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Research article

Nutritional insights into octopus diets in aquaria

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Abstract

Common octopus *Octopus vulgaris* are a popular exhibit in aquaria; however, there is limited research on the nutritional requirements of this species. The current information available is from the aquaculture industry and thus focused on young individuals and maximising growth rates. Diets for 17 common octopus housed in aquaria in Europe were collected and ingredients identified. Nutritional analyses of these items were undertaken, including protein, fat, energy and a range of minerals to produce profiles of each animal's weekly diet. All but one collection fed a mixture of fish and marine invertebrates with shore crabs being the most provided item followed by molluscs (mussels and clams), mimicking the natural diet. Octopus were fed between 3 and 7 times per week. All of the diets had protein levels above 50 % (in dry matter, DM) and many of the diets (59 %) had protein levels of over 60 % DM, which is expected as protein is the main macronutrient for octopus. Fat levels were variable between collections with most diets being higher in fats than recommended. This study highlights the variation in diets provided to common octopus. Further research on the impact of these diets on growth, development and longevity would be beneficial in developing recommendations for octopus diets.

Introduction

As one of the five domains of animal welfare, providing suitable nutrition to animals in captive environments is an essential part of their care; this includes a balanced diet, often by providing a variety of food items, and ensuring appropriate food quantities (Mellor 2017). However, nutrition is not as well studied as other domains for aquarium species, as historically the importance of diet and nutritional research focuses on large charismatic mammals (Fens and Clauss 2024). Thus there is a need for more evidence-based practice for aquarium species.

Common octopus, *Octopus vulgaris* (Cuvier 1797), are a popular exhibit in aquaria; however, there seems to be limited research on how octopus diet can be used to support longer-term welfare. As a species that is used in aquaculture, there has been an increase in research on their nutritional requirements (Estefanell et al. 2011), primarily focused on protocols for paralarvae stages and feeding using enriched live *Artemia* spp. and crustacean zoeae (Iglesias and Fuentes 2014). Aquaculture research often focuses on maximising yield and growth rates, which is not necessarily conducive to long-term welfare, with faster growth rates in fish linked to a reduction in locomotory performance, for example (Royle et al. 2006). With high food conversion rates, short lifespans, along with their opportunistic and generalised feeding strategy, common octopus are favourable for commercial use (Casalini et al. 2023), though maintaining health and welfare of individuals in zoos and aquariums needs a more welfare-targeted approach. Octopus have a high food conversion rate (40-60% of intake) (Garcia and Gimenez 2002) gaining weight quickly when overfed. Morillo-Velarde et al. (2014) reviewed lipid utilisation in common octopus finding that higher levels of lipids in the diet hindered diet digestibility, possibly due to a lack of emulsifiers in the cephlapod digestive tract (Navarro et al. 2014).

Whilst there are no specific dietary husbandry guidelines for the care of common octopus, the Association of Zoos and Aquariums care manual for the giant Pacific octopus *Enteroctopus dofleini* states that overfeeding is not a concern in octopus due to their high feed conversion rates and the fact that they do not store fat, with excess energy being put into rapid growth (AZA 2014). Common octopus are semelparous, as most perform a singular breeding season and after spawning, senescence is the final stage of their normal life cycle (Vidal and Shea 2023). Estimated wild lifespans from beak ageing suggest around a year survival, with males often living longer than females (Rosa et al. 2024). Whilst there is some research on diets in the wild (Smith 2003; Ajana et al. 2018) as well as some studies on feeding octopus in aquaculture (Estefanell et al. 2011) and laboratory settings (García and Giménez2002; Villanueva et al. 2009) there is currently no known published literature on the feeding practices in public aquaria.

This study aims to describe and expand some of the current knowledge on nutrition for common octopus in captivity by investigating the diets being fed in 17 different European collections.

Methods

Several commercial European aquariums that housed common octopus were contacted requesting their common octopus diet. This included the amount, frequency and types of food offered to their octopus as well as information on the individual.

Samples of a range of different fish and marine invertebrates were collected from different SEA LIFE UK sites in October 2024 and February 2025. These items were kept frozen until ready to be freeze dried in the laboratory facilities at University Centre Sparsholt. The food items came from two different commercial, sustainable seafood suppliers based in the UK; where sites had different suppliers for the same items, samples from both suppliers were sourced.

Samples analysed included haddock *Melanogrammus aeglefinus* (n=4), herring *Clupea harengus* (n=4), mackerel *Scomber scombrus*)(n=4), sprats *Sprattus sprattus*, (n=4), whiting *Merlangius merlangus* (n=2), mussels *Mytilus edulis* (n=3), razor clams *Ensis ensis* (n=4), shore crab *Carcinus maenas* (n=3), prawns Penaeidae (n=4), shrimp *Crangon crangon* (n=2) and squid *Doryteuthis (Loligo) opalescens* (n=4). The number of samples is the number of runs completed on separately collected batches of items. Within that run could be several individual items from that batch.

Shells were removed from the mussels, razor clams, prawns, shrimp and shore crabs after freeze drying, but before grinding. Some of the individual shore crabs were small so removing the shell was challenging and whilst all effort was made to remove the shell, it is likely that some particles remained and were ground up with the sample. Sprats were processed whole. Larger fish species were gutted and squid had the gladius removed. The weight of the consumable components of the diet have been estimated from the weight of the shells of the items removed prior to analysis.

Food was analysed using standard analysis processes (Animal Feed 2023). Protein was analysed for using Kjeldahl process, fats were assessed via Soxhlet methods, energy was analysed using bomb calorimetry and minerals were evaluated via Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES).

Adjustments from standard procedure

Kjeldahl apparatus measures nitrogen content of food and uses a factor of 6.25 to convert this to a protein amount. However, research has shown that this conversion factor overestimates the amount of protein in fish and marine invertebrates, so the conversion factor of 5.71 has been used for the fish and 5.45 for marine invertebrates (Diniz et al. 2013; Diniz et al. 2014).

Findings from proximate analysis were entered into Zoo Diet Navigator software (Bissell 2025) and used to calculate the weekly average nutritional profile of each octopus' diet. Diets were categorised based on the most common components in the diet (crustaceans, fish or molluscs). Nutritional values for each individual species can be found in the supplementary material.

Results

Feeding frequency of octopus varied between sites with feeding occurring between three times a week (24%) and daily (59%). All but one collection offered a mixture of fish, crustaceans and molluscs; the remaining collection just offered crustaceans and molluscs. Figure 1 highlights the range of dietary components across all collections.

Amount of variation in the weekly diet also differed between collections, with some sites offering only two different food items and others offering up to seven. Nearly 70% (7/10) of collections offered four items or less as part of their diet plan. Crustaceans and molluscs feature prominently in common octopus diets in our sample, with 88% (N=15) of diets having at least one crustacean and 77% (N=13) of diets containing mussels and/or clams, 94% (N=16) of diets contained at least one species of fish. The most commonly fed fish species were sprats (35% of diets) and mackerel (29% of diets). Both items are oily fish so have a higher fat content, with sprats averaging 26% fat DM and mackerel 18% fat (DM) (Table S1).

Average weekly gross energy values were 833±438 kJ GE per week with a range from 92 to 1743 kJ GE provided each week.

Supplementation was either offered once per week or every time the animal was fed, though 23.5% of collections did not provide any supplements. Amount of consumable food provided varied from 5 g to 112 g per day on the days fed, averaging between 20 g and 336 g per week.

Figure 2 demonstrates the impact different conversion factors have on the dry matter (DM) crude protein values.

Nutritional values varied between the different collections (Figure 3), with diet categorisation not seeming to impact on the levels of protein, fat and ash provided.

The mineral composition of the diets provided is displayed in Figure 4; Ca levels appeared highest in diets based on fish.

Discussion

Studies on the wild diet of common octopus highlight the diversity of prey. Smith (2003) identified 39 different prey species in the stomachs of octopus, and Ajana et al. (2018) evidenced smaller octopus tend to consume more crustacea (with *Liocarcinus* spp. crabs being the most common) and larger octopus predating more on mollusc species (*Callista clione* most commonly found).

In octopus aquaculture, protein levels of 30-40% DM are commonly provided; however, this is based on maximising food conversion and growth rates (Yadav et al. 2019). Protein is the primary macronutrient used by octopus for locomotion and growth, so the fact that the majority of diets contain 30-50% protein DM is not unexpected. However, due to the large variation in the amount of food offered between collections, there is a bigger variation in the grams of protein each octopus receives weekly with a range of 3 g to 74 g DM and an average value of 30.7 g DM.

Cephalopods, including the common octopus, lack lipid emulsifiers in their digestive tracts (Navarro et al., 2014). Therefore, it is likely that higher fat items such as oily fish are not as efficiently digested as marine invertebrate species which are low in fats and higher in protein. García García and Valverde (2006) highlighted that lipid values of 2-3% as fed were optimal; this would translate into 6.2-9.4% DM, with higher levels of fats impacting on protein digestion. None of the collections had values for fat in the range suggested by García García and Valverde; however, some were near to this level. Fourteen of the collections had fat levels in

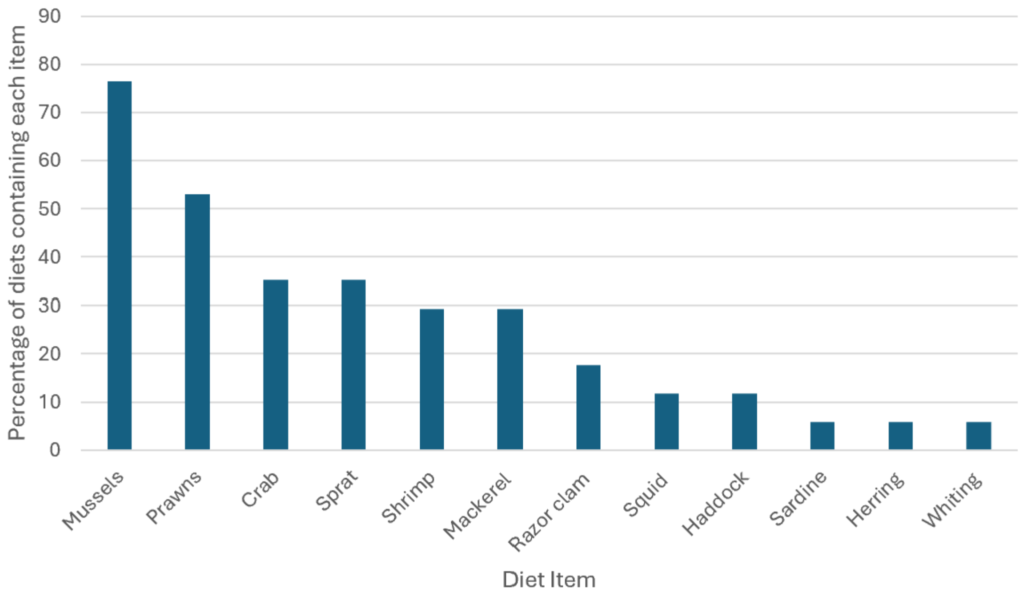

Figure 1. Range of items provided to octopus across the different collections, mussels (N=13 diets) were the most commonly fed item, followed by prawns (N=9) and crab and sprat (both N=6)

excess of 13%, which may negatively impact on overall diet digestibility (Morillo-Velarde et al. 2014). Morillo-Velarde et al. (2014) did find, however, that digestibility of polar lipids, in particular phospholipids, remained high. Our study did not test the polarity of the different lipids. This should be considered in the analysis of samples of items fed to octopus in the future. Diets containing large amounts of oily fish had higher fat levels, at 19-20% DM, diets that were mostly prawns and clams had the lowest levels of fat, followed by haddock, crabs and squid. So, diets that have a mixture of fish and shellfish, such as prawns and clams, could help balance out fat levels in the diet over a week. Further research would be useful to assess whether octopus receiving high-fat diets had specific health concerns, or would just not grow as fast as conspecifics on lower-fat diets.

How often octopus were fed varied, with many collections feeding daily. This is inline with recommendations on the BIAZA

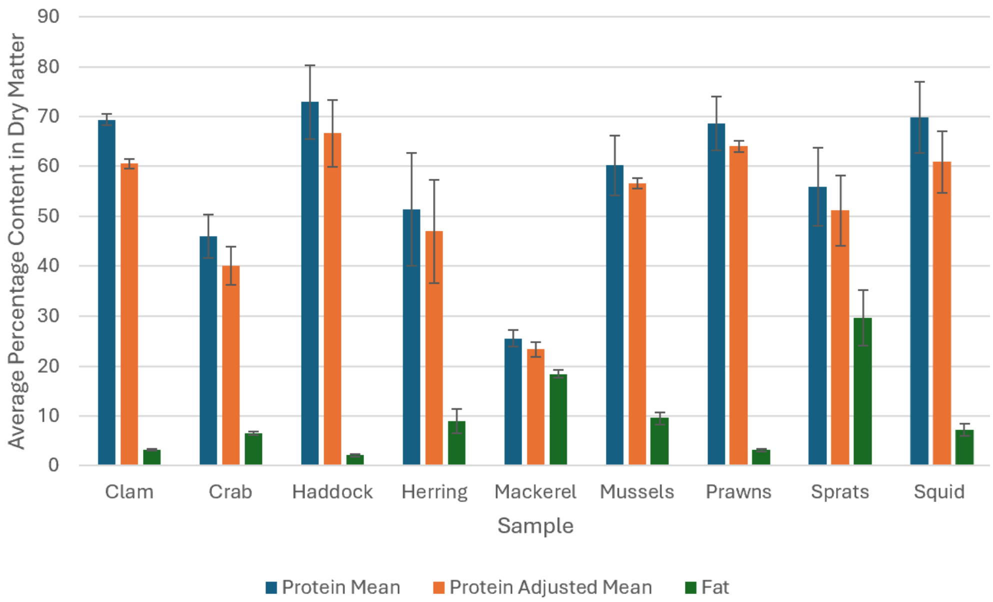

Figure 2. Dry matter crude protein values using nitrogen conversion factor of 6.25 (blue) and the adjusted conversion factors for fish and marine invertebrate (orange) as well as the fat content

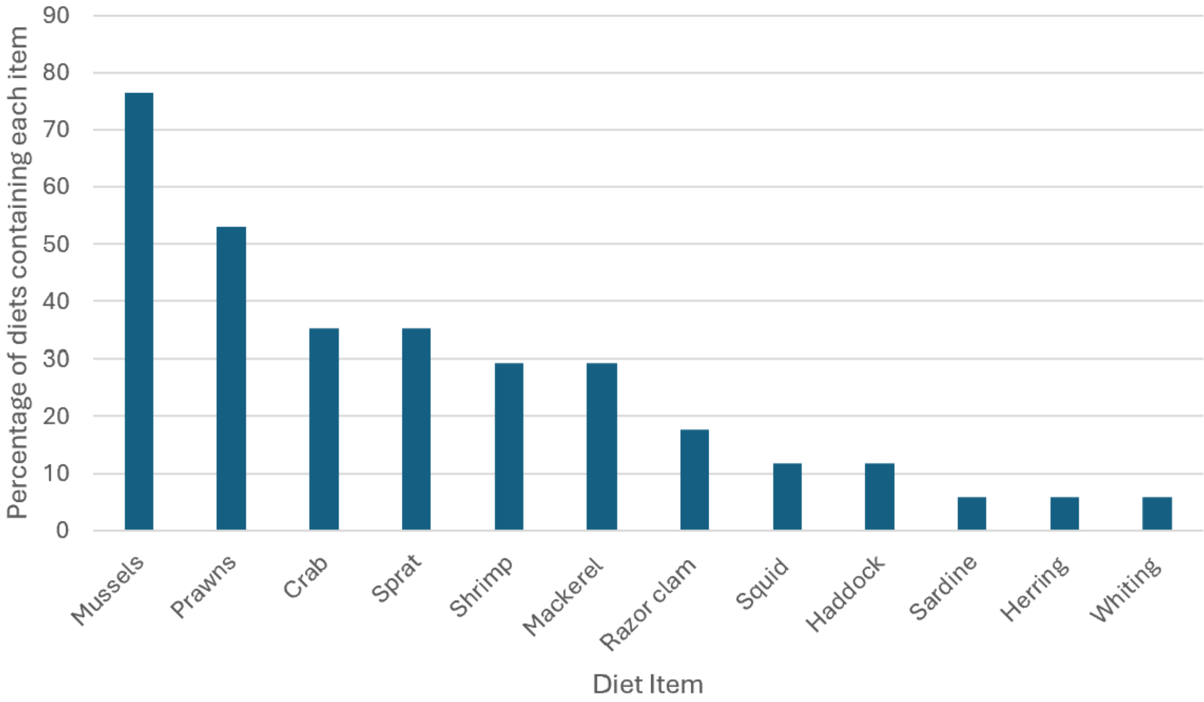

Figure 3. Percentage of protein, fat and ash (dry matter) in each collection's weekly octopus diet. Diets are categorised based on which component of the diet was most common, diets with majority crustaceans (blue), majority fish (purple) and majority mollusc (green) . For each collection left bar is protein, central bar is fat and right side bar is ash. NB: Nitrogen conversion factors of 6.25 was utilised.

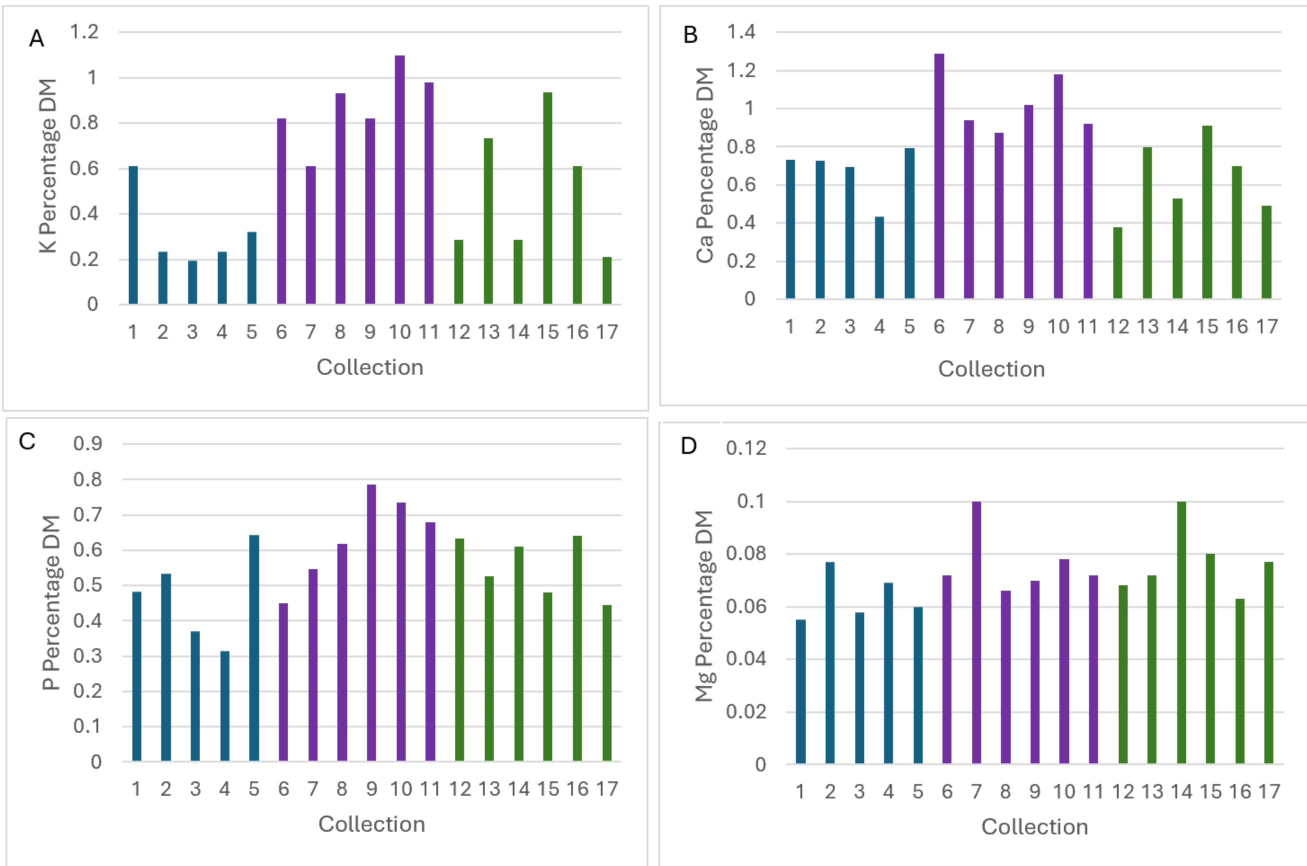

Figure 4. Minerals in the different collection diets as a percentage dry matter. Diets are categorised based on which component of the diet was most common, blue is diets that had majority crustaceans, purple for diets that were mostly fish and green is mostly mollusc species. A= percentage potassium, B= percentage calcium, C= percentage phosphorus and D= percentage magnesium.

(accessed online 2025) care sheet for common octopus, which state small amounts of food daily will help ensure an active and engaging individual. Rodríguez-González et al. (2018), however, suggested that 2 or 3 fasting days in the week mimic natural feeding patterns without having any impact on survival of individuals or digestibility of diets. Onthank (2008) is cited in the AZA giant Pacific octopus care manual stating that common octopus need 56 kJ/kg/day at 20˚C metabolizable energy (ME). This would suggest that common octopus at a weight of 2kg need around 782 kJ ME each week. Metabolism is highest at 20˚C, so temperatures both above and below this are likely to decrease energy requirements (Katsanevakis et al. 2005). Therefore, diet quantities should factor in the environmental temperature. Weekly energy content varied from 92 to 1743 kJ gross energy (GE) however, most diets were between 523 and 991 kJ with a mean value of 833 kJ GE per week, very close to the claimed requirement of Onthank (2008). Petza et al. (2006) found that on average 70 % of the GE consumed was lost through excreta, with 58 % of this through respiration, this suggests the diets in this study offered between 28 and 523 kJ ME per week. Octopus have very high food conversion rates (Garcia and Gimenez 2002) so excess of energy can be used to increase growth rates. Unfortunately, weights of the individual octopus were not available, so it was not possible to calculate the amount of energy provided per kg body weight. Future studies would benefit from considering this in analysis.

Whilst outside the scope of this study, Lourenço et al. (2017) highlighted that specific fatty acids, C18:1n9 and 22:6n3 (DHA), are beneficial for growth in octopus, so further research on which food items have the right fatty acid profile could aid in diet development, especially for young octopus. Fats are also required for fat soluble vitamin metabolism (Vitamins A, D, E and K). Vitamin E in particular degrades quickly in fish and marine invertebrates after animals are killed, and continues to degrade even in frozen items, with vitamin E destroyed after just a few weeks freezing (Bernard and Allen 2002). Most of the sites included supplementation, and these all include some vitamin E. All octopus were fed previously frozen fish and marine invertebrates, so supplementation is expected and necessary.

Though Katsanevakis et al. (2005) state that 20 °C is the temperature where metabolism is highest in common octopus, this varies depending on the size of the octopus and for animals over 200 g, 15°C is sufficient for optimizing metabolic rate (Miliou et al. 2005). Most of the collections in this study (72%) kept the octopus at a temperature between 16 and 17 °C (mean=17 °C; range 14.7- 19.0 °C). It would be beneficial to have accurate weights of each octopus to consider proportional diet composition. Crabs and in some cases clams and mussels are fed in shells, so that the octopus would deshell them before consumption.

Whilst there is no research on the specific mineral requirements of octopus, Lourenço et al. (2009) provided analyses on the muscle tissue of common octopus, finding that magnesium, chlorine, sodium, sulphur, potassium, phosphorus and calcium are the most abundant minerals. There is also evidence that direct uptake from seawater is possible, so the values stated in diet items are not indicative of all the minerals available to octopus. Yet, whilst some of the mineral requirements can be absorbed from seawater, dietary sources provide most essential minerals (Navarro et al. 2014). Diets containing fish were higher in calcium than diets that did not contain fish. Various diets had similar levels of magnesium and phosphorus, and diets containing more fish had higher levels of potassium. Future studies should consider the level of the other common minerals to provide a more comprehensive overview of the minerals provided to aquarium octopus.

Perkins (2023) reviewed public comments on the welfare of invertebrate species in aquaria, and octopus received significantly more negative comments than any other species (such as crabs, jellyfish and even animals in touch pools), so any research to improve welfare could be beneficial to both the individuals kept and public perception towards them. With the publication of the Standards of Modern Zoo Practise for Great Britain (Defra 2025) highlighting the requirement for evidence-based justification for diets, research on a wider range of species requirements is needed.

This study shows that there is considerable variation in the amount and type of foods that are fed to common octopus in European aquaria. This variation leads to large differences in theamount of protein and energy each octopus was receiving, while there is so far no indication that this variation affects individual animal welfare. Further research on the impact of these different diets on growth, development and longevity would be beneficial in developing clearer recommendations for octopus diets.

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