Artificial dens as a hiding place and shelter for *Octopus vulgaris* in the North Adriatic Sea at Krk island, Croatia

Research Project

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Abstract

Octopuses are fascinating species with many cognitive skills. But they also are an increasingly targeted group by fisheries. In this preliminary study we tried to observe the preferences of the Common Octopus *Octopus vulgaris* concerning depth, den equipment and environment in the North Adriatic Sea around Krk island, Croatia. We placed six artificial dens consisting of plastic tubes in grey, orange or transparent color. Some tubes had one closed ending and tied stones for the possibility for the octopuses to close an open ending. The dens were placed at 14-, 16-, 24-, 67- and 90-meter depth. The dens were monitored from May to July 2024 once a week with a remotely operated vehicle (ROV) of the brand Fifish from Qysea. The models Fifish V6, Fifish V6S and Fifish Pro V6 Plus were used. In the seven weeks of monitoring, no octopus was observed in one of the dens. However, on the last day of monitoring there was a mussel shell inside the 16 m deep den. This prey item possibly indicates a short stay of an octopus. As the diameter of the pipes used for the dens are rather large, small octopuses might have seen the den as not protective enough. Large octopuses' bodies fit better into the artificial dens. Further the monitoring later in the year will provide more observations because of the higher number of large octopuses in winter. We plan to repeatedly observe the dens in the coming months. Additionally, an associated citizen science project is being initiated that will allow us to collect videos, photos and reports from divers visiting the dens.

1. Introduction

Cephalopods like octopus, cuttlefish and squid are found throughout the world's oceans. They can live in shallow and deep waters (Hanlon & Messenger, 2018). *Octopus vulgaris* (Common Octopus) is an invertebrate and belongs to the family Octopodidae, which consists of more than 200 species and is the most common octopus species in the Mediterranean Sea (Jereb et al., 2016). They inhabit temperate and tropical seas, and they are well adapted to different habitats such as sandy and muddy bottoms, rocky areas, coral-reefs and seagrass habitats (Mangold, 1983). The species is an opportunistic carnivorous predator, preying mostly upon crabs, molluscs, polychaetes and bony fish (Mangold, 1983). But they also play an important role in marine food webs as they are the prey for larger fish, turtles, dolphins and whales (ICES, 2014).

The highly developed nervous system of an octopus centralized as a brain with a relatively larger size than that seen in fish and reptiles leads to the assumption that they are intelligent animals (Gutnick et al., 2016; Ikeda, 2009; Packard, 1972). This assumption is strengthened by their ability to do observational learning and their memory capabilities (Gutnick et al., 2016; Mather, 2008; Williamson & Chrachri, 2004). It is possible that the intelligence in cephalopods developed through a different route of evolution. The different body plan but well developed neural network enables them to collect and process information (Yoshida et al., 2015). With their sophisticated sense organs like lensed eyes and tentacles they seek and find food and suitable shelter (Budelmann, 1994; Forsythe & Hanlon, 1997). Due to their specific biology like rapid growth rate (García García & Cerezo Valverde, 2006) and short lifespan (Katsanevakis & Verriopoulos, 2004b), cephalopods are highly sensitive to changes in environmental conditions (Lauria et al., 2016; Pierce et al., 2008).

But Cephalopods also represent a significant and increasing landing of fishery worldwide (FAO, 2016). While most landings are catched offshore by trawlers, the coastal artisanal fishery has a high local economic and social importance in southern Europe (Pierce et al., 2008). *Octopus vulgaris* is also frequently caught by recreational fishermen near the coast (Morales-Nin et al., 2005). Even if Octopuses represent only 10 % of total cephalopod fishery (FAO, 2016), conservation and fishery management is needed. And indeed, octopus landings decreased over the last decades (FAO, 2018, 2023). Furthermore, local divers near to our investigation area observed less octopuses in the last years.

Octopus vulgaris depends on shelter and always seeks or forms new ones to survive in its habitat (Ulaş et al., 2019). Often the availability of solid materials for den construction is a limiting factor for the distribution of the species. Even trash of human origin like tires or plastic bottles, or an enrichment with artificial dens allowed the establishment of octopus populations in areas with zero octopus densities (Katsanevakis & Verriopoulos, 2004b). Many studies show the efficiency of artificial dens used in fisheries management for *Octopus vulgaris* to protect the sensitive environment from fishing activities and create new habitats or restore and improve existing ones (Castège et al., 2016; Ulaş et al., 2019; Ulaş et al., 2011). Artificial dens can also be a support for spawning (Mereu et al., 2014; Mereu et al., 2018) and can probably be used by many generations of this species (Guerra et al., 2014).

To protect the population of *Octopus vulgaris* in the North Adriatic Sea, we made a preliminary study to see, where, in which depth and which kind of dens *Octopus vulgaris* prefers around Punat, on the island Krk in Croatia. In May 2024 we placed 6 artificial dens, made of plastic tubes and mostly with one closed ending at 14-, 16-, 24-, 67- and 90-meter depth and checked the occupancy with a remotely operated vehicle once a week for four respectively seven weeks.

Later, when we know more about the preferred habitat of *Octopus vulgaris* the intention is in a further study, to investigate the observational learning and social interactions for this species.

2. Material and Methods

Six artificial dens were built (H1, H3, H4, H5, H6, H7) and placed around Krk island, Croatia at different depths. The exact locations can be seen in Figure 1. The spots were selected by their different environmental conditions like sandy or structured area and depth, and in a field of *Posidonia oceanica*. The exact conditions of the dens and the area can be seen in table 1. H1 and H3 were placed on 11th May 2024 respectively 13th May 2024 and H4 to H7 from 30th May to 2nd June 2024. All dens consisted of plastic tubes tied on a roof pile or a big stone. The variants were one or two plastic tubes and one or two open endings. But also, orange (PVC), grey (polypropylen) or transparent (acryl) tubes and stones tied on the endings for the possibility for the octopus to close the tubes. If there were two plastic tubes, each tube had one side closed and the open endings of each tube showed in opposite directions. The seventh tube H2 had to be pulled out of the water untimely and was no subject of the investigation anymore. H1 had a diameter of 110 mm. All other tubes had a diameter of 125 mm. All tubes had a length of 30 – 50 cm. Bright yellow and green tape was put on the tubes to find them again easily. The artificial dens were placed on sand or mud.

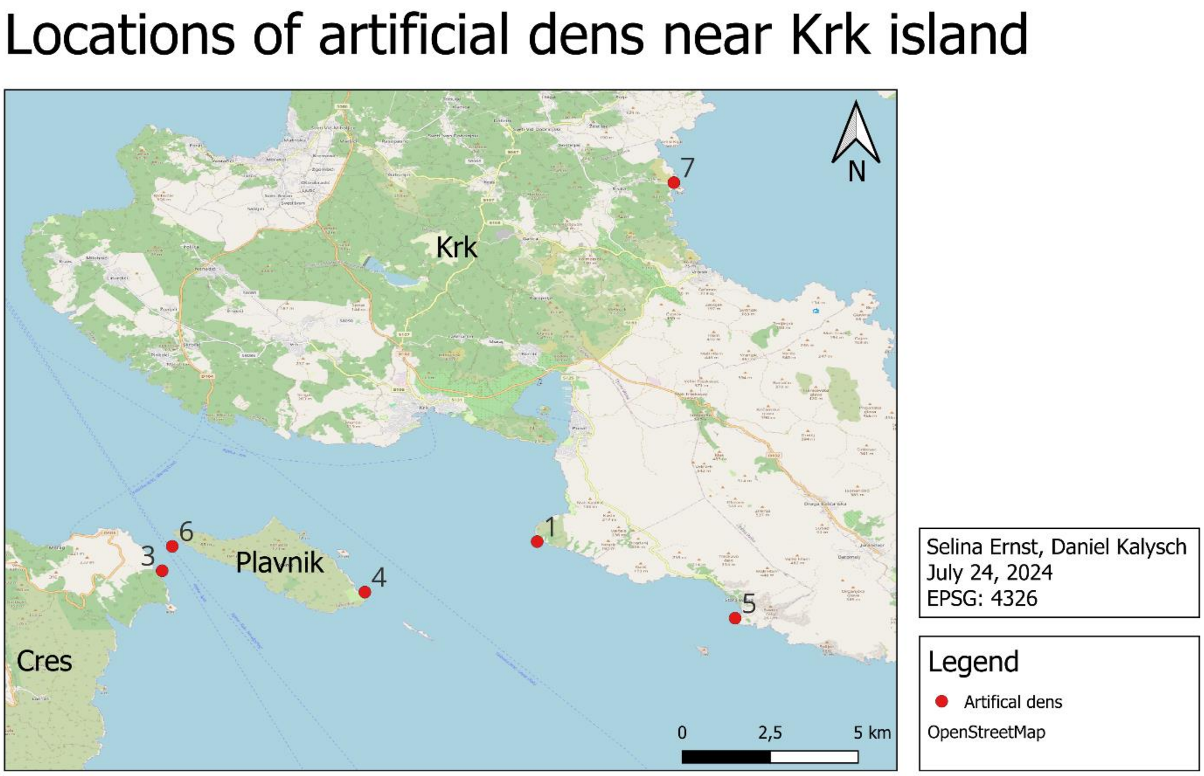

Figure 1: Locations of artificial dens H1, H3 - H7

The settlement of octopuses in the tubes were controlled once a week until 2nd July 2024. This process was carried out with a remotely operated vehicle (ROV) of the Brand Fifish from Qysea. The models Fifish V6, Fifish V6S and Fifish Pro V6 Plus were used. The exact day of monitoring depended on weather conditions and was carried out at daylight or while the sun was setting.

Table 1: Characteristics of the dens

Den	Characteristics of the den	Depth in Meter	Setting
H1	One orange PVC tube.	16	Near a structured area.
H3	Transparent acryl tube with grey polypropylen endings in 90° and stones for closing on each side.	67	Sandy and near to a few potential natural dens.
H4	Two grey polypropylen tubes. Each has only one open ending and they show in opposite directions. Both have a stone for closing.	14	In a field of *Posidonia oceanica.*
H5	One orange PVC tube with only one open ending and a stone for closing.	16	Between a sandy area and a structured reef. Near to a few potential natural dens.
H6	Two grey polypropylen tubes. Each has only one open ending and they show in opposite directions. Both have a stone for closing.	90	In the deep Krusija Canal. Strong current.
H7	Two grey polypropylen tubes. Each has only one open ending and they show in opposite directions. Both have a stone for closing.	24	Between a sandy area and a structured reef.

3. Results

In the four, respectively seven weeks the dens were monitored, no octopus came there to spawn or sleep for a longer period (Figure 2-6). On the last day of monitoring, 2nd July 2024, there was one mussel shell in the den H5 (Figure 7), which possibly indicates a short stay of an octopus.

Figure 2: H1

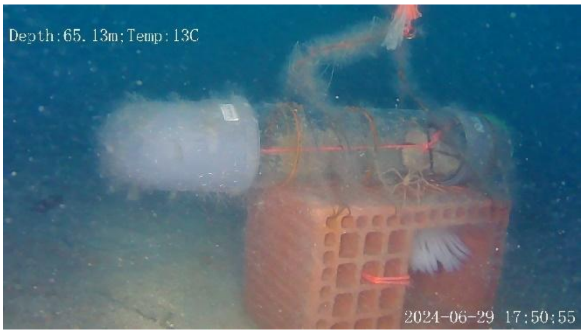

Figure 3: H3

Figure 4: H4

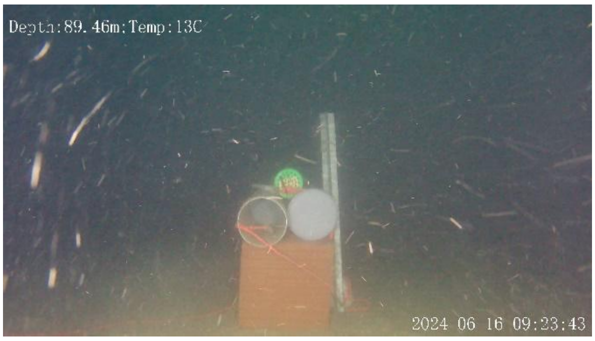

Figure 5: H6

Figure 6: H7

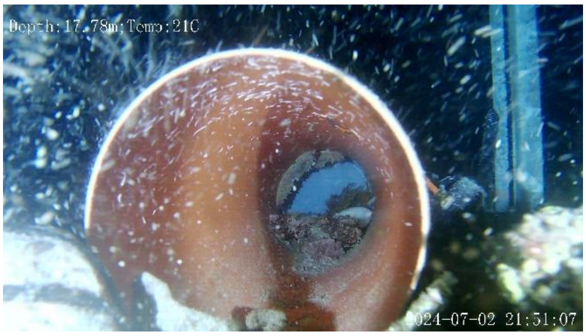

Figure 7: H5 with prey remains

4. Discussion

Purpose of the dens was to provide a shelter for octopuses. As in Mereu et al. (2014) and Ulaş et al. (2019) we interpreted mussel shells as a short settlement of an octopus. Because *Octopus vulgaris* spends most of the daytime in the den (Katsanevakis & Verriopoulos, 2004b; Mather, 1988), we checked the den the next day at daylight but there was no octopus inside. So, it seems the octopus was not using the den as a sleeping place, but rather for a short time to rest and eat. Because many studies confirm the effectiveness of artificial dens (Mereu et al., 2014; Mereu et al., 2018; Petetta et al., 2021; Ulaş et al., 2019; Ulaş et al., 2011; Whitaker et al., 1991), and octopuses even preferred them with a rate higher than 50 % in contrast to natural ones (Ulaş et al., 2019), more octopuses were expected to settle in the dens. But all the studies were carried out over a period of a few years, whereas our dens just were monitored for a few weeks. We assume that the longer the dens were monitored, the more octopuses would settle there. Our dens were not removed from the water, and we will continue to monitor in the coming months and years. In addition, other studies had hundreds of replicates. So, the probability that an octopus will wattle in one of them is much higher than in our six dens. We plan to place an additional number of dens in September 2024.

However, fishery studies with pots or traps have documented that artificial dens become occupied within a few days (Sânchez & Obarti, 1993; Sauer et al., 2019; Whitaker et al., 1991), but also say that pots are size-selective and juvenile octopuses don't enter the pots, because the pots are too large for them. For juveniles, soft bottom substrate is more suitable, because of the greater growth rate of small octopuses (Katsanevakis & Verriopoulos, 2004b; Mather, 1994). On soft bottoms, small octopuses can easily modify their shelter by blowing or pushing sand out and increase the size of the den. For protection they rearrange rocks or shells in front of them. This allows the growing octopus to stay longer in one den and is not forced to move to a new one within a few days (Guerra et al., 2014). The slower growth rate of adult octopuses enables them to stay in a den for a longer period without modifying it and to find shelter on hard bottom substrates and crevices or artificial dens (Guerra et al., 2015).

Additionally, octopus density is associated with season (Arechavala-Lopez et al., 2019; Dridi et al., 2022; Katsanevakis & Verriopoulos, 2004a; Whitaker et al., 1991). Katsanevakis & Verriopoulos (2004a) found in Greece most small *Octopus vulgaris* in summer, medium sized in summer and autumn, and large octopuses in winter. This is supported by the seasonal breeding peak in spring from April to May, Dridi et al. (2022) found near Morocco. Many authors also found a spawning peak in spring (Gonzalez et al., 2011; Otero et al., 2007; Silva et al., 2002). Due to all this, it is possible that in the spring to early summer months, when our dens were monitored, most of the octopuses were still too small for the 110 to 125 mm diameters of the plastic tubes to use them as a safe space. Because only specimens of a certain size settle in dens of a given volume (Kim et al., 2015; Petetta et al., 2021). Also, Whitaker et al. (1991) found that octopuses were smallest during summer. So, the observation of our dens should be practiced longer until autumn or even winter, because then there would be a higher probability to find larger *Octopus vulgaris,* fitting in our dens.

Octopuses occupy dens for short periods (average 10 days) (Mather, 1994) but may stay longer in areas where preferred prey is available (Mather & O'Dor, 1991). Therefore, the availability of food affects immigration (Katsanevakis & Verriopoulos, 2004b) and therefore the frequency of potential settlements into the artificial dens. In the area of H5 we filmed a few Octopuses with the ROV for longer periods (18 to 56 minutes). While foraging it seemed they always found food quickly and were eating frequently. Consequently, enough food should be available, and octopuses may use a "Win-Stay" foraging strategy in this area. In addition, this area was highly structured and there were many potential natural dens. So, when an octopus was searching for a new shelter, the probability was high that it took another natural den instead of our artificial one. The same phenomenon could have happened at H1 and H7, because the environmental conditions like the structured area are similar here. To confirm this assumption and to determine the food availability in all other areas, more octopuses have to be observed there in further studies and at different times of the year.

The dens H3 and H6 were at greater depth (>66 m). As octopus density often decreases with depth (Avendaño et al., 2022; Belcari et al., 2002), it is possible that the population of octopuses in this region was not high and the few octopuses in that region did not encounter the artificial dens in that short amount of time. During the later summer months when the average surface area water temperature increased up to 28° C, animals might have moved to colder areas in the deeper water. But the deeper areas in this region are rather sandy and muddy and not structured. Therefore, it is important to place artificial dens there to provide shelters for octopuses. Mature octopuses can lay their eggs there and the population can increase.

Petetta et al. (2021) and Borges et al. (2015) say that *Octopus vulgaris* prefers black, respectively darker colors for a shelter. But on our dens, we attached bright yellow and green tape to find them again more easily. It is possible that the bright colors displeased some octopuses, and they searched for an alternative shelter than our den. For the next dens it will be better to use darker colors.

As shown in figure 3 sessile organisms are settling on the den. Other cephalopods are utilizing the structure to attach their eggs to it. Therefore, the den was integrated into the environment and the material was adequate.

To conclude the results, the use of artificial dens probably can be an efficient tool to offer *Octopus vulgaris* an additional, extra safe place, including spawning. It is important to leave the dens over an extended period of time in the water, at least for one year but preferably for longer to establish a permanent structure for shelters. Especially when the artificial dens are more complex, equipped with screens, to communicate with the octopuses, which is the purpose of further studies. To give detailed information about the den preferences of *Octopus vulgaris* concerning doors, depth, bottom structure and environment, further studies with more replicates are needed. But we had at least one mussel shell in one of our dens, which indicates the potential of the dens to offer a safe space and maybe also to establish an octopus population in a region with no octopus density before.

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