The cable connection ensures the communication and with that the control over the actions of the ROV [Liu, 2022]. The ROV can be powered by an external power supply unit or with batteries onboard of the ROV. [Liu, 2022; Sward et al., 2019]. ROVs are used for underwater observation or exploration of the seabed as well as underwater construction, maintenance, inspection, or cleaning of structures [Christ and Wernli, 2008; Liu, 2022; Sward et al., 2019]. ROVs provide real-time video observations and environmental parameters like depth or temperature [Liu, 2022; Sward et al., 2019]. They also can operate via a manipulator [Barry et al., 2023; Liu, 2022].
The research question of this study is:

- Are Remote Operating Vehicles a good instrument to study the population density of *Octopus vulgaris*?

2 Materials and Methods

To measure the population density of *Octopus vulgaris* Remote Operating Vehicles (ROVs) were used. Diving was made with small observation-class ROVs from QYSEA. Table 1 lists the characteristics of the three different ROV models used in this study. The ROVs were connected via a 100 m or 200 m long cable to the pilot for communication. All dives were recorded for later analyses.

Table 1 Used Remote Operating Vehicle models from QYSEA fifish.

Model	V6	V6s	Pro V6 Plus
Dimension (mm)	383 x 331 x 143	383 x 331 x 143	383 x 331 x 158
Weight (kg)	3.9	4.1	5
Max. depth (m)	100	100	150
Max. speed (m/s)	1.5	1.5	1.5
Camera	4k	4k	4k
LED (Lumens)	4000	4000	6000
Battery capacity (Wh)	97	156	156

All surveys were conducted from May 11 to July 2, 2024 near the island of Krk, Croatia. Figure 1 shows the diving locations in detail and table 2 shows the characteristics of each location. The ten different locations were selected, because of their different depths, bottoms, and ecological conditions. The maximum depth in the different locations varied between 7 and 115 m and the locations had different bottom materials. The ROV dives were carried out at daytime or in the night and started from land or boat, all depending on the location and their accessibility. The ROV was manoeuvered to the ground directly after its release. The hight above the ground at which the ROV was manoeuvered depended on the visibility and varied between 0.01 m and 2 m. At each location the ROV was driven around randomly to film the habitat. If signs of octopuses, like food leftovers, dens, or an octopus itself, were sighted, they were observed for as long as needed or in case of an octopus, as long as possible. Octopuses were filmed also to observe their behaviour in their natural habitat. The observation lasted until the battery of the ROV was empty. The recorded videos were viewed again and the recording start and end time, the maximum depth, the temperature, signs of octopuses like food leftovers, natural dens and octopuses were noted.

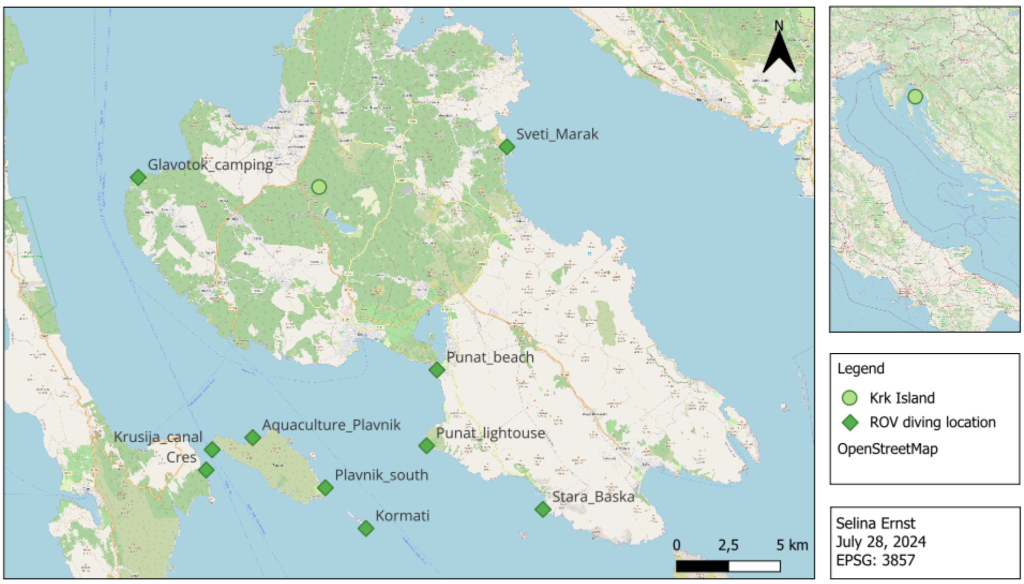

Figure 1 Map of the ROV diving locations in the croatian North Adriatic Sea.

Table 2 Characterisitcs of ROV diving locations.

Location	Coordinates	Max. depth (m)	Ground
Glavotok Camping	45.0946, 14.4395	7	Rocks, sand
Sveti Marak	45.1078, 14.6652	27	Rocks, sand
Punat Beach	45.0114, 14.6223	8	Rocks, sand
Krusija Canal	44.9770, 14.4848	115	Mud
Aquaculture Plavnik	44.9821, 14.5096	60	Mud
Punat Lighthouse	44.9787, 14.6160	20	Rocks, sand
Cres	44.9682, 14.4811	75	Sand
Plavnik South	44.9605, 14.5540	44	Posidonia
Stara Baska	44.9511, 14.6872	31	Rocks, sand
Kormati	44.9429, 14.5789	30	Posidonia

3 Results

The total recording time with the ROVs during 40 dives was 18:50 hours. The individual dives lasted from 00:27 hours to 2:27 hours, with an average diving time of 01:04 hours. During the total time of recording 7 octopuses were detected and observed for a total time of 02:01 hours. The shortest octopus observation lasted only for 5 seconds, because the pilot did not recognize the octopus while manoeuvering the ROV. The octopus was only identified later in the video analysis. The longest octopus observation lasted for 56 minutes. With that 0.37 octopuses per hour were seen and 6.5 minutes per hour observed. With an estimated average speed of the ROV of 3 km/h and an estimated field of view of 0.7 m width, the total observation area was 39 543 m^2 large. With this many estimations this study found 0.177 octopuses per 1000 m^2 in the area of Krk Island. The octopuses were seen at depths between 3 and 85 m. The maximum depth of an ROV dive was 115 m at the deepest part of the North Adriatic Sea in the Krusija Canal. The water temperature varied between 13 and 27° C. Octopuses were observed in temperatures of 13 to 21° C. One out of seven octopus was filmed at 1:59 pm, in 85 m depth. All other six octopuses were filmed after sunset, between 8:30 pm and 10:55 pm. The observed octopuses were active and foraging. They noticed the ROVs' appearance, but did not show signs of stress.

4 Discussion

Using ROVs to study the population density of *Octopus vulgaris* has several advantages compared to the previously used methods. The ROV allows to stay underwater for a long time. The ROV models used in this study could dive up to 2.5 hours and they can dive deep. The used ROVs can dive to depths of 100-150 m, which is much deeper than SCUBA divers could do [Hunt et al., 2000]. Additionally, manoeuvering the ROV is less dangerous for humans than diving, because the pilot and team stay on the waters' surface [Raoult et al., 2020]. Boavida et al. [2015]; Raoult et al. [2020] and Jessop et al. [2024] showed that small ROVs are a capable alternative to video assessed by divers or snorkelers. Sometimes the ROV provides even better video data. Octopuses can sense the motions and light of ROVs and actively avoid them [Battaglia et al., 2023; Robinson et al., 2021; Vecchione, 1991]. On the other hand, ROVs are aural and visual less intrusive than divers, because ROVs can move at the same speed the whole time and do not produce cavitation bubbles as divers do [Raoult et al., 2020]. The in this study observed octopuses were aware of the ROV, but were not disturbed. The observed animals probably are less fearful of the silhouette of small ROVs than of humans and ignore the presence of the ROV [Raoult et al., 2020]. However, there are also some challenges, some individuals could be not detected using the ROV. In some cases, it may be difficult to identify an octopus species only using video recordings [Vecchione, 1991]. But due to the modern high resolution cameras on the ROV and multi observer agreeing, all observed cephalopods could be identified. With ROVs it is difficult to look into dens, in which octopuses remain inactive, especially during daylight [Katsanevakis and Verriopoulos, 2004b; Mather, 1988]. Therefore, it is important to map octopuses with an ROV in the dark, when the octopuses are active and foraging. In this study all observed *Octopus vulgaris* were seen in the dark. Other studies, mainly with SCUBA divers, were conducted in daylight [Oosthuizen and Smale, 2003; Guerra et al., 2015]. This may work, because divers can look into dens much better than an ROV-pilot.
The traditional methods like trawling work efficient only on soft bottoms [Quet-

glas et al., 1998] and trawling has a large negative effect on the habitat [Kaiser et al., 2002]. ROVs work on soft and hard bottoms without and with different vegetation like seagrass and even more important without destroying the habitat. Thus, different habitats can be observed with ROVs.

The collected data is potentially problematic for an exact measureing of the population density of *Octopus vulgaris* in the area of Krk Island, because each detected octopus was filmed and followed as long as possible. For a precise determination of the population density, it would be better to only sight an octopus and move on searching for other individuals. Despite this, we estimated the population density of *Octopus vulgaris* as 0.177 octopuses/1000 m^2. This is in the same magnitude as population densities measured in other studies in the Mediterranean Sea. Belcari et al. [2002] measured only 0 to 0.01 octopuses/1000m^2 in Croatia with the method of trawling. And Katsanevakis and Verriopoulos [2004a] found up to 6.88 octopuses/1000m^2 in Greece with SCUBA diving. In the Atlantic Sea Fonseca et al. [2002] found 0.154-0.495 octopuses/1000m^2 with trawling and Guerra et al. [2014] 3.38 octopuses/1000m^2 and Guerra et al. [2015] 0.0298 octopuses/1000m^2 with SCUBA diving.

Another unit to measure population density is octopuses/hour, which is used in the diving methods and can also be applied with the ROV approach. In this study, 0.3717 octopuses/hour were seen. Guerra et al. [2015] saw 3.5413 octopuses/hour in the Atlantic Sea, in Spain and Leite et al. [2009] found 0 to 3.9 octopuses/hour in Brazil. With the ROV and how it was used, less octopuses per hour were seen than in the other studies with different methods.

Some studies, especially the ones using fishing methods like trawling, use different units to describe the population density of octopuses. They use kg, kg/year, or kg/unit, which are not comparable to the data collected with the ROV.

The population density of *Octopus vulgaris* measured in this study can differ from the ones measured in other studies, because the density is associated with season [Katsanevakis and Verriopoulos, 2004a; Hernandez-Garcia et al., 1998; Leite et al., 2009; Tsangridis et al., 2002] and depth [Belcari et al., 2002; Leite et al., 2009; Avendaño et al., 2022]. At the Canary Islands, Hernandez-Garcia et al. [1998] found a peak of maximum catch in April to May and September to November. On the other hand, in Greece, Katsanevakis and Verriopoulos [2004a]

found that the total density peaked in summer, which may be the same in Croatia. The depth is important, because the shallower the more abundant octopuses are [Belcari et al., 2002; Avendaño et al., 2022]. In addition, octopuses live in patchy patterns [Belcari et al., 2002; Oosthuizen and Smale, 2003; Leite et al., 2009]. Thus, at some locations may live no octopuses, in other locations even more. In future studies, the different locations under study should be compared. Their different conditions, like depth, bottom material, temperature gradients, and season, should be recorded and connected to the population density of *Octopus vulgaris*.
Even if it was possible to to estimate the population density of *Octopus vulgaris*, the ROV based method should be improved to get higher quality data. First of all, the sighted octopuses should not be observed for as long as possible, but just be sighted and then the ROV should move on. In this study the ROV was manoeuvered randomly in the habitat. But the pilot should follow a fixed pattern in an area where the size is known or can be measured to make the observed areas comparable. Fixed transects are used in many studies with SCUBA divers [Katsanevakis and Verriopoulos, 2006; Leite et al., 2009; Guerra et al., 2014] and are applicable to the ROV based method. Another method to measure the exact size of the observed area could be to attach a pipe with two weights hanging from each end and touching the bottom to trace a corridor, as Katsanevakis and Verriopoulos [2004a] did in a SCUBA diving based approach. With 16 parallel and consecutive corridors they created a 1600 m^2 big transect. This method though, is only applicable on soft sediment, but the pipe could also be attached on to an ROV. Moreover, the ROV should be manoeuvered at a consistent speed and even more important, the exact speed should be known.
In summary, ROVs are a promising tool to study octopus populations, but further improvements of this method are necessary.

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