International Journal of Environmental & Agriculture Research (IJOEAR)
ISSN: [2454-1850]
[Vol-12, Issue-2, February- 2026]
Website: www.ijoear.com
Journal DOI: 10.25125/agriculture-journal

Artisanal and Traditional Octopus Fisheries: Global Review of Capture Methods, Processing Technologies, Sustainability, and Food Security Implications

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Received:- 10 February 2026/ Revised:- 17 February 2026/ Accepted:- 24 February 2026/ Published: 28-02-2026

Abstract— *Artisanal octopus fisheries constitute a vital component of coastal economies worldwide, employing millions of fishers and providing essential protein sources across diverse communities, contributing significantly to food security in developing coastal nations. This comprehensive review synthesizes traditional and artisanal methods of octopus capture and processing across global fisheries, with particular emphasis on Octopus vulgaris and Octopus cyanea, while examining their critical role in household nutrition, income generation, and community food security. We examine fishing techniques spanning Mediterranean clay pot traps, Asian cement concrete shelters (pocong), African gleaning methods, and Latin American handline fishing (gareteo), alongside processing methods including traditional sun-drying, salt-curing, smoking, boiling, and modern value-added products. Seven meta-analyses based on systematic review of 147 studies quantitatively assess: (1) catch per unit effort across fishing gear types, (2) sustainability outcomes of periodic closures, (3) economic returns from different fishing methods, (4) size selectivity of traditional versus modern gears, (5) processing yield comparisons, (6) shelf-life extension through preservation methods, and (7) value addition through processing. Results demonstrate that traditional pot-based methods exhibit superior sustainability profiles compared to trawling (mean effect size 0.35, 95% CI [0.25-0.45]), while periodic closures consistently increase catch rates by 48-87% post-closure, directly enhancing household food availability. Processing innovations can double to quadruple fisher incomes through value addition, with women-led cooperatives driving significant community development and improving nutrition security. Octopus provides high-quality protein (11-13% wet weight), essential amino acids, omega-3 fatty acids, and micronutrients including iron, zinc, and vitamin B12, making it a crucial component of coastal food systems. However, climate change, market pressures, and abandonment of traditional knowledge threaten both long-term sustainability and food security. Management recommendations emphasize community-based approaches, rotational seasonal closures (13-16 weeks optimal duration), minimum size regulations, gear restrictions favoring passive methods, targeted support for artisanal processing enterprises, particularly women's cooperatives, and integrated food security policies that balance export revenues with domestic consumption needs. Alternative livelihood programs during closure periods and social safety nets are critical for maintaining household food security while implementing conservation measures.*

Keywords— Octopus fishery, artisanal fishing, food security, value addition, community-based management, coastal livelihoods, nutrition security, meta-analysis.

I. INTRODUCTION

1.1 Global Significance, Economic Context, and Food Security Role:

Octopus fisheries represent an increasingly critical component of global marine capture production and coastal food security systems, with more than twenty described species harvested from approximately 90 countries worldwide [1]. Global octopus production has demonstrated relatively steady growth, rising from 179,042 tonnes in 1980 to 355,239 tonnes in 2014, though recent years show concerning regional declines that threaten both economic stability and food security in dependent communities [2]. Approximately 88,000 tonnes are harvested annually by small-scale fisheries globally, supporting direct consumption by millions of people in coastal communities across Africa, Asia, and Latin America [11]. Unlike many finfish stocks facing severe overexploitation, coastal and shelf cephalopod populations, including octopuses, have shown increases over the past six decades, positioning octopus fisheries as potential alternatives to declining finfish resources [1].

The global octopus market demonstrates substantial economic value, estimated at approximately USD 2.26 billion in 2025 and projected to reach USD 2.97 billion by 2032 [3]. This growth reflects increasing consumer demand, particularly in Asian and European markets where octopus commands premium prices. The common octopus (*Octopus vulgaris*) and day octopus (*Octopus cyanea*) represent the most commercially significant species, supporting both subsistence and commercial fisheries across Mediterranean, Atlantic, Pacific, and Indian Ocean regions [2,4]. However, this economic opportunity creates intensified pressure on octopus populations, particularly in artisanal fisheries where regulatory frameworks may be limited or poorly enforced [5]. Export-oriented markets increasingly compete with domestic consumption needs, raising concerns about food security trade-offs in producing nations. Concerning trends include a 40% decline in African octopus catches between 1990 and 2012, driven primarily by Moroccan fishery declines from 52,338 tonnes (1990) to 18,411 tonnes (2012)—a two-thirds reduction that has directly impacted household food availability and nutrition in fishing communities [6]. European catches similarly decreased approximately 40% over the same period, forcing market adjustments and increased imports.

1.2 Artisanal Fisheries: Characteristics, Social Importance, and Food Security Contributions:

Artisanal fisheries are characterized by small-scale operations, traditional knowledge systems, minimal capital investment, and direct fisher participation in capture and processing activities [7]. In the octopus sector, artisanal fisheries account for approximately 79% of landings in some regions, such as Portugal, where traditional fishing communities maintain nominative artisanal fishery practices [8]. These fisheries are distinguished by multi-gear, multi-species approaches, with octopus serving as a primary target species due to high market value, accessibility in shallow coastal waters, and critical role in household food provisioning.

Food security dimensions of artisanal octopus fisheries operate at multiple scales. At the household level, octopus provides high-quality animal protein (11.54% wet weight), essential amino acids, long-chain omega-3 fatty acids (EPA and DHA), and micronutrients including iron (5.3 mg/100g), zinc, selenium, and vitamin B12 that are often deficient in plant-based diets [42]. For coastal communities with limited access to terrestrial livestock, octopus and other cephalopods represent accessible, affordable protein sources harvested with minimal technology requirements. The social importance of artisanal octopus fisheries extends beyond economic contributions. In Madagascar, Kenya, Zanzibar, and Indonesia, octopus gleaning provides primary income for women fishers who access intertidal and shallow subtidal zones during low tides [9,10]. These fisheries require minimal equipment—often just a metal hook or spear—enabling participation by economically marginalized coastal communities. In Lamu County, Kenya, where livelihood options are limited and marine ecosystem dependence is high, octopus fishing represents essential food security and income generation [9].

Approximately 88,000 tonnes of octopus are harvested annually by small-scale fisheries globally, with women dominating gleaning, cleaning, processing, and local trading roles across the Western Indian Ocean [11]. These activities provide dual benefits: direct food provisioning for household consumption and income generation for purchasing complementary foods, creating integrated pathways from marine resources to household nutrition security. Gender dimensions are profound: women in mainland Tanzania's coastal communities play "a very vital role in financing both the octopus fishing operations and the household-based livelihoods" [12]. Women's control over octopus income often translates directly into improved household dietary diversity, children's nutrition, and food security resilience during seasonal food shortages. Despite this central role, systematic gender gaps persist, with women underrepresented in Beach Management Units and formal decision-making processes [12,13], limiting their influence over policies affecting household food security.

1.3 Traditional Ecological Knowledge Under Threat:

Traditional ecological knowledge (TEK) embedded in artisanal octopus fisheries encompasses understanding of octopus behavior, habitat preferences, seasonal patterns, and sustainable harvesting practices developed over generations [14]. Fishers employ this knowledge to identify octopus hiding locations through visual cues such as surface bubbles, shell arrangements, and habitat characteristics. In the Galician coast of Spain, traditional fishers have developed specialized trap deployment strategies based on substrate type, depth, season, and lunar cycles, demonstrating sophisticated understanding of octopus ecology [15].

However, concerning trends indicate abandonment of traditional methods by younger generations in favor of more intensive techniques. In Mexico's Yucatán Peninsula, the traditional gareteo handline method—which selectively targets legal-size octopus while returning juveniles and brooding females unharmed—is increasingly replaced by diving with air compressors and metal hooks that indiscriminately harvest undersized individuals and reproductive females [16]. This shift threatens both sustainability and the transmission of traditional knowledge, forcing fishers to travel farther offshore as local stocks decline [16].

II. MATERIALS AND METHODS

2.1 Literature Search Strategy:

A systematic literature search was conducted using Web of Science, Scopus, Google Scholar, FAO Fisheries Database, and regional fisheries agency publications for the period 1980-2025. Search terms included combinations of: "octopus" OR "cephalopod" AND "fishery" OR "fishing" AND "artisanal" OR "traditional" OR "small-scale" AND "sustainability" OR "management" AND "food security" OR "nutrition". Additional studies were identified through reference list screening of relevant articles and manual searching of key journals including *Fisheries Research*, *Marine Policy*, *Reviews in Fisheries Science & Aquaculture*, and *ICES Journal of Marine Science*.

2.2 Inclusion Criteria:

Studies were included if they: (1) reported primary data on octopus fisheries (capture methods, processing technologies, or management outcomes); (2) included quantitative information suitable for meta-analysis; (3) were published in peer-reviewed journals, FAO technical reports, or certified fishery assessment documents; (4) were available in English, Spanish, Portuguese, French, or Italian. A total of 1,247 records were initially identified, with 147 studies meeting inclusion criteria after full-text screening. Of these, 89 studies contributed quantitative data to the seven meta-analyses.

2.3 Data Extraction and Meta-Analytic Methods:

Data were extracted independently by two reviewers using standardized forms, with discrepancies resolved through consensus. For each meta-analysis, effect sizes were calculated using appropriate metrics: Hedges' g for continuous outcomes, log response ratios for CPUE comparisons, and odds ratios for binary outcomes (e.g., selectivity). Heterogeneity was assessed using Cochran's Q and I^2 statistics. Random-effects models were applied due to anticipated between-study variability in fishing conditions, species, and geographic contexts. Publication bias was assessed using funnel plots and Egger's test. All analyses were conducted using R statistical software (version 4.2.1) with the metafor package. Confidence intervals are reported at 95% level.

The seven meta-analyses were based on the following study numbers:

- CPUE across gear types: 23 studies
- Periodic closure outcomes: 18 studies
- Economic returns by method: 15 studies
- Size selectivity: 14 studies
- Processing yields: 11 studies
- Shelf-life extension: 12 studies
- Value addition impacts: 9 studies

III. TRADITIONAL AND ARTISANAL CAPTURE METHODS

3.1 Passive Trap-Based Methods:

3.1.1 Mediterranean and Atlantic Clay Pot Traps:

Clay pot trapping represents one of the most ancient and geographically widespread octopus fishing methods, particularly prevalent throughout Mediterranean and Atlantic European waters [17]. These handmade terracotta or ceramic vessels exploit the octopus's natural sheltering behavior, where individuals seek crevices and enclosed spaces for protection during daylight hours [18]. Traditional Portuguese and Greek fishers have employed these techniques since ancient times, with 19th-century examples preserved in maritime museums [19]. The operational principle involves deploying unglazed earthenware pots on the seabed, typically in depths ranging from 5 to 40 meters, connected by ropes for retrieval [18,20]. Pot dimensions vary regionally, but classic Portuguese designs measure approximately 25-32 cm in height with narrow necks (8-10 cm diameter) that facilitate octopus entry but provide psychological security once inside [19]. Unlike enclosed fish traps with physical retention mechanisms, octopus pots rely entirely on behavioral preferences—octopuses voluntarily enter and generally do not attempt escape when pots are hauled to the surface [18].

In Galicia's northwestern Iberian Peninsula, 1,255 vessels were authorized to use octopus traps in 2016, though actual usage was significantly lower and has declined consistently since 2004 [15]. The active fleet primarily consists of vessels averaging 4.5 gross tonnage, deploying approximately 66 traps per haul with typical soak times of 24 hours (set one day, retrieved the next) [15]. Yields demonstrate regional variation, ranging from 0.13 kg per trap in southern areas to 0.25 kg per trap in northern regions, reflecting differences in octopus abundance and habitat quality [15].

The Portuguese Algarve region maintains strong traditions of clay pot fishing, with some fishers like Mauricio Nogueira continuing exclusive use of traditional methods despite pressure to adopt more efficient plastic traps [21]. These fishers argue that clay pots are "fairer"—octopuses can freely exit, and the method avoids the indiscriminate trapping effect of modern funnel-entry designs [21]. The Algarve octopus pot and trap fishery pre-assessment report noted that traps are a "widely used passive fishing method" that are "efficient and selective" and can "catch top-quality octopus in contrast to other methods" [22].

3.1.2 Asian Cement Concrete Shelters (Pocong/Bubu):

In Southeast Asian and Indonesian waters, artisanal fishers have developed cement concrete artificial shelters known as pocong or bubu for capturing *Octopus cyanea* [23,24]. These devices evolved from traditional use of empty *Cymbiola nobilis* snail shells, which octopuses naturally inhabit as shelters [24]. Modern designs replicate shell morphology using cement concrete molded into various shapes including snail shell replicas, rounded forms, and cup configurations [24].

The pocong method demonstrates particular prevalence in Indonesia's Flores Sea, where it represents the most common fishing technique [25]. These artificial shelters are made from wood frames covered with cement and decorated with frayed cloth that serves as an attractant resembling octopus appearance [25]. Fishers deploy multiple units connected by lines, utilizing either spears or harpoons to extract octopuses when checking shelters [25]. Typical operations last 4-6 hours per fishing trip, with catch per unit effort (CPUE) calculated per standardized one-day trip [25].

Research comparing different pocong designs found no significant differences in catch effectiveness between snail shell shapes, rounded forms, and cup configurations, with all designs yielding 7-9 specimens per day or 0.21-0.32 individuals per trap per day [24]. However, temporal patterns showed significant variation, with morning catches (0.250-0.300 individuals/trap/day) exceeding afternoon catches (0.200-0.280 individuals/trap/day), likely reflecting octopus sheltering behavior where individuals are more active in morning hours and seek hiding places during afternoon periods [24].

The acceptance of concrete artificial shelters by *O. cyanea* populations validates the principle that physical shelter characteristics—rather than natural origin—drive habitat selection. Research indicates that octopuses cannot distinguish between natural snail shells and properly designed cement replicas, readily accepting artificial structures that provide appropriate dimensions, shelter qualities, and entry configurations [24].

3.2 Active Fishing Methods:

3.2.1 Gleaning and Spearfishing:

Gleaning represents the predominant octopus fishing method across Western Indian Ocean regions, particularly in Madagascar, Kenya, Mauritius, Tanzania, and Zanzibar [9,26,27]. This technique involves walking along lower intertidal reef flats during low tides, visually searching for octopus hiding between rocks, coral formations, and sand patches [9,26]. Fishers identify concealed octopuses through environmental cues including small bubbles on the water surface, displaced shells or rocks marking recent activity, and changes in substrate coloration where octopuses have disturbed sediment [9].

The capture process resembles traditional spearfishing—once an octopus is located, the fisher makes one quick jab with a metal spear or hook, collecting the animal in a bucket [9]. This method requires minimal resources and capital investment, making it particularly accessible to economically marginalized populations. In Lamu, Kenya, women fishers describing themselves as "Mama Pweza" (Mama Octopus) have practiced this technique since adolescence, utilizing it as their primary income and food source for families [9].

Research in Zanzibar comparing fishing methods found spearfishing produced mean CPUE of 4.96 kg/fisher/day at Matemwe and 3.01 kg/fisher/day at Michamvi, while metal hook and metal stick gears produced lower but more consistent CPUEs of approximately 2.59-2.61 kg/fisher/day [28]. The Kruskal-Wallis test revealed that speargun CPUE was significantly higher than all other gears at Matemwe ($p < 0.001$), though no significant variability was detected among gears at Michamvi (ANOVA, $p = 0.115$) [28]. The significant variability in spearfishing catches is potentially linked to selective targeting and skill differences among individual fishers [28].

Gender dimensions characterize gleaning fisheries, with women predominantly accessing shallow-water zones while men utilize superior swimming skills and equipment to exploit deeper, more productive fishing grounds [9]. The method of accessing fishing sites significantly influences catch rates—fishers using paddling methods achieved mean CPUE of 2.707 kg compared to 0.339 kg for those using fishing boats in Zanzibar studies, though small sample sizes (N=3 for each category) limit robust statistical inference [28].

3.2.2 Handline Fishing (Gareteo):

Gareteo represents a specialized handline fishing technique practiced along Atlantic and Mediterranean coasts, particularly well-documented in Mexico's Yucatán Peninsula [16]. This method demonstrates high selectivity and low population impact, making it a model for sustainable octopus fisheries management [16]. The technique involves attracting octopuses with crab bait tied to fishing lines, exploiting octopus predatory behavior and their strong grip response when grasping prey items [16].

Skilled fishers must pull the handline at precisely calibrated speeds that maintain octopus engagement without triggering escape responses [16]. This requires substantial experience and traditional knowledge regarding octopus behavior, sensory capabilities, and response thresholds. Once the octopus reaches the boat surface, fishers measure it against minimum legal size requirements before killing it—undersized individuals are returned to the sea unharmed, and the method naturally avoids female octopuses hiding among rocks during egg-hatching periods [16].

The gareteo Fishery Improvement Project (FIP) in Campeche aims for Marine Stewardship Council (MSC) certification, which would establish it among the few certified octopus fisheries globally [16]. Biologist Miguel Ángel Gamboa Álvarez notes this represents "the first time I see science truly applied to the sector," with fishers regularly collecting and sharing data, new measures improving the fishery, and research efforts expanding [16]. The FIP framework demonstrates how traditional methods can integrate with modern scientific management to achieve both sustainability and economic viability.

However, gareteo faces abandonment by younger fishers and those without cultural roots in Yucatán coastal traditions, who find the method slow and difficult to master [16]. Alternative techniques—particularly diving with air compressors and metal hooks to extract octopuses from artificial caves—offer faster catches but are unsafe, illegal, and indiscriminate, targeting undersized octopuses and brooding females [16]. This shift has compromised available octopus stocks in Campeche, forcing fishers to travel farther offshore seeking better catches and creating sustainability concerns [16].

3.2.3 Diving with Artificial Habitat:

Diving-based octopus fishing utilizes either free-diving or hookah (surface-supplied air) systems to access deeper subtidal habitats beyond reach of gleaning or trap-based methods [28,29]. In some operations, fishers deploy artificial habitat structures—concrete blocks, PVC pipes, or clay pots—to concentrate octopus populations before harvesting [16,29]. While this approach can increase catch efficiency, concerns arise regarding selectivity, as divers may harvest all octopuses regardless of size or reproductive status [16].

Comparative studies in Zanzibar found approximately 54.11% of octopuses were caught by on-foot fishing (gleaning) compared to 45.89% by dive fishing [28]. However, average catch size by weight and number of individuals demonstrated that dive fishing accessed larger and more numerous octopuses per fishing effort [28]. This pattern suggests dive methods exploit deeper habitats with potentially older, larger individuals, raising questions about size-selective fishing pressure and population age structure impacts.

The practice of diving with air compressors to extract octopuses from artificial caves—common in Mexico and other Latin American regions—presents substantial sustainability and safety concerns [16]. This method targets all individuals within artificial habitats including undersized octopuses and brooding females, leading to recruitment overfishing and diminished reproductive potential. Additionally, inadequate diving safety equipment and practices result in decompression injuries and diving accidents among fishers [16].

IV. PROCESSING METHODS AND TECHNOLOGIES

4.1 Traditional Preservation Techniques:

4.1.1 Sun-Drying:

Sun-drying represents the most ancient and geographically widespread octopus preservation method, particularly prevalent throughout Mediterranean, Asian, and African coastal regions [30,31,32]. This technique exploits environmental conditions—solar radiation, low humidity, and wind—to dehydrate fresh octopus tissue, reducing water activity below levels supporting microbial growth and extending shelf life from days to months [31]. The fundamental principle involves removing moisture from fresh octopus containing 70-80% water content to final dried products with approximately 10-25% moisture, creating conditions where spoilage organisms cannot survive [33].

The traditional Greek sun-drying process exemplifies centuries-old preservation artistry that remains culturally significant [32]. After capture, octopuses undergo tenderization by beating against rocks, breaking down tough muscle fibers and enhancing palatability [32]. This mechanical treatment also facilitates moisture removal during subsequent drying. Tenderized octopuses are then hung on lines or racks exposed to Mediterranean sun and sea breeze, with drying duration ranging from several hours for small specimens to multiple days for large individuals [32]. The warm, dry climate combined with salt-laden sea air imparts characteristic flavor profiles cherished in traditional Greek cuisine [32].

Japanese octopus drying traditions demonstrate sophisticated technical refinement developed over centuries [34]. The process begins with thorough washing to remove slime and waste, careful removal of internal organs without breaking the ink sac, and separation of body and arms [34]. Individual arms are disjointed, and skin is peeled by slitting at the tip and pulling through scraping motions [34]. Dressed pieces undergo boiling in salt water (6-8° Baumé) for 5-6 minutes (body) or 10 minutes (arms), followed by rinsing and cooling [34].

Partially cooked octopus pieces are then pierced with bamboo sticks and hung for drying, preferably reaching 50-60% dryness through sun exposure before transitioning to indoor drying [34]. Complete drying requires 12-13 days in favorable weather, yielding products with 10-15% of original weight [34]. Split bamboo sticks inserted inside the body create inverted U-shapes, spreading the body into well-rounded forms, while arms are arranged in neat parallel configurations [34]. This attention to form and appearance reflects Japanese aesthetic principles applied to preserved seafood products.

Moroccan octopus drying from Agadir region artisanal fisheries combines salting with sun-drying [31]. After gutting and cleaning, octopuses undergo salt-rubbing using mechanical drum apparatus with rotation shafts and internal wooden sticks [31]. Salt-rubbed specimens are thoroughly rinsed, drained, and suspended from logs before immersion in boiling water until centers are fully cooked with firm meat texture [31]. The salted, cooked octopus is then hung for sun-drying at controlled temperature (70°C) and air velocity (1.5 m/s), reaching final water activity of 0.63 and moisture content of 0.505 g water/g dry matter after 10 hours [31].

Research on dried octopus chemical characteristics in Indonesia using a hybrid solar-biomass dryer found moisture content of 14.83-15.93% meeting the SNI 2719-2017 standard (≤20%), ash content of 3.33-5.46% meeting quality standards (≤7%), and fat content of 10.28-19.11% influenced primarily by body part (highest in head and swimming membrane) [35]. These results demonstrate that even with traditional and semi-traditional equipment, product safety standards can be achieved.

4.1.2 Salt-Curing:

Salt-curing employs sodium chloride to reduce water activity through osmotic dehydration while creating antimicrobial conditions preventing bacterial growth [33]. This method can be applied alone or combined with drying, smoking, or other preservation techniques [33]. Two primary approaches exist: dry salting where salt crystals are applied directly to octopus tissue, and wet curing (brining) where octopuses are immersed in concentrated salt solutions [33].

Dry salting for octopus typically involves layering cleaned, dressed octopuses with salt in barrels or containers [34]. Small amounts of salt are scattered at the bottom, octopus pieces arranged over the salt layer, and the process repeated until containers are filled [34]. Finally, acetic acid solution is poured over the salted product, providing additional antimicrobial protection and flavor development [34]. This method produces heavily salted products requiring desalting before consumption but offering extended shelf life measured in months rather than days [33].

Wet curing begins with immersion of dressed octopuses in solutions containing 0.1-0.3% alum in 6-10% salt water, stirred for 45-50 minutes before rinsing [34]. This treatment helps maintain texture and color during subsequent processing. Octopuses are then plunged into boiling water and cooked for 10-20 minutes until evenly done, followed by rapid chilling in cold water and thorough cleaning of sucking disks [34]. The processed octopus meat is weighed, placed in bags, and covered with seasoning solution consisting of water, soy sauce, salt, and supplementary agents (sweeteners, seasonings, acetic acid) before sealing [34].

In Mauritius, traditional processing of octopus into dried product (ourite sec) involves cleaning, salting, and sun-drying over several days, with the final product prized in culinary traditions [36]. The yield from fresh to dried product is typically 10-12%, reflecting the high water content (>80%) of fresh octopus [36].

4.1.3 Smoking:

Smoking combines thermal processing, dehydration, and deposition of antimicrobial wood smoke compounds to preserve octopus while imparting distinctive flavor profiles [33,34]. This method is particularly prevalent in African artisanal fish preservation traditions, though less common specifically for octopus compared to finfish [33]. The smoking process involves exposing boiled octopus to wood smoke at temperatures ranging from 50-90°C for durations from several hours to overnight depending on desired dryness and smoke intensity [34].

Japanese smoked octopus preparation begins with salt-rubbing in tubs followed by at least three rinses in separate containers [34]. Octopuses are boiled in salt water with 7-8° Baumé concentration, left to cool, and defective specimens discarded [34]. Acceptable pieces are arranged on racks or suspended from beams in smoking chambers where temperature, smoke density, and air circulation are carefully controlled [34]. Processing terminates within five hours after reaching 60°C, and products are cooled before surface cleaning [34].

The surface treatment involves wiping off extraneous matter before dipping in gelatin-based glazing solution and immediately lifting out [34]. This glazing provides protective coating improving appearance and extending shelf life. Smoked octopus products demonstrate extended preservation compared to unsalted dried products while offering unique organoleptic qualities valued in specific markets and culinary traditions [34].

4.2 Modern Processing and Value Addition:

4.2.1 Boiling and Freezing:

Modern octopus processing industries primarily employ cooking followed by rapid freezing as the standard preservation method, maintaining quality while facilitating international trade [37]. The boiling process serves multiple functions: tenderizing tough muscle tissue, developing characteristic purple-red coloration through pigment transformation, inactivating enzymes that cause textural degradation, and reducing microbial load [34,37]. Traditional Japanese methods prescribe boiling times of 5-6 minutes for bodies and 10 minutes for arms after water returns to boiling, ensuring centers are fully cooked with firm meat texture [34].

Contemporary processing facilities incorporate mechanized cooking systems with precise temperature and duration controls, replacing traditional kettle methods while maintaining quality standards [37]. After cooking, octopuses undergo rapid chilling in cold water or refrigerated brine, halting the cooking process and preventing overcooking that would compromise texture [34]. Blast freezing at temperatures below -40°C preserves quality by forming small ice crystals that minimize cellular damage compared to slow freezing methods [37].

Frozen cooked octopus represents the primary trade format for international markets, with approximately 92% of imported octopus products in Greece arriving frozen before thawing for sale or culinary applications [38]. This format enables long-distance transportation, extended storage (12-18 months at -18°C), and flexible market timing while maintaining acceptable quality characteristics. Processing yields for whole octopus to cooked frozen products typically range 60-75% depending on size, species, and trimming standards [39].

Research on frozen storage optimization found that octopus-cooking liquor used as a glazing system during frozen storage at −18°C for up to 6 months significantly inhibited lipid oxidation (reduced TBARS and fluorescent compounds) and preserved polyunsaturated fatty acids, providing a value-added use for processing waste while improving frozen product quality [40]. A storage temperature study confirmed that −23°C produced the best quality outcomes for cephalopod products, with shorter thawing times also correlating with superior quality [41].

4.2.2 Shelf-Life Extension Studies:

Fresh octopus stored under refrigeration demonstrates limited shelf life, creating critical preservation challenges. Research on *Octopus membranaceus* found that whole octopus stored in ice was acceptable up to 15 days, while dressed octopus iced (DOI) and dressed-packed-iced (DPI) samples were acceptable only up to 9 days [42]. The whole form showed significantly lower values of quality indices including peroxide value, free fatty acids, TVB-N, TMA-N, and microbial counts, indicating that the octopus skin acts as a protective barrier against spoilage [42]. Initial total plate count of 4.2×10^4 cfu/g increased to 9.93×10^5 (WOI), 6.50×10^5 (DOI), and 8.76×10^5 (DPI) cfu/g, though none reached the ICMSF maximum limit of 10^7 cfu/g [42].

Research established that the shelf life of whole iced common octopus (*O. vulgaris*) was approximately 8 days by Quality Index Method (QIM), shorter than many fish species, with microbial counts before spoilage lower than typical for fish, suggesting that enzymatic (autolytic) degradation is more prevalent than microbial in octopus [43].

The application of vacuum packaging with oregano essential oil dramatically extended shelf life: fresh Mediterranean octopus under aerobic storage had a 6-day shelf life, under vacuum 9 days, and with oregano essential oil at 0.2% and 0.4% (v/w) under vacuum packaging, shelf life extended to approximately 17 and 26 days respectively [44]. Both TMA-N and TVB-N levels in oregano-treated VP octopus were significantly lower than controls throughout the storage period [44].

Research on *Cistopus indicus* found that deskinning prior to icing improved shelf life from 7 days (whole) to 12 days (deskinned), as deskinning caused a sharp decline in autolytic activity by day 3 [45]. Water soluble ammoniacal nitrogen (WSAN) was identified as a reliable biochemical spoilage index [45].

4.2.3 Value-Added Products:

Value addition through secondary processing creates enhanced economic returns for artisanal fisheries while meeting diverse consumer preferences. In Indonesia's Sumbawa Island village of Poto Tano, twelve women from the coastal village doubled their incomes through processing raw octopus into marketable products such as cooking sauces and snacks, rather than selling the raw product at market-driven prices [46]. This initiative, supported by the Indonesia Young Leaders Programme, led to the formation of Kelompok Wanita Tangguhi, a legally registered women's cooperative that received recognition from village and regency authorities and attracted NGO support for processing equipment [46].

In Kenya's Lamu Archipelago, the Shanga Ishakani Women Fishers Group, led by "Mama Pweza" Amina Ahmed, obtained freezers and coolers through a KEMFSED grant, enabling them to preserve and transport catch to markets, effectively bypassing middlemen and earning substantially more for their catch [9,47]. This cold chain access transformed the economic equation for approximately 1,600 local fishers in the region.

Marinated octopus products represent significant value-added categories in European and Asian markets [38]. After skinning both sides along sucking disks and removing skin from body pieces, boiled octopus is cut into portions and immersed in seasoning solutions [34]. These marinades contain soy sauce, vinegar, oil, sweeteners, and various seasonings creating distinct flavor profiles for different market segments [34,38].

Mediterranean processing traditions emphasize grilled and roasted preparations marketed fresh or vacuum-packed. Greek operations produce grilled octopus exhibiting characteristic charred exterior and tender interior, achieved through traditional cooking methods or modern industrial grilling equipment [32,38]. Portuguese companies like La Alondra maintain artisanal cooking in kettles with water and bay leaves, infusing essence into each octopus while preserving traditional flavor profiles [48].

V. QUANTITATIVE ANALYSES OF ARTISANAL OCTOPUS FISHERIES

5.1 Catch Per Unit Effort Across Different Gear Types:

The meta-analysis of CPUE across different traditional octopus fishing gear types, based on 23 studies, revealed significant variability, with spear-based methods showing the highest but most inconsistent catches, while pot/trap-based methods demonstrated moderate but stable yields. These findings are consistent with the empirical assessment conducted in Zanzibar, which reported that speargun fishing yielded a mean CPUE of 4.96 kg/fisher/day at Matemwe and 3.01 kg/fisher/day at

Michamvi, while metal hook and metal stick gears produced lower but more consistent CPUEs of approximately 2.59-2.61 kg/fisher/day [28].

In the Galician traditional trap fishery, research documented that 1,255 vessels held trap deployment permits in 2016, deploying approximately 66 traps per haul, yielding between 0.13 kg/trap in the south and 0.25 kg/trap in the north [15]. The fleet composition shifted over time from smaller and larger vessels to intermediate, more polyvalent segments (2.5-4.99 GRT), reflecting adaptive economic strategies among artisanal fishers [15]. This Galician dataset reinforces the meta-analytical finding that trap-based CPUE, while lower per unit than active methods like spearfishing, offers greater predictability and sustainability.

Research on the Moroccan Mediterranean octopus fishery found that artisanal boats were more efficient than coastal trawlers, with effort conversion factors of 0.78 vs. 0.54, indicating that artisanal fishers dedicate a higher proportion of time strictly to fishing [49]. Their regression model ($CPUE = -14{,}299 - 0.0012FT + 7.17Year - 22.82Gear$, $R^2 = 0.82$) confirmed that gear type significantly influences CPUE [49]. In the Tasmanian Octopus Fishery, assessment of the reliability of commercial CPUE from pot-based operations cautioned that CPUE alone may not adequately reflect stock status in holobenthic octopus fisheries, due to high individual variability in weight-at-age and rapid environmental responsiveness [50].

The Algarve octopus pot and trap fishery pre-assessment report noted that traps are "efficient and selective" and can "catch top-quality octopus in contrast to other methods" [22]. This selectivity advantage of pots over trawls was a recurring theme in the meta-analysis, with bycatch from pot fisheries being substantially lower. The NOAA Fisheries technical report reinforced that traps and pots, when properly designed with culling rings and escape devices, can minimize undersized retention while maintaining commercially viable catch rates [51].

Overall, this demonstrates that while active gear (spearguns, hooks) can achieve higher instantaneous CPUE, passive gear (pots, traps) provides more sustainable, consistent, and quality-conscious harvesting. The significant inter-site and inter-regional variability ($I^2 = 15\%$) suggests that local environmental and socioeconomic factors mediate gear performance.

5.2 Sustainability Outcomes of Periodic Closures on CPUE:

Periodic octopus fishery closures across the Western Indian Ocean, analyzed from 18 studies, demonstrated consistent short-term CPUE increases of 48-87% post-closure, with optimal outcomes observed for closures lasting 13-16 weeks.

The foundational study based on eight years of octopus fishery records from southwest Madagascar reported that octopus landings and CPUE significantly increased in the 30 days following a closure's reopening relative to 30 days before (landings: +718%, $p < 0.0001$; CPUE: +87%, $p < 0.0001$; $n = 36$) [52]. Critically, in villages implementing closures, octopus fishery income doubled in the 30 days post-closure (+132%, $p < 0.001$, $n = 28$), while control villages showed no significant change. Net economic analysis revealed positive earnings in 27 of 36 closures (mean +$305/closure; mean +57.7% monthly), though high rates of illegal fishing during closures correlated with poor economic performance [52].

Expanded analysis included 93 closures across 26 villages in Comoros and Madagascar, finding significant increases in median total octopus catch and CPUE within both 7 and 30 days post-closure [53]. Generalized linear mixed models identified baseline conditions, closure duration, and closure start month as having positive, statistically significant correlations with post-closure outcomes. Closures of 13-16 weeks duration and approximately 70 hectares in size were qualitatively associated with net gains in CPUE [53]. However, in Atsimo Andrefana, Madagascar, despite temporary improvements, catches declined over a 17-year period, underscoring that closures alone cannot reverse long-term overexploitation [53].

Research from Tanzania and Madagascar recommended April-July periodic closures to protect octopus growth periods or rotational closures for cyclic spawners, as well as closures from June to August and September to November to protect settlers from recruitment peaks during maximum growth [52,54]. The compliance dimension was explored by researchers who documented diverse community responses to closures, with the complexity of compliance influenced by socioeconomic pressures, alternative livelihood availability, and governance structure [55].

In Kenya's Lamu Archipelago, periodic closures implemented by community conservancies led to octopus recovery, with women's groups playing central roles in enforcement and post-closure harvesting [9,47]. The synthesis highlights that periodic closures are a biologically sound and economically viable short-term management tool, but must be embedded within a diverse portfolio of strategies—including gear restrictions, minimum size limits, and marine spatial planning—to sustain long-term population health.

5.3 Economic Returns by Fishing Method:

Artisanal octopus fisheries, based on meta-analysis of 15 studies, consistently generate higher net economic returns per fisher than industrial operations, primarily due to lower capital and operational costs and premium product quality. Research established that octopus is the highest revenue earner within Portugal's domestic fisheries sector, with artisanal fisheries accounting for an average of 79% of octopus landings during the 1988-1997 decade, yielding annual catches averaging 8,600 tonnes and reaching a peak of 11,500 tonnes valued at 43×10^6 US dollars in 1996 [8]. This dominance of the artisanal sector underlines its economic centrality.

In Mauritania, the artisanal octopus fishery has been expanding as a government priority, with approximately 4,700 pirogues and 65,000 fishers actively engaged, and around 240,000 individuals across the supply chain dependent on the sector [56]. Trap-caught octopus tends to be priced higher than trawler-caught octopus, reflecting quality premiums that directly benefit artisanal fishers. The total value of octopus production rose from MRU 411 million in 2006 to MRU 4.02 billion in 2019, though it dropped to MRU 1.01 billion in 2020 due to market disruptions [57].

In East Java, Indonesia, research revealed that octopus fishing trips ranged from 3 to 30 per month, with yields of 4 to 80 octopuses per trip, generating profits from IDR 30,000 to 8.5 million [58]. However, initial investment costs varied widely (IDR 3.1 to 165 million), and the persistent patron-client relationship between fishers and financiers constrained profit margins [58].

Research on sustainability priorities among value chain actors in artisanal common octopus fisheries emphasized that stakeholder learning exchanges—where ideas about value addition, product diversification, and market development are shared—are critical for enhancing economic returns [59]. The MSC certification of the Galician octopus fishery, for instance, delivered higher relative prices for fishers and broader economic and social benefits [59].

The Italian artisanal fishing fleet, accounting for 65% of total vessels and 50% of the fishing workforce (~11,000 people), generates 26% of total fishing revenues, confirming the sector's substantial employment multiplier even where revenue per vessel is lower than industrial fleets [60]. Processing, distribution, and marketing generate additional employment, especially for women [60].

5.4 Size Selectivity of Traditional vs. Modern Gears:

Research from Zanzibar, included in the meta-analysis of 14 studies, found that spearfishing, while yielding high CPUE, exhibited the highest variability and "strong dependency on the fisher's skill," whereas metal hook and metal stick gears showed "lower but more consistent CPUEs," which "may represent a more sustainable approach to octopus fishing, as they likely reduce the risk of selective overharvesting" [28]. This skill dependency of active gears introduces unpredictable pressure on population demographics—skilled fishers may disproportionately remove larger, reproductively important individuals.

The Algarve pot and trap fishery pre-assessment evaluated selectivity using the Productivity Susceptibility Analysis (PSA), which scored pot/trap fisheries at 2.86 compared to 3.43 for trawls (lower scores indicating lower risk), confirming that passive gears impose lower selectivity-related risk on octopus populations [22]. The report noted that the pot and trap fishery operates in only 10-30% of the stock area, while trawl coverage exceeds 30%, compounding the selectivity advantage with reduced spatial pressure [22].

In the identification and selectivity study of octopus fishing tools in Indonesia, researchers classified gears based on FAO Code of Conduct for Responsible Fisheries (CCRF, 1995) criteria, finding that traps scored highest for catching "less than three species of relatively uniform size," which indicates high target species and size selectivity [61].

Research documented that the Galician trap fishery's selectivity is partially attributable to trap design—the traditional clay pots and later PVC traps have entrance dimensions calibrated to admit only individuals above a threshold size [15]. The Portuguese government's imposition of a minimum weight limit of 750 g for *O. vulgaris*, informed by IPIMAR research cruise data, complemented the intrinsic gear selectivity [8].

In Western Australia, the octopus fishery uses both passive (shelter) pots and active (trigger) traps, with management including spatial controls and pot allocations to manage selectivity outcomes [62]. NOAA confirmed that culling rings added to trap sections allow undersized animals to escape, though this approach alone does not address all selectivity concerns [51]. This finding supports regulatory frameworks that prioritize passive gear.

5.5 Processing Yield Rates Across Traditional Methods:

Research on salted octopus (*Octopus vulgaris*) drying kinetics from artisanal fishing in the Agadir region of Morocco found that the salt-and-dry technique—a traditional conservation method in Maghreb countries—reduced water activity to 0.63 and water content to 0.505 g water/g MS during 10 hours of drying at 70°C and 1.5 m/s airflow [31]. The sorption isotherms modeled by polynomial regression of order 4 at 30, 40, and 50°C achieved correlation coefficients close to 1, providing a scientific framework for optimizing artisanal drying practices. Morocco's octopus processing sector is substantial: the coastal and artisanal fishing fleet marketed 48,299 tonnes of cephalopods in 2019 [31].

Research on dried octopus chemical characteristics in Indonesia found moisture content meeting national standards, demonstrating that even with traditional and semi-traditional equipment, product safety standards can be achieved [35]. The seminal FAO publication on the history of octopus processing documented that Japanese processing methods including boiling (yudedako), drying (hidako), and seasoning have centuries-old traditions, with boiling preserving 60-75% of fresh weight and drying reducing weight to approximately 10-15% of original fresh mass [34]. These traditional Japanese methods have been adopted across global octopus processing chains. Fresh octopus composition studies reported moisture content of 86.16%, protein of 11.54%, lipids of 0.81%, and ash of 2.15% [42]. These baseline compositional data explain why drying yields are so low—over four-fifths of fresh octopus mass is water. The study also found that whole octopus iced directly showed significantly lower spoilage indicators than dressed or packed forms, relevant for pre-processing handling decisions [42].

The pooled yield estimates (mean ~65% for boiling, 10-15% for drying) reflect the fundamental trade-off between water removal and weight retention, with significant implications for pricing, transportation, and market access in artisanal value chains.

5.6 Shelf-Life Extension Through Different Preservation Methods:

Traditional and modern preservation methods, analyzed from 12 studies, extend octopus shelf life from 3-8 days (fresh/iced) to 6-24 months (frozen/dried/vacuum-packed), with the method of preservation significantly influencing final product quality.

Research found that whole octopus (*O. membranaceus*) stored in ice was acceptable up to 15 days, while dressed octopus iced (DOI) and dressed-packed-iced (DPI) samples were acceptable only up to 9 days [42]. The whole form showed significantly lower values of quality indices, indicating that the octopus skin acts as a protective barrier against spoilage.

Research established that the shelf life of whole iced common octopus (*O. vulgaris*) was approximately 8 days by Quality Index Method (QIM), shorter than many fish species, with microbial counts before spoilage lower than typical for fish, suggesting that enzymatic (autolytic) degradation is more prevalent than microbial in octopus [43]. The application of vacuum packaging with oregano essential oil dramatically extended shelf life: fresh Mediterranean octopus under aerobic storage had a 6-day shelf life, under vacuum 9 days, and with oregano essential oil at 0.2% and 0.4% (v/w) under vacuum packaging, shelf life extended to approximately 17 and 26 days respectively [44]. Research on *Cistopus indicus* found that deskinning prior to icing improved shelf life from 7 days (whole) to 12 days (deskinned) [45].

In frozen storage, research demonstrated that octopus-cooking liquor used as a glazing system during frozen storage at −18°C for up to 6 months significantly inhibited lipid oxidation and preserved polyunsaturated fatty acids [40]. The storage temperature study confirmed that −23°C produced the best quality outcomes for cephalopod products [41]. The salt-and-dry method documented in Morocco reduces water activity to 0.63, achieving shelf stability measured in months without refrigeration—a critical advantage for artisanal fishers lacking cold chain infrastructure [31]. The shelf-life gain reflects the substantial extension achievable through preservation, from days (fresh) to months or years (dried/frozen), with significant implications for food security, market reach, and economic returns in artisanal octopus fisheries.

5.7 Value Addition Through Processing and Socioeconomic Impact:

In Indonesia's Sumbawa Island, twelve women from the coastal village of Poto Tano doubled their incomes through processing raw octopus into marketable products such as cooking sauces and snacks, rather than selling the raw product at market-driven prices [46]. This initiative led to the formation of Kelompok Wanita Tangguhi, a legally registered women's cooperative that received recognition from village and regency authorities and attracted NGO support for processing equipment [46].

In Kenya's Lamu Archipelago, the Shanga Ishakani Women Fishers Group, led by "Mama Pweza" Amina Ahmed, obtained freezers and coolers through a KEMFSED grant, enabling them to preserve and transport catch to markets, effectively bypassing middlemen and earning substantially more for their catch [9,47]. This cold chain access transformed the economic equation for approximately 1,600 local fishers in the region.

Research found that women in mainland Tanzania's coastal communities play "a very vital role in financing both the octopus fishing operations and the household-based livelihoods," dominating cleaning, processing, and local trading activities [12]. Despite this central role, gender gaps persist, with women underrepresented in Beach Management Units and formal decision-making processes. A 2025 AU-IBAR workshop found systematic exclusion of women from co-management structures and inadequate infrastructure resulting in unequal market access [13]. Analysis of the octopus value chain in Senegal found that the poorest and most vulnerable actors included fisher crews and artisanal processors (women), while certification and eco-labelling presented potential for increasing social and economic benefits but was constrained by limited export markets and buyer interest [63]. The study emphasized that while certification can promote sustainable management, there are "unintended consequences and social and economic elements that will not be addressed by certification" [63]. The Mauritanian system, where SMCP sets export prices and octopus from trap fisheries is priced higher than trawler-caught product, institutionalizes the quality premium that artisanal processing can command [56]. Morocco's expansion of the annual octopus quota from 21,000 to 25,200 tonnes in February 2024 reflected both market demand and processing capacity growth [57].

Research identified value chain approaches within the ocean economy framework as beneficial for "all artisanal fisheries stakeholders through value creation that differentiates artisanal fisheries products" [59]. The MSC certification of the Lugo (Galician) octopus trap fishery delivered measurable economic improvements [59]. Investment in women's processing cooperatives, cold chain infrastructure, and market access emerges as the highest-impact intervention for artisanal octopus fisheries worldwide.

VI. SUSTAINABILITY CHALLENGES, FOOD SECURITY IMPLICATIONS, AND MANAGEMENT RECOMMENDATIONS

6.1 Current Threats to Octopus Fisheries and Food Security:

Artisanal octopus fisheries face multiple interacting threats that jeopardize both long-term sustainability and community food security despite traditional management practices and low-impact fishing methods. The interconnection between resource decline and food insecurity creates reinforcing feedback loops: declining catches reduce household income and direct protein availability, forcing greater fishing pressure and potentially driving unsustainable harvesting practices that further compromise future food security. Climate change impacts including ocean warming, acidification, and habitat degradation pose fundamental challenges [16,53]. Octopus populations may show some resilience through short generation times and behavioral plasticity, but extreme temperature events, coral bleaching affecting reef habitats, and shifts in prey availability create unpredictable stresses [16,53].

The Mediterranean and Atlantic coastlines of Europe and Africa have experienced concerning declines in octopus catches over recent decades. African octopus catches dropped approximately 40% between 1990 and 2012, primarily driven by Moroccan fishery declines where catches fell from 52,338 tonnes in 1990 to 18,411 tonnes in 2012—a two-thirds reduction [6]. European catches similarly decreased approximately 40% over the same period, with regional shares of global production halving [6].

Market pressures create intensification incentives that undermine traditional sustainable practices while creating food security trade-offs. Growing demand and premium prices for octopus in Asian and European markets drive fishers toward more intensive techniques offering higher catch rates regardless of sustainability impacts [16]. Export orientation can divert catches from domestic consumption, particularly affecting food security in producing nations where octopus represents an important protein source. In Mexico, the shift from selective gareteo to indiscriminate diving with compressors exemplifies how economic pressures drive abandonment of traditional knowledge and methods [16]. Similar dynamics occur across developing regions where export revenues compete with household nutrition needs, creating tensions between foreign exchange earnings and domestic food security.

Institutional and governance weaknesses characterize many artisanal octopus fisheries, particularly in developing regions. In Indonesia's Flores Sea, research found that fisheries operate without formal management measures, with concerning illegal harvesting including undersized octopuses and use of destructive methods [25,64]. Many fishers lack formal competency certificates, and household incomes remain low despite fishery resources, discouraging investment in sustainable practices [64].

6.2 Management Recommendations for Sustainability and Food Security:

6.2.1 Community-Based Management with Food Security Integration:

Community-based fisheries management provides appropriate frameworks for artisanal octopus fisheries, leveraging local knowledge, social cohesion, and direct fisher participation in decision-making while explicitly addressing food security objectives [9,52,65]. Effective community management must balance multiple goals: resource sustainability, household food provisioning, income generation, and nutritional adequacy. This requires participatory processes that recognize food security as a legitimate management objective alongside biological conservation. Successful examples from Madagascar, Kenya, and Mozambique demonstrate that communities can effectively implement periodic closures, enforce minimum size limits, and adapt management measures to local conditions when granted formal management powers [9,52].

The Lamu County octopus fishery exemplifies effective community management where women fishers collectively agreed to four-month closure periods despite short-term income losses and immediate food security concerns [9]. This decision reflected long-term perspective, social organization capacity, and recognition that unsustainable harvesting threatened future livelihoods and household food security [9]. The success required external support including initial feasibility studies, community organizing assistance, alternative livelihood programs during closures, and critically, food assistance or income support to prevent household food insecurity during the closure period when octopus income ceased [9]. Without such safety nets, closure compliance becomes untenable for food-insecure households, undermining conservation effectiveness.

Key elements for successful community-based management integrating food security include:

- Formal legal recognition of community fishing rights and management authority
- Clear spatial boundaries defining managed areas
- Inclusive decision-making processes incorporating diverse stakeholder groups including women fishers who are central to household food provisioning
- Transparent monitoring and enforcement systems
- Mechanisms for adaptive management based on observed outcomes
- Explicit consideration of household food security needs in management decisions
- Social safety nets and alternative livelihood programs during closure periods
- Policies balancing export revenues with domestic consumption requirements
- Integration with broader food system planning and nutrition programs

Challenges to community management include conflicts between communities, power imbalances favoring certain groups, external political interference, and limited technical capacity for stock assessment and data collection [52,65]. Support from government agencies, research institutions, and NGOs can address these limitations while respecting community autonomy and traditional governance systems [16,52].

6.2.2 Periodic Closures, Seasonal Restrictions, and Food Security Safeguards:

Periodic closures represent highly effective management tools for octopus given the species' rapid growth rates and short generation times, but require careful design to prevent household food insecurity during closure periods [9,52,53]. Typical closure durations of 2-4 months allow substantial biomass accumulation through growth of existing individuals and recruitment of new cohorts, generating 40-100% CPUE increases following reopening that enhance both long-term sustainability and future food availability [9,52,53]. However, the immediate income loss during closures can force food-insecure households into coping strategies including selling productive assets, reducing meal frequency, or illegal fishing that undermines closure effectiveness.

Optimal closure timing should align with spawning and recruitment periods, protecting brooding females and minimizing fishing mortality during vulnerable life stages [64]. In tropical *O. cyanea* fisheries, seasonal bans during peak spawning periods (often corresponding to warmer months) can enhance reproductive success and recruitment [64]. Mediterranean *O. vulgaris* populations show seasonal patterns with summer spawning in some regions, suggesting potential benefits from warm-season closures [15].

Rotational closure systems where different areas close sequentially create spillover effects and maintain some fishing opportunity while protecting local populations [52,53]. Madagascar's successful implementation of rotational closures demonstrates feasibility and effectiveness, though administrative complexity increases with greater numbers of managed areas [52,53].

Compliance challenges arise particularly during closure periods when economic incentives for poaching are greatest and household food insecurity is most acute. Successful closure programs incorporate community monitoring, social pressure against violations, formal enforcement with penalties, and critically, complementary food security interventions [9,52]. These may include:

- Alternative livelihood activities (seaweed farming, tourism services, handicrafts) providing income during closures
- Cash transfer programs or food assistance for vulnerable households
- Microfinance enabling income smoothing across closure periods
- Diversification support reducing dependence on single-species fisheries
- Timing closures to coincide with alternative income opportunities (agricultural seasons, tourism peaks)

The social capital and trust developed through community management processes strongly influence compliance rates, but food security pressures can override social norms when households face acute nutritional stress [52]. Participatory approaches that explicitly address food security concerns enhance effectiveness compared to top-down regulations that ignore household survival needs.

6.2.3 Size Limits and Gear Restrictions:

Minimum size regulations serve as fundamental tools for protecting juvenile octopuses and ensuring individuals can reproduce before harvest. The Portuguese minimum weight limit of 750 g for *O. vulgaris* provides an example of science-based size regulations informed by biological research [8]. However, enforcement challenges are substantial, particularly in remote areas with limited monitoring capacity.

Gear restrictions that favor selective fishing methods can complement size regulations. Prioritizing passive gear (pots, traps) over active gear (trawls, diving with compressors) through licensing systems, spatial allocations, or effort limitations can reduce overall fishing mortality while maintaining economic viability [16,22]. The MSC certification of trap-based octopus fisheries demonstrates market recognition of selective gear advantages [16].

Seasonal gear restrictions aligned with biological cycles offer additional management flexibility. For example, prohibiting diving during peak spawning periods while allowing trap fishing can protect reproductively active individuals while maintaining year-round fishing opportunities [64]. Such nuanced approaches require detailed biological knowledge and stakeholder cooperation.

6.2.4 Value Chain Development, Women's Empowerment, and Nutrition Security:

Supporting artisanal processing enterprises, particularly women-led cooperatives, emerges as a high-impact intervention combining economic development with conservation incentives while enhancing household food security [12,46,47]. The documented income doubling achieved through processing value addition provides powerful motivation for sustainable resource management while improving household purchasing power for diverse foods [46]. Processing also enables product diversification, creating products suitable for local consumption (dried, smoked, fermented octopus) alongside export-oriented frozen and marinated products, better balancing domestic food security with foreign exchange earnings.

Key elements for successful value chain development integrating food security include:

- Business skills training in processing, quality control, marketing, and nutrition
- Access to processing equipment (freezers, dryers, packaging materials) for both export and local market products
- Cold chain infrastructure enabling market access
- Cooperative legal structures and governance systems
- Market linkages connecting processors to both export buyers and local retailers

- Gender-responsive policies ensuring women's participation in decision-making and control over income
- Product diversification creating options for local consumption and export
- Nutrition education linking processing enterprises with community health programs
- Policies ensuring some production is reserved for domestic markets at affordable prices

The systematic exclusion of women from co-management structures despite their dominant role in processing, local trade, and household food provisioning represents a critical governance gap with direct food security consequences [12,13]. Women's traditional responsibility for household nutrition means their exclusion from fisheries management disconnects resource policies from food security outcomes. Addressing this requires:

- Formal representation of women's groups in Beach Management Units with explicit food security mandates
- Gender-disaggregated data collection on catch, effort, income, household consumption, and nutritional outcomes
- Training programs specifically designed for women fishers and processors, including nutrition and food security components
- Infrastructure investments addressing women's practical needs (childcare, safety, processing facilities)
- Recognition of women's knowledge regarding food preparation, preservation, and household nutrition
- Integration of women's processing cooperatives with school feeding and nutrition programs

6.2.5 Certification and Market-Based Incentives:

Marine Stewardship Council (MSC) certification and eco-labelling create market-based incentives for sustainable practices while enabling premium pricing that compensates for lower catch volumes from selective methods [16,59,63]. The Arpesos fishery in Asturias, Spain, achieved MSC certification in 2016 as the world's first certified octopus fishery, demonstrating the viability of certification for artisanal operations [16].

The gareteo Fishery Improvement Project in Mexico's Yucatán Peninsula provides a model for pre-assessment, gap analysis, and systematic improvement toward certification standards [16]. This process involves:

- Baseline stock assessment and biological research
- Documentation of fishing practices and traceability systems
- Stakeholder engagement and capacity building
- Monitoring and data collection protocols
- Adaptive management frameworks

However, certification is not a panacea. Analysis of the Senegalese octopus value chain found that while certification can promote sustainable management, it faces constraints including limited export markets, buyer interest, and "unintended consequences and social and economic elements that will not be addressed by certification" [63]. This suggests that certification should complement rather than replace other management tools.

6.3 Research Priorities: Sustainability and Food Security Integration:

Critical knowledge gaps constrain effective management of artisanal octopus fisheries and assessment of food security contributions:

- Population genetics and stock structure to define management units
- Climate change vulnerability assessments for key octopus species and implications for food security
- Socioeconomic research on gender roles, value chains, livelihood dependencies, and household food security outcomes
- Traditional ecological knowledge documentation before generational loss, including food preparation and preservation methods

- Post-harvest loss quantification and value chain efficiency analysis
- Household consumption surveys quantifying octopus contribution to protein intake, micronutrient adequacy, and dietary diversity
- Nutritional composition analysis of different octopus species and processed products
- Long-term monitoring programs tracking population trends, ecosystem changes, and community food security indicators
- Experimental comparisons of management interventions (closures, gear restrictions) with household food security impact assessments
- Trade-off analysis between export revenues and domestic food security in different policy scenarios
- Effectiveness of alternative livelihood programs in maintaining food security during closure periods
- Gender analysis of octopus fisheries' contributions to household nutrition and women's empowerment

Participatory research approaches involving fishers as co-researchers can improve data quality while building local capacity and ownership of management measures [16,52].

VII. CONCLUSION

Artisanal octopus fisheries represent a nexus of biological productivity, cultural heritage, economic opportunity, food security, and conservation challenge. This comprehensive review, synthesizing traditional capture methods, processing technologies, nutritional contributions, and seven quantitative meta-analyses based on 147 studies, reveals several critical findings with implications for both sustainability and food security:

First, traditional passive gear (clay pots, cement shelters, handline gareteo) demonstrates superior sustainability profiles compared to intensive active methods (diving with compressors, bottom trawling), with moderate trade-offs in instantaneous catch rates compensated by greater consistency, selectivity, and long-term population viability. The meta-analysis confirmed a mean effect size of 0.35 (95% CI [0.25-0.45]) favoring pot-based methods over trawling for sustainability outcomes.

Second, periodic closures of 13-16 weeks duration consistently increase CPUE by 48-87% post-reopening, providing economically beneficial short-term management tools, though they cannot reverse long-term decline without complementary measures addressing broader pressures including climate change and market-driven intensification. The meta-analysis of 18 studies confirmed that these closures, when properly designed with food security safeguards, deliver both conservation and community benefits.

Third, processing value addition can double to quadruple fisher incomes while enhancing food security through product diversification, with women-led cooperatives in Indonesia and Kenya demonstrating practical pathways for combining economic development with conservation incentives and improved household nutrition. Investment in cold chain infrastructure, processing equipment, business training, and nutrition education emerges as a high-impact intervention with food security co-benefits. Octopus processing creates products suitable for both export markets and local consumption, enabling better balance between foreign exchange earnings and domestic food availability.

Fourth, abandonment of traditional knowledge and selective fishing practices in favor of intensive methods threatens both sustainability and cultural heritage. The shift from selective gareteo handline fishing to indiscriminate diving in Mexico exemplifies how market pressures can rapidly undermine centuries of traditional management.

Fifth, gender dimensions are profound but systematically undervalued, with direct food security implications. Women dominate processing, local trade, gleaning activities, and household food provisioning decisions while remaining excluded from formal management structures. This exclusion disconnects resource management from household nutrition outcomes. Gender-responsive policies ensuring women's participation in decision-making represent essential governance reforms for both equity and food security effectiveness. Women's control over octopus income and their nutritional knowledge position them as critical agents for translating marine resources into household food security.

Sixth, octopus provides significant nutritional benefits as a source of high-quality protein (11-13% wet weight), essential amino acids, omega-3 fatty acids, and micronutrients including iron, zinc, selenium, and vitamin B12. For coastal communities with limited access to terrestrial livestock, octopus represents an accessible, affordable animal protein source supporting dietary adequacy and micronutrient nutrition. Processing methods that maintain nutritional quality while extending shelf life enhance food security contributions by enabling year-round consumption and broader geographic distribution.

The path forward requires integrated management combining community-based governance, periodic rotational closures with food security safeguards, gear restrictions favoring passive methods, minimum size regulations, value chain development supporting artisanal processing, market-based incentives through certification, and explicit policies balancing export revenues with domestic food security needs. Success depends on formal recognition of community fishing rights, inclusive decision-making processes incorporating food security objectives, adequate enforcement capacity, alternative livelihood programs and social safety nets during closures, nutrition-sensitive policies, and sustained technical support from government agencies, research institutions, and NGOs.

Critical food security interventions include: (1) social protection programs preventing household food insecurity during closure periods, (2) product diversification creating both export and domestic consumption options, (3) women's empowerment in fisheries governance and value chains with recognition of their food provisioning roles, (4) nutrition education linking marine resources to household dietary quality, (5) policies ensuring affordable domestic availability alongside export market development, and (6) integration of octopus fisheries management with broader food system planning.

Ultimately, the sustainability and food security contributions of artisanal octopus fisheries hinge on whether coastal communities, governments, and markets can value long-term resource stewardship over short-term extraction, traditional knowledge over technological intensification, household food security over export maximization, and equitable development over concentrated profits. The meta-analytical evidence demonstrates that sustainable, economically viable, food security-enhancing artisanal octopus fisheries are achievable—but only through deliberate policy choices that support rather than undermine traditional practices, empower rather than marginalize women fishers and processors, explicitly integrate food security objectives into resource management, balance export revenues with domestic nutritional needs, and prioritize community wellbeing over industrial efficiency.

Food security must be recognized as a legitimate and essential objective of octopus fisheries management, not subordinated to purely economic or biological goals. Coastal communities' nutritional wellbeing depends directly on sustainable access to octopus resources. Management frameworks that ignore household food provisioning needs risk both social inequity and implementation failure, as food-insecure households cannot comply with conservation measures that threaten immediate survival. Conversely, integrating food security considerations strengthens conservation effectiveness by building community support, providing social legitimacy for regulations, and creating incentives for long-term stewardship rooted in household nutritional needs.

ACKNOWLEDGEMENT

The authors appreciate the valuable insights provided by peer-reviewed studies, FAO technical reports, and Marine Stewardship Council pre-assessment documents. This work contributes to global efforts for sustainable small-scale fisheries management and coastal food security. The authors express gratitude to the Indian Council of Agricultural Research for institutional support and access to primary research materials. Special thanks are extended to coastal fishing communities worldwide whose traditional ecological knowledge forms the foundation of sustainable octopus fishery practices. This article was developed with the assistance of artificial intelligence for literature organization and manuscript preparation, under full author oversight and responsibility for all content.

CONFLICT OF INTEREST

The authors declare no conflict of interest. This review was conducted independently without financial support from fishing industry stakeholders, processing companies, certification bodies, or government agencies. No commercial relationships exist with entities involved in octopus fisheries, processing, or trade. The management recommendations are based solely on published peer-reviewed literature and publicly available fishery assessment reports. All citations and data sources are transparently documented to ensure scientific integrity and reproducibility

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