Recognizing cephalopod boreholes in shells and the northward spread of *Octopus vulgaris* Cuvier, 1797 (Cephalopoda, Octopodoidea)

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ABSTRACT

Octopuses prey on molluscs by boring through their shell. Among the regular naticid borings, traces of cephalopod predation should be found soon on Dutch beaches. Bottom trawling has declined, and by the effects of global warming *Octopus* will find its way back to the North Sea where it lived before. I describe the distinguishing characters for *Octopus* bore holes, give an introduction into this type of behaviour, present a short history of Dutch octopuses and a prediction of their future.

INTRODUCTION

Aristotle was the first to observe octopuses feed on molluscs (see D'Arcy Thompson, 1910), but it was Fujita who discovered in 1916 that a hole was bored in the shell of cultured pearl oysters prior to its owner being eaten; a behaviour independently discovered by Pilson & Taylor (1961) in laboratory tanks. Octopuses are versatile carnivores with a diverse array of prey, ranging from soft bodied to heavily armoured organisms, such as bivalves, gastropods and crustacean (Nixon, 1987). There are different techniques of penetrating a shell to gain the meat inside (Steer & Semmens, 2003). *Enteroctopus dofleini* (Wülker, 1910), for example, has four techniques of getting into a clam. If possible, they use the easiest way, according to the optimal foraging model, resorting to drilling only when other methods are unsuccessful (Mather & Anderson, 2007). Regardless of their prey size, *Octopus* will always try the pulling method first (Fiorito & Gherardi, 1999), but if unsuccessful, it changes its tactics and initiates a drilling response (Hartwick et al., 1978).

This drilling is well documented in 11 Octopodoidea species: *Octopus bimaculatus* Verrill, 1883; *O. bimaculoides* Pickford & McConnaughey, 1949; *O. joubini* Robson, 1929; *O. mimus* Gould 1852; *O. rubescens* Berry, 1953; *O. vulgaris* Cuvier, 1797; *Amphioctopus fangsiao* (d'Orbigny, 1839); *Enteroctopus dofleini*; *Callistoctopus dierythraeus* (Norman, 1992); *C. macropus* (Risso, 1826) and *Eledone cirrhosa* (Lamarck, 1798) (Fujita, 1916; Pilson & Taylor, 1961; Arnold & Arnold, 1969; Wodinsky, 1969; Hartwick et al., 1978; Boyle & Knobloch, 1981; Cortez et al., 1998; Steer & Semmens, 2003; Anderson et al., 2008; for taxonomical updates see Norman & Hochberg, 2005). However, the habit of drilling may prove to be more widespread within octopods since only few species have actually been investigated (Bromley, 1993). Drilled holes were found in polyplacophoran, gastropod and bivalve mollusc shells, *Nautilus* and crustacean carapaces (Tucker & Mapes, 1978; Saunders et al., 1991; Nixon & Boyle, 1982; Guerra & Nixon, 1987; Nixon et al., 1988; Mather & Nixon, 1990; Nixon, 1987).

Arnold & Arnold (1969) and Wodinsky (1969) both describe the act of drilling in detail. This behaviour consists of the following steps (Wodinsky, 1969): recognizing and selecting the prey, drilling a hole in the shell, ejecting a secretory substance into the drilled hole, and removing the mollusc from its shell and eating it.

Octopus makes its boreholes by rasping the shell. The shells are penetrated at a rate of 1.25 mm per hour (Arnold & Arnold, 1969), with individual rasps of 0.3 to 0.4 second in duration (Wodinsky, 1969). *Octopus vulgaris* can drill both gastropod and bivalve shells in less than two hours (Arnold & Arnold, 1969; Nixon, 1980), which is rather fast compared to other molluscan shell-borers, some of which take as long as 134 hours to drill and eat an oyster (Fretter & Graham, 1962).

At first the radula was considered to be the instrument of drilling (Pilson, 1961; Wodinsky, 1969; Arnold & Arnold, 1969). But then it turned out that *Octopus* can still drill holes in mollusc shells after part of its radula had been removed (Nixon, 1980). The drilling activities seem to be carried out by another structure within the buccal mass, namely the small conical teeth on the tip of the muscular salivary papilla (Nixon, 1979a), as not one out of ten octopuses drilled again after surgical removal of their salivary papilla (Nixon 1979a; 1979b). Since the discovery of octopus drillings there has been speculation about possible chemical action on the shell (Fujita, 1916; Pilson & Taylor, 1961; Arnold & Arnold, 1969; Wodinsky 1969; 1973). After comparison of the shell surface it was indeed concluded that some chemical dissolution during drilling may occur (Nixon et al., 1980; Ambrose, 1988).

Striking is the small size of the interior opening of the octopus boring. The function of the hole is purely to provide an entrance for the post-drilling secretion by the posterior salivary glands. Pilson & Taylor (1961) reported that a newly-drilled abalone was weaker than normal. Removed from the octopus however, it did recover within weeks. The octopus thus weakens the snail, but does not kill it (Wodinsky, 1969). The ejected secretion does immobilize, paralyze, or weaken the snail causing an abalone or chiton to release its hold on the substrate, a bivalve to relax the adductor muscles, or a gastropod to weaken the closure of its operculum (Pilson & Taylor, 1961). By selective drilling, octopus targets a particular area on the shell. Some bivalves are drilled in the region of adductor muscle attachment directly weakening the union between the two valves (Nixon & Macconachie, 1988; Cortez et al., 1998) while the boreholes in gastropods are often located in the apical spire (Nixon & Macconachie, 1988). However, attacks can be unsuccessful by not penetrating the shell. Thick shells are more likely to have incomplete boreholes (Ambrose et al., 1988).

DUTCH DISTRIBUTION

Octopus vulgaris is one of the 12 species of cephalopods known to occur in Dutch waters (Lacourt & Huwae, 1981). Little has been written about the history of Dutch cephalopods in comparison to the other molluscs (Kaas, 1939). An arm fragment of a Dutch *O. vulgaris* from as early as 1842, as well as many more specimens from before the 1940s are preserved in the collection of Naturalis Biodiversity Center, Leiden, The Netherlands. Almost all were fished near Noorderhaaks and the Terschellinger bank. The last Dutch *O. vulgaris*, preserved in alcohol, was caught in 1960. Boer (1971) saw a strong decline of octopuses near the Dutch coast since the 1960s. This was later explained by De Heij & Goud (2013) as an effect of the intensive bottom trawling in the North Sea. The species seemed to have completely disappeared (De Heij & Goud, 2013). However, because of a decline in bottom trawling (personal communication by Stichting De Noordzee) and the effects of climate change, *O. vulgaris* may return.

The marine environment is where some of the greatest ecological impacts of climate change are being observed (Poloczanska et al., 2013). Particularly common are poleward range extensions or a shift in the distribution of a species, which is seen in the Australian *O. tetricus* Gould, 1852 (Ramos et al., 2014). *Octopus vulgaris* now lives in a territory ranging from the Mediterranean to the English Channel (De Heij & Goud, 2013) and enters the southern part of the North Sea in warm summers (Kristensen, 1966). Kristensen (1966) described these individuals as 'being lost' instead of attributing their presence to seasonal migration. In the past, octopuses were often caught in the Netherlands, at times when they were rich in numbers in the English Channel (Kristensen, 1966). Since the North Sea is rising rapidly in temperature – rising by 1.7°C in half a century according to the Alfred Wegener Institute (Ecomare, 2012) – climate change will most likely cause a poleward range extension for *Octopus*. Together with a ban on bottom trawling (Rijksoverheid, 2012), our Dutch waters are becoming more welcoming for new populations of *O. vulgaris*.

A range shift of *O. vulgaris* into Dutch waters, however, has not yet been confirmed by North Sea divers (personal communication Stichting ANEMOON). Fisheries and divers should pay close attention to the differences of *E. cirrhosa* and *O. vulgaris*, and report their findings. The following differences are the most striking: *O. vulgaris* has two rows of suckers per arm along their lengths, while *E. cirrhosa* has only one (Kaas, 1939; Lacourt & Huwae, 1981; De Heij & Goud, 2013). Furthermore, the arms of *O. vulgaris* are three times the length of its mantle, while the arms of *E. cirrhosa* are only twice the length of the mantle (De Heij & Goud, 2013). When *O. vulgaris* starts invading the North Sea again, we will also find their borings on the shorelines. The first boring on the Dutch shore still needs to be found (Cadée & Wesselingh, 2008). Below, I provide details on the typical shape of *Octopus* boreholes and how to distinguish them from boreholes produced by other organisms.

BOREHOLE DETERMINATION

Predatory snails (Fig. 1)

Bored shells are a common find on the Dutch beaches (Cadée & Wesselingh, 2008). Round borings are often made by predatory snails (Kabat, 1990). Almost all bored Dutch shells have been drilled by Naticidae (Cadée & Wesselingh, 2008). They drill through shells with their radula and consume their prey via the borehole. The boreholes made by Naticidae are round and conical. A boring made by the muricid gastropod *Nucella* looks like a naticid boring, but has an almost vertical wall (Fretter & Graham, 1962; Cadée & Wesselingh, 2008).

Octopus boring (Fig. 2)

All first discoverers, Fujita (1916) and Pilson & Taylor (1961) describe *Octopus* borings as oval in shape. Wodinsky (1969), however, mentions that the borings can vary from oval, circular, cross-shaped, and multi-sided polygon, to extremely irregular. Rasping happens only in a straight line, but even so, variation can occur. A rotation while rasping in straight lines can result in a variable shape, especially if this manoeuvre may be repeated in different directions (Wodinsky, 1969). A 90° rotation while drilling is pictured by Bromley (1993). Irregularities in boreholes could also be due to the shell structure (Nixon, 1979b; Ambrose et al., 1988). According to Pilson & Taylor (1961), a typical octopus boring is 0.8 mm long and 0.6 mm wide at the top, narrowing at the bottom to an opening of 0.3 mm long and 0.2 mm wide. Boreholes are larger in thicker shells (Ambrose et al., 1988). The size of the borehole varies depending on the thickness and hardness of the shell, the species of prey, but also on the size of the octopus (Wodinsky, 1969). However, even a large *Octopus* will produce a hole

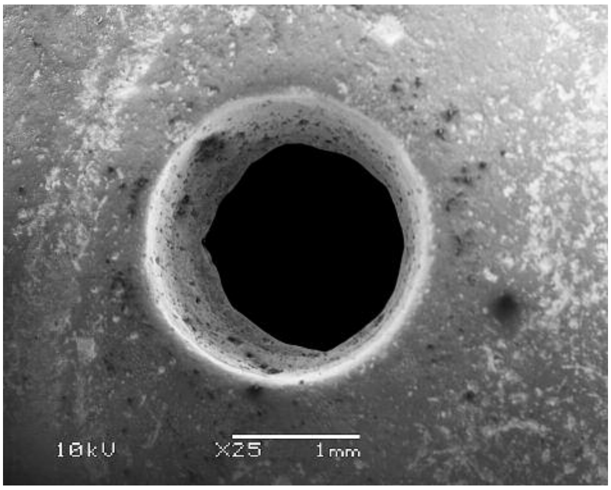

Fig. 1. Scanning electron micrograph of a naticid (*Euspira* sp.) boring in a specimen of the bivalve *Macoma balthica* (RMNH.5003997). Note the typical round shape. Scale bar = 1 mm.

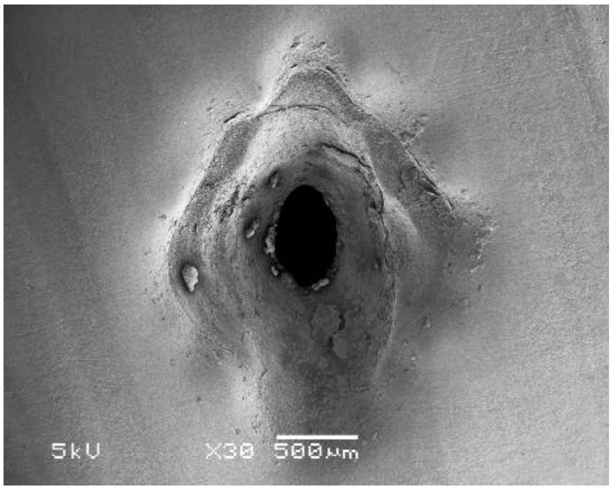

Fig. 2. Scanning electron micrograph of an *Octopus* boring in a *Nautilus pompilius* (RMNH.5003996). Note the oval shape and smaller size. Scale bar = 0.5 mm.

which is generally smaller than those typically drilled by carnivorous snails (Pilson & Taylor, 1961). Although several different species of *Octopus* are known to drill their prey, it is not possible to identify the species responsible on the basis of borehole geometry alone (Saunders, 1991).

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