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OCTOPUSES IN CAPTIVITY: THE EFFECTS OF ENVIRONMENTAL ENRICHMENT ON BEHAVIOUR, COGNITION, AND DEVELOPMENT

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ABSTRACT

This study explores how environmental enrichment affects the behaviour and development of octopuses in captive environments. Octopuses are known for their high intelligence, strong problem-solving abilities, and complex behaviours, meaning that the conditions they are kept in can significantly influence how they act and respond. Secondary research from scientific studies and experiments was used to examine the impact of enrichment. In this context, environmental enrichment refers to the inclusion of features such as hiding spaces, objects to manipulate, and more complex surroundings that allow interaction and exploration. Overall, the findings show a clear pattern. Octopuses in enriched environments tend to display a wider range of behaviours, increased exploration, and more frequent interaction with their surroundings. They also show stronger engagement in problem-solving tasks and fewer stress-related behaviours compared to those kept in minimal environments. These results support the idea that enrichment plays an important role in both behavioural expression and overall well-being. It highlights how important it is to consider environmental conditions when studying or housing octopuses, particularly given their cognitive complexity.

KEYWORDS: Octopuses Behaviour, Environmental Enrichment, Object Manipulation, Cognitive Engagement, Stress-Related Behaviours

INTRODUCTION

Octopuses are among the most cognitively complex invertebrates known. They learn quickly, retain information over time, and can solve conditional discrimination tasks that require them to apply different rules depending on context (Hvorecny et al., 2007). Their behavioural repertoire in captivity includes exploration, den building, object manipulation, and play-like interaction with novel items (Mather & Anderson, 2001; Godfrey-Smith, 2017). This behavioural flexibility is supported by an unusual body plan: eight independently controlled arms lined with hundreds of chemically and mechanically sensitive suckers, and specialised skin cells called chromatophores that allow rapid changes in body pattern for camouflage and communication (Casalini et al., 2023).

This combination of intelligence and behavioural complexity raises particular questions about how octopuses should be housed. Cephalopods are the only invertebrates included in European legislation governing animals used in scientific research, and consensus guidelines for their care and welfare have since been developed by the research community (Fiorito et al., 2015; Ponte et al., 2023). The ethical case for this inclusion rests on evidence that cephalopods possess the neural complexity associated with the capacity to suffer (Mather & Anderson, 2007). Despite this recognition, cephalopod welfare remains an area of ongoing debate, with substantial disagreement about which husbandry conditions are adequate and how welfare should be measured (Mather

& Kuba, 2023; Monnissen & De Block, 2026).

Environmental enrichment is one of the primary strategies proposed to address these concerns. In this context, enrichment refers to the deliberate inclusion of features such as hiding spaces, manipulable objects, and structurally complex surroundings that allow interaction and exploration. Research has associated enriched housing with greater behavioural diversity, more frequent body pattern changes, and improved physical condition in *Octopus vulgaris* (Casalini et al., 2023), and with accelerated development of camouflage behaviour in juvenile cephalopods (Yasumuro & Ikeda, 2016). However, enrichment protocols differ substantially between studies and facilities, and much of the available evidence concerns short-term behavioural change rather than long-term welfare outcomes. This makes it difficult to determine how consistently enrichment produces benefits, and across which measures.

This study therefore investigates the following research question: *To what extent does environmental enrichment affect the behaviour, cognitive engagement, and development of octopuses in captivity?*

Based on the existing literature, it was hypothesised that octopuses housed in enriched environments would display a wider range of behaviours, increased exploration, more frequent interaction with their surroundings, and fewer stress-related behaviours than those housed in minimally enriched environments.

LITERATURE REVIEW

Environmental enrichment is considered extremely important for the well-being of octopuses in captivity, as they have advanced nervous systems and impressive problem-solving capabilities, which increase their desire to explore, play, and understand their environment. A study by Mather & Anderson (1999) supported the importance of providing octopuses with enriched environments, as it encourages natural behaviour, including den building, object manipulation, and exploration of their surroundings. Recent studies reinforce these findings; for example, Casalini et al. (2023) showed that octopuses kept in enriched aquatic environments displayed much higher behavioural diversity, more frequent body pattern changes, and increased weight compared to those kept in bare tanks.

Enrichment has also been shown to affect the development of octopuses, as a study by Yasumuro & Ikeda (2016) demonstrated that cryptic behaviour developed significantly faster, indicating that enrichment can shape development in juveniles. Synthesising these studies with further evidence from studies conducted on cephalopods (Hvorecny et al., 2007), a consistent pattern emerges, wherein enrichment reduces stress and stereotypic behaviours, increases interaction with the environment, and promotes natural behaviours such as hiding, foraging, and object manipulation. Collectively, these studies demonstrate that enrichment is extremely important for the enhancement and captive care of octopus species to maintain their behavioural, cognitive, and psychological health.

While these studies converge on the benefits of enrichment, they differ substantially in how enrichment is operationalised, ranging from the provision of simple objects to complex structural modification. This heterogeneity, combined with a reliance on short-term behavioural measures rather than long-term physiological indicators, makes it difficult to determine how consistently enrichment produces welfare benefits and across which outcomes. This review addresses that question by synthesising the available evidence across five behavioural and developmental categories.

METHODOLOGY

This study employed a secondary research design, drawing on peer-reviewed experimental studies, observational research, and published welfare guidelines (Fiorito et al., 2015; Ponte et al., 2023) to examine the effects of environmental enrichment on octopuses in captivity. A secondary approach was selected because primary experimental work with cephalopods requires specialised aquarium facilities and ethical approval under cephalopod research regulations, both of which fall outside the scope of this study. A substantial body of published experimental data already exists, providing an adequate evidential basis for synthesis.

Sources were identified through Google Scholar and academic databases using combinations of the search terms environmental enrichment, octopus behaviour, cephalopod welfare, captive cephalopods, and behavioural enrichment. Sources were included if they were published in peer-reviewed journals, reported behavioural, cognitive, developmental, or welfare outcomes in cephalopods, and made a comparison between enriched and non-enriched conditions or otherwise addressed the role of environmental complexity. Both quantitative experimental studies and qualitative observational research were included, alongside published welfare guidance documents providing regulatory and ethical context.

The selected literature was analysed thematically. Rather than summarising each study individually, findings were grouped according to recurring outcome categories that appeared across multiple studies: exploratory and manipulative behaviour, cognitive engagement, developmental outcomes, activity levels, and stress-related or abnormal behaviours. This approach allows conclusions to be supported by convergent evidence from multiple independent investigations rather than a single dataset.

Two limitations of this approach should be noted. First, enrichment protocols differ substantially between studies, which restricts direct quantitative comparison. Second, the absence of original experimentation means that experimental conditions could not be standardised or controlled.

RESULTS

Before presenting these findings, an important qualification should be noted. While several of the reviewed studies examined octopus species directly, particularly *Octopus vulgaris* and *Octopus rubescens*, others investigated related cephalopods including cuttlefish (*Sepia pharaonis*). Cuttlefish share with octopuses a highly developed nervous system, chromatophore-based camouflage, and comparable learning capabilities, and cephalopod welfare research is frequently generalised across these taxa. However, they are distinct species with differing ecology and behaviour. Where findings in this review derive from non-octopus cephalopods, this is indicated in the text, and such findings should be treated as suggestive rather than directly transferable. Table 1 summarises the outcomes reported across the reviewed studies.

Table 1: Summary of outcomes reported across reviewed studies. Italicised entries indicate findings derived from non-octopus cephalopods.

Table 1: Behavioural and Developmental Outcomes Reported Across Enriched and Non-Enriched Conditions

Outcome Measure	Enriched Environment	Minimal / Barren Environment	Supporting Sources
Behavioural diversity	Wider behavioural repertoire; more frequent body pattern changes	Restricted range of behaviours	Casalini et al. (2023)
Exploratory and manipulative behaviour	Frequent, repeated object interaction; tactile investigation	Reduced exploration; more time inactive	Mather & Anderson (2001); Casalini et al. (2023)
Cognitive engagement	Task learning; faster completion on repeated exposure; differential gene expression associated with cognitive stimulation	Cognitive capacity underutilised	Maselli et al. (2020)
Developmental rate (juveniles)	Earlier onset of cryptic and camouflage behaviour *(cuttlefish)*	Delayed behavioural development	Yasumuro & Ikeda (2016)
Activity level	Increased movement, climbing, object relocation	Reduced overall activity	Casalini et al. (2023)
Stress-related / stereotypic behaviour	Reduced occurrence of repetitive and abnormal behaviours	Higher occurrence of abnormal behaviours	Casalini et al. (2023); Fiorito et al. (2015)
Physical condition	Increased weight gain	Comparatively poorer condition	Casalini et al. (2023)

Table 1: Summary of outcomes reported across reviewed studies. Italicised entries indicate findings derived from non-octopus cephalopods. Source: Compiled by author.

Source: *Compiled by author.*

Across the reviewed literature, environmental enrichment was consistently associated with measurable behavioural and developmental changes in octopuses. These changes were observed in areas including exploratory behaviour, cognitive engagement, stress-related behaviours, and developmental outcomes.

Exploratory and Manipulative Behaviour

Several studies reported increased exploratory and manipulative behaviour when enrichment items were introduced into captive environments (Mather & Anderson, 1999). Octopuses exposed to objects such as shells, toys, or puzzle feeders interacted with them frequently and demonstrated repeated manipulation, indicating increased behavioural engagement and activities. Observations showed that individuals displayed curiosity-driven exploration, including tactile investigation and problem-solving behaviours when interacting with enrichment objects. These interactions often involved repeated handling of objects, which suggests that octopuses actively engaged with environmental stimuli as opposed to ignoring them, in contrast to the more limited environmental responsiveness documented in many other marine invertebrates (Casalini et al., 2023; Godfrey-Smith, 2017).

Cognitive Engagement

Evidence also indicated that enrichment promoted cognitive activity, with cognitive stimulation producing measurable changes in gene expression (Maselli et al., 2020). Studies examining problem-solving tasks reported that octopuses could learn to manipulate objects to access food rewards, demonstrating behavioural flexibility and learning ability. Repeated exposure to similar tasks resulted in faster task completion times, suggesting learning and memory retention. These results indicate that enriched environments can stimulate the advanced cognitive abilities already documented in cephalopods.

Developmental Outcomes

Developmental effects were also reported in experimental studies. Research examining the ontogeny of cryptic behaviour in juvenile cephalopods found that pharaoh cuttlefish raised in enriched environments developed camouflage behaviour significantly earlier than those in standard environments (Yasumuro & Ikeda, 2016). While conducted on cuttlefish rather than octopuses, this finding suggests that environmental complexity can accelerate the behavioural development of cephalopods more broadly.

Activity Levels

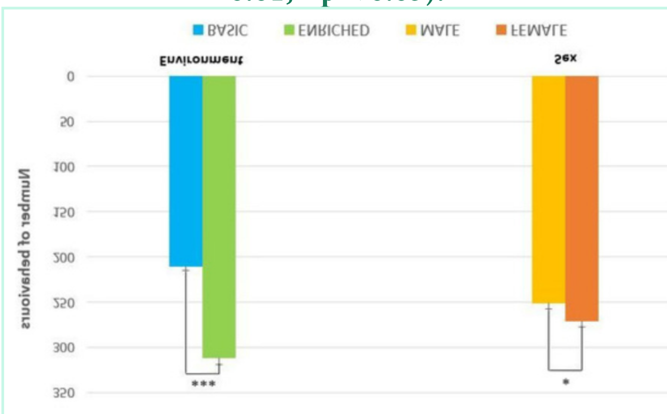
Changes in activity levels were another commonly reported result. Octopuses housed in enriched conditions demonstrated increased movement, exploration, and interaction with their surroundings compared with individuals in barren environments. Enrichment objects provided opportunities for physical activity such as climbing, manipulating, and relocating objects within the enclosure.

Stress-Related and Abnormal Behaviours

Studies examining welfare indicators also documented behavioural differences associated with enrichment. Enriched environments were associated with reduced occurrences of stress-related or abnormal behaviours that can occur in captive cephalopods. Individuals with access to environmental stimuli showed more diverse behavioural repertoires and spent less time inactive or exhibiting repetitive behaviours (Casalini et al., 2023).

Overall, the studies consistently reported increased behavioural complexity, enhanced exploration, improved cognitive engagement, and accelerated behavioural development in octopuses exposed to environmental enrichment. These findings were observed across multiple experimental and observational studies using different enrichment types and species.

Fig. 1: Effect of environment (basic vs. enriched) and sex on the total number of behavioural observations. Data shown as mean ± standard deviation. Asterisks indicate statistically significant differences (PERMANOVA; *** p < 0.01, * p < 0.05).



Source: *Casalini et al. (2023)*

Figure 1 demonstrates that octopuses housed in enriched environments produced significantly more behavioural observations than those in basic conditions, with the effect holding across both sexes. This provides quantitative support for the broader pattern identified across the reviewed literature.

DISCUSSION

The findings show a clear connection between environmental enrichment and changes in octopus behaviour, supporting the original hypothesis that octopuses in enriched environments display a wider range of behaviours, increased exploration, and more frequent interaction with their surroundings. Across the sources analysed, octopuses in enriched environments consistently displayed more active, complex, and varied behaviour than those kept in unenriched conditions. The consistency of this pattern across studies using different enrichment protocols, different facilities, and different species strengthens confidence in the finding.

One of the key ideas that emerges from the results is that enrichment encourages more natural behaviour in octopuses. Activities such as exploring, hiding, and manipulating objects were observed much more frequently when octopuses were given access to structures or items within their environment. This supports findings discussed in the literature review, particularly the idea that enrichment allows captive animals to behave as they would normally in the wild. Without these sources of enrichment, behaviour becomes more limited, which can explain the reduced activity seen in unenriched environments.

The increase in cognitive engagement is also significant. Octopuses are recognised for their intelligence, and the results suggest that this intelligence is much more clearly expressed when the environment provides some level of challenge or stimulation for the octopuses to interact with. Tasks involving food rewards showed that cephalopods could learn and improve over time to access a food supply, with cuttlefish demonstrating the capacity to delay gratification in exchange for a preferred reward (Schnell et al., 2021). This indicates problem-solving ability, memory, and adaptability. It raises the point that in environments without enrichment, these cognitive abilities may not be fully utilised, and in the case of juveniles, could hinder the proper development of these skills, which could have long-term effects on the well-being of the octopuses.

Another important point is the role enrichment plays in development, especially in juveniles in captivity. The earlier appearance of behaviours such as camouflage and hiding in enriched environments suggests that environmental complexity can influence how quickly certain skills are learned. This supports the idea that behaviour is not only biologically driven, but also shaped by external conditions. In this sense, enrichment does not just improve current behaviour, but may also affect how octopuses develop over time.

The reduction in stress-related behaviours is also important for octopuses. Octopuses in enriched environments showed fewer repetitive or abnormal actions and instead demonstrated a wider behavioural range (Casalini et al., 2023). This is often used as an indicator of improved welfare for octopuses, suggesting that enrichment has both psychological and behavioural benefits. However, while behavioural patterns are useful, they do not always give a complete picture, as there is still limited long-term physiological data available, which makes it difficult to fully understand the extent of these welfare improvements.

Overall, the research gathered reinforces the idea that environmental enrichment plays a major role in shaping octopus behaviour, brains, and development. While there are still gaps in the research, particularly in terms of standardisation and long-term data, the evidence strongly suggests that enrichment is extremely important for supporting the natural behaviours and well-being of octopuses in captivity.

Limitations

Several limitations should be considered when interpreting these findings.

First, enrichment protocols varied considerably across the reviewed studies, ranging from the provision of simple objects such as shells and balls to complex structural modifications and puzzle feeders. Because enrichment was not operationalised consistently, direct quantitative comparison between studies is not possible, and the magnitude of effects reported cannot be pooled.

Second, several of the reviewed studies examined cephalopod species other than octopuses, most notably cuttlefish. While cephalopod welfare findings are commonly generalised across these taxa, species-specific differences in ecology, sociality, and behaviour mean that such extrapolation carries uncertainty.

Third, the majority of available research measures short-term behavioural change. Long-term physiological data, including cortisol-equivalent stress markers, immune function, and lifespan outcomes, remain scarce. Behavioural indicators alone provide an incomplete picture of welfare.

Fourth, sample sizes in cephalopod enrichment studies are typically small, reflecting the practical and ethical constraints of housing large numbers of these animals experimentally. This limits statistical power and the generalisability of individual findings.

Finally, as a secondary review, this study is bounded by the scope and quality of published research. Publication bias may mean that studies finding positive enrichment effects are more likely to have been published than those finding no effect.

CONCLUSION

This review examined how environmental enrichment affects the behaviour, cognitive engagement, and development of octopuses in captivity. The evidence assembled here supports the original hypothesis. Across the reviewed studies, octopuses housed in enriched environments displayed greater behavioural diversity, more frequent exploration and object manipulation, stronger engagement in problem-solving tasks, and fewer stress-related or repetitive behaviours than those held in barren conditions (Mather & Anderson, 1999; Casalini et al., 2023).

Three findings stand out. First, enrichment does not simply increase activity but appears to permit the expression of behaviours that would otherwise remain absent, including den building, tactile investigation, and camouflage. Second, cognitive stimulation produces measurable biological change, with enriched conditions associated with differential gene expression in *Octopus vulgaris* (Maselli et al., 2020). Third, enrichment influences development as well as immediate behaviour, since juvenile cephalopods raised in complex environments acquired camouflage behaviour earlier than those in standard conditions (Yasumuro & Ikeda, 2016). Taken together, these findings indicate that environmental complexity shapes not only what a captive octopus does, but what it becomes capable of doing.

These conclusions carry practical implications. Cephalopods are the only invertebrates protected under European research legislation, and consensus welfare guidelines already recommend environmental complexity in captive housing (Fiorito et al., 2015; Ponte et al., 2023). The evidence reviewed here supports that recommendation and suggests that enrichment should be treated as a baseline requirement of ethical husbandry rather than an optional enhancement. This applies to research aquaria, public aquariums, and any facility housing these animals.

Important caveats remain. Enrichment protocols differ substantially between studies, several key findings derive from cuttlefish rather than octopuses, and the available evidence measures short-term behavioural change rather than long-term physiological welfare. Behavioural indicators alone cannot establish that an animal is thriving. Future research should prioritise standardised enrichment protocols to allow direct comparison between facilities, and long-term studies incorporating physiological stress markers, immune function, and lifespan outcomes. Whether the benefits observed over weeks translate into improved welfare across an animal's life remains an open and important question.

What this review does establish is that barren captivity constrains the behaviour of an animal whose defining characteristic is behavioural flexibility. For a species capable of learning, problem-solving, and adapting to novel challenges, an environment offering nothing to learn from or solve is not a neutral condition. The available evidence strongly indicates that environmental enrichment is essential to the ethical care of octopuses in captivity.

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