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RESEARCH

Sustainable fish production in Egypt: towards strategic management for capture-based aquaculture

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Abstract
This study assessed the sustainability of capture-based aquaculture (CBA) practices in Egypt, identified challenges, and proposed solutions to enhance sustainability. It relied on published data and studies, revealing that these practices are globally widespread for cultivating a diverse range of marine and freshwater species based on wild seed collection. The assessment showed that these practices in Egypt cultivate a variety of fish species. In 2021, they contributed to approximately 34% of the total aquaculture production, amounting to an estimated value of USD 1.476 billion, representing about 57% of the total value of the aquaculture sector. Additionally, these practices provided around 106,022 full-time jobs. Official fishery statistics have not indicated any negative impact of CBA on fish stocks over the past 30 years. Measures aimed at enhancing the sustainability of these practices included granting licenses for the collection of wild seeds for specific species under specific regulations. Facilitating licensing procedures for hatcheries, providing incentives, and promoting farmers' preferences for hatchery seed were also part of these measures. Furthermore, these actions include facilitating access to financing under favorable conditions, selective breeding, training hatchery workers in best management practices, implementing biosecurity measures, and establishing an accurate statistical system. The implementation of the proposed plan to transition from capture-based aquaculture to hatchery-based aquaculture will contribute to achieving sustainability for both aquaculture and fisheries.

Keywords Aquaculture · Fisheries · Wild seed · Impact of CBA · Challenges · Sustainability

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Introduction

Aquaculture is widely recognized as the fastest-growing sector in the food industry. Out of the total global fish production of 178 million tonnes in 2020, 87.5 million tonnes, representing 49%, was produced through aquaculture (FAO 2022). In contrast, the supply of wild capture has remained relatively static since the 1980s. Therefore, aquaculture plays an increasingly crucial role in meeting the growing global demand for fish consumption (FAO 2022).

However, not all commercially important aquatic animals can spawn and be raised under farming conditions, due to various factors such as feasibility and cost-effectiveness. For certain fish and shellfish species, a system involving the collection of wild seed (juvenile) at different life stages and rearing them in controlled facilities has been employed (Chandararathna et al. 2021). Capture-based aquaculture (CBA) is a significant segment of the aquaculture industry. It can be defined as a practice where wild aquatic organisms are collected for aquaculture. This method allows for bypassing the challenging hatchery stage, distinguishing it from closed aquaculture (Vergara-Solana et al. 2019; Pettersen et al. 2023). Although CBA has been practiced for many decades, it was only in 2004 that this term was introduced. The introduction aimed to provide a clear definition of this practice and distinguish it from both hatchery-based aquaculture (HBA) and capture fisheries (Ottolenghi et al. 2004).

CBA was widely practiced in various countries and species. Where Norwegian and foreign sailing vessels were involved in keeping cod fish alive on board (Hermansen 2018). In Cameroon, the Nkam River basin serves as a source for collecting seeds of Clarias species (Pouomogne 2008). In the Mekong basin, two groups of taxa, namely Pangasiid catfishes and snakeheads, are prevalent (Poulsen et al. 2008). In Bangladesh, major carp seeds are collected from rivers to supply the carp's aquaculture industry (Rahman 2008). Additionally, the cultured yellowtail culture in Japan has experienced significant growth due to the ample supply and low cost of wild-caught seed, including bycatch (Nakada 2008). Grouper culture in many Southeast Asian countries involves capturing wild grouper seeds for use as seed stock and raising them until they reach marketable size (Tupper and Sheriff 2008). Notably, one of the most controversial species cultured through this method is the bluefin tuna, with a global average annual growth rate of 9% and an annual production volume of about 35 thousand metric tonnes (FAO 2023).

CBA is expected to be a profitable economic activity in both the short and long term for many species. This practice is adopted for various reasons, such as livelihood, controlling access to fishery resources, meeting market demand, and enhancing yield when done correctly. However, it is crucial to note that this practice does not necessarily lead to sustainable hatchery-based aquaculture (HBA) practices and may not effectively reduce pressure on wild fish populations (Sadovy de Mitcheson and Liu 2008). Efforts should be made to manage and regulate these practices to promote sustainability and prevent potential negative impacts on the environment and the fishing industry, such as overfishing. Due to its direct connection to wild populations, it has the potential to lead to overfishing, introductions of diseases, and increased genetic risks (Ottolenghi et al. 2004; Ateweberhan et al. 2018; Clavelle et al. 2019). Furthermore, these practices have other negative environmental impacts, such as the variability in the quality of wild-caught seed, and there are challenges in ensuring. In addition, there are ethical considerations associated with these practices, as some fish species are not genetically predisposed to thrive in intensive aquaculture. Consequently, their welfare may be at risk compared to their domesticated counterparts (Chandararathna et al. 2021). Utilizing wild fish poses a critical challenge, demanding the dual efforts of sustainable fisheries management and the establishment of regulatory frameworks in aquaculture to foster continuous innovation (Clavelle et al. 2019).

In Egypt, CBA has been in place for almost a century (Saleh 1991). Despite the historical roots and considerable importance of these cultivation practices, they have not undergone a comprehensive evaluation. Therefore, the current study aimed to analyze the trends of these practices and assess their economic, social, and environmental impacts. Additionally, it aimed to identify challenges and propose measures to enhance the sustainability of these practices, promoting sustainable growth in the aquaculture sector without harming fisheries and fishermen's communities.

Methods

This study relied on quantitative data related to seed capture and aquaculture in Egypt, focusing on species whose seeds are collected from the wild and raised in fish farms. The data were obtained from FAO statistics over 30 years. Additionally, fish hatchery production data were sourced from the Lakes and Fish Resources Protection and Development Agency (LFRPDA), formerly known as GAFRD General Authority for Fish Resources Development (GAFRD). Specific data and information were also gathered from published research, studies, and personal communications.

Descriptive economic analysis was applied to the aggregated data to understand and elucidate trends related to the production of CBA in Egypt, additionally clarifying the economic and social impacts, including the quantity and value of production from these practices, their contribution to the overall sector production, and the employment opportunities they provide. Furthermore, a comparison of data between aquaculture and fisheries production data for species whose seeds are collected from the wild and raised in fish farms was conducted to explore the environmental impact.

Results and discussion

Status and trends of fish seed in Egypt

Aquaculture in Egypt has rapidly grown, with production increased from 24,000 tonnes (15.4% of total fish production) in 1982 to 1,576,189 tonnes (78.7% of total fish production) in 2021 (FAO 2023). The growth of the aquaculture sector in Egypt can be attributed to several factors, including increased demand for fish due to population growth amid fisheries production stability. Additionally, the evolution of practices and the availability of essential components for aquaculture, including the human workforce, whose technical capabilities have been enhanced through accumulated experiences and training, have played a significant role. Obtaining credit from fish traders, aquafeed traders, and aquafeed factories has also been crucial. Remarkable advancements in fish feed production, water treatment technology, and aeration have contributed to the progress of this sector. Moreover, the availability of water and land resources, the widespread availability of tilapia mono-sex fry, and the availability of wild seeds for some marine species have also contributed significantly to the growth of the aquaculture sector (Macfadyen et al. 2012; Nasr-Allah et al. 2014a; Hebisha and Fathi 2014; El-Sayed et al. 2015, 2022).

Available estimates indicate that CBA contributed approximately 20% to the total global aquaculture production (FAO 2004). In Egypt, these practices accounted for about 34% of the total aquaculture production in 2021. Over the 30 years from 1992 to 2021, there has been an average fluctuation of around 25%, as illustrated in Fig. 1. According to LFRPDA (2024), aquaculture of mullets, meagre, catfish, eels, and bayad in Egypt relies entirely on seeds collected from the wild. Seabass and seabream spawning, on the other hand, depend on two sources of seed supply: hatcheries and the wild. However, the available statistics only cover the number of seeds produced by hatcheries, with no data on seeds collected from the wild.

Hatchery-based aquaculture

Egypt engages in induced spawning and fry production for some freshwater species, including Nile tilapia, carp, catfish, and basa. Additionally, they undertake the induced spawning of certain marine species, including seabass, seabream, and shrimp, and conduct experimental spawning trials for mullets.

Freshwater fish fry

1) Nile tilapia

In the early 1980s, the Egyptian government's attempt to culture tilapia faced challenges, resulting in limited success. Due to a scarcity of tilapia fingerlings in the market, fish farmers collected smaller tilapia from fishponds, mainly comprising a mix of species, with at least 50% from the inferior *T. zilli* and *S. galilaeus*. Over-wintered tilapia seed often reached sexual maturity at the start of the grow-out season, posing a risk of uncontrolled spawning if mixed-sex tilapia were used. Consequently, tilapia was not intentionally farmed for commercial purposes before the mid-1990s but was incidentally harvested as a byproduct from carp fish ponds. (Saleh 2007; Radwan 2008). The rediscovery of tilapia

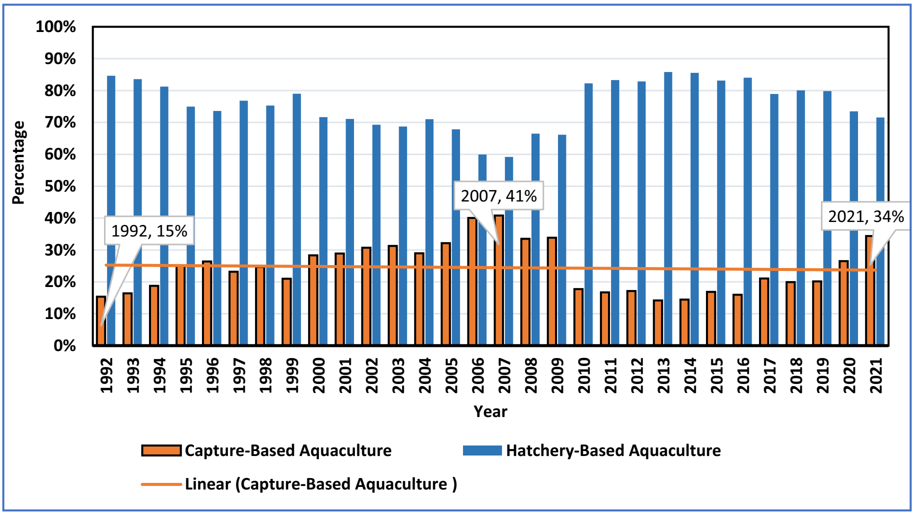


Fig. 1 Capture and hatchery-based aquaculture in Egypt (FAO 2023)

occurred after implementing mono-sex technology, leading to the establishment of the first hatchery for producing mono-sex Nile tilapia in 1991. By the year 2000, the number of tilapia hatcheries in Kafr El Sheikh alone had reached approximately 300 (El-Sayed 2017a; Radwan 2008). In 2021, the government-operated hatcheries numbered 16, while licensed private hatcheries amounted to 108, in addition to over 500 unlicensed private hatcheries (LFRPDA 2024). Private tilapia hatcheries produce sex-reversed tilapia, primarily sold as fry rather than fingerlings, and the average hatchery production is about 10 million annually (Nasr-Allah et al. 2014b).

Egypt's aquaculture industry growth has been accompanied by the development of many tilapia hatcheries, all producing male sex-reversed fry (Nasr-Allah et al. 2014b). There are three main tilapia hatchery systems in Egypt: hapa-based in earthen ponds (hapa), hapa-based in greenhouse tunnels (greenhouse), and concrete tanks in greenhouse tunnels with water heating (heated greenhouse; Nasr-Allah et al. 2014a). Greenhouses are increasingly used in Egypt for tilapia hatcheries to produce fry. This is due to the controlled environment they provide and the higher water temperature, which enables tilapia to spawn at least a month before the natural spawning season (Brummett 2007). While heated water tilapia hatcheries can deliver higher production levels, the additional expenses associated with them imply that they are less profitable than hapa-based or simple greenhouse-based systems. If fry prices continue to decrease and costs continue to rise, it is necessary to enhance the sustainability of heated greenhouse tilapia hatchery systems by making their designs more efficient (Nasr-Allah et al. 2014a).

2) Carps

In the 1980s, Egypt's hatcheries sector, initiated by the General Fisheries Authority, established 14 freshwater hatcheries dedicated to producing carp fry, including various carp species such as *Aristichthys nobilis*, grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), and black carp (*Mylopharyngodon piceus*) (Saleh 2007; Brummett 2007). This fry played a crucial role in the stocking of rice fields and irrigation channels nationwide to control bilharzia snails, macrophytic weeds, and excessive algae blooms (Brummett 2007). The introduced carp species cannot spawn naturally in the local environment; therefore, spawning is induced in ripe broodfish through the injection of locally prepared common carp pituitary extract. The collected eggs and sperm are then used for fertilization (Brummett 2007). As of 2021, Egypt had 14 government hatcheries producing approximately 34 million carp fry, contributing to the production of 162 thousand tonnes in aquaculture and fisheries (LFRPDA 2024). These hatcheries produced about 213 million fry in 2011. Simultaneously, these seeds contributed to the production of 217 thousand tonnes in both aquaculture and fisheries (GAFRD 2013). This indicates a notable decline in fry production of this species within just 10 years, to less than a tenth, while overall production has remained relatively stable. Such trends may suggest inaccuracies in statistics and potentially signify a lack of expansion by farmers in culture carps, possibly due to its lower prices compared to tilapia, as highlighted in the study by Macfadyen et al. (2012).

3) Catfish

The challenges faced by the African catfish aquaculture in Egypt, such as the limited availability of fingerlings and reliance on hormonal injections, prompted the WorldFish

Centre to explore non-hormonal spawning technologies in 2000. A methodology was identified in 2002, with further improvements in 2003–2004. Training activities have been conducted in Egypt for technicians and farmers from other countries (El-Naggar 2008). The technology developed by the WorldFish organization has alleviated the shortage of African catfish fingerlings for Egyptian farmers, enabling them to produce and sell these fingerlings (El-Naggar 2008). However, the scale of catfish aquaculture in the country remains modest (Nasr-Allah et al. 2014b).

4) Basa

Basa (*Pangasianodon hypophthalmus*) seeds are currently produced in several Egyptian hatcheries through induced spawning. The estimated 2022 production of basa fry and fingerlings did not exceed 1 million (Deyaaeddien Abdulrahman, personal communication). Commercial-induced spawning of this species began in Egypt in 2018 (Hisham Mohamed personal communication). However, farmers are hesitant to expand production due to marketing challenges and the species' sensitivity to low winter temperatures. Hatcheries face difficulties producing large quantities at the season's start, and there are no specialized feeds available, leading farmers to use feeds designed for tilapia.

Marine fish fry

To secure marine species seeds and alleviate pressure on fisheries resources, Egypt is in the process of establishing more hatcheries. However, these initiatives are currently in their early stages and necessitate further development through the incorporation of modern technology. Hatcheries have been identified as a crucial factor in limiting the growth of marine aquaculture in Egypt, a need that has become more pressing than ever (Sadek 2000; Saleh 2007).

1) Seabream and seabass

To secure marine fish fry and reduce pressure on natural resources, Egypt is establishing more new hatcheries, but these efforts are in their early stages. Currently, nature remains the primary source of marine fish fry and fingerlings. In 2011, Egypt had four private and government marine hatcheries that collectively produced 1.6 million seabass and 2.3 million seabream fries. By 2021, the number of hatcheries increased to five, and seed production increased to 4.4 million seabass and 6.4 million seabream fries. During this period, the farmed production of seabass and seabream increased from approximately 32 to 76 thousand tonnes (GAFRD 2013; LFRPDA 2024).

2) Mullets

In the early 1980s, the American International Development Foundation financed the first mullets hatchery production, which utilized induced spawning techniques, near Alexandria, Egypt. However, due to limited production capacity and high costs, the project was discontinued (Saleh 1991). In contrast, Mousa's experiments at the National Institute of Oceanography and Fisheries successfully induced spawning of Thin-lipped mullet (*Liza amada;* Mousa 2010).

Capture-based aquaculture

CBA practices have a long history in Egypt, as evidenced by a prominent 4000-year-old engraving from "Theban tomb." The engraving depicts a nobleman fishing in a drainable artificial pond, with tilapia being transferred from the Nile to both noble and common ponds (Chimits 1957). The traditional form of aquaculture, known as "Hosha," was a cornerstone of the Northern Delta lake region's aquaculture industry until a few decades ago (Saleh 2007; Radwan 2008). This practice involved constructing ponds on lake shores, allowing uncontrolled water flow from the lake, and using any agricultural products and by-products as fish feeds. Harvesting occurred after 2–3 months, and production did not exceed 100–200 kg/hectare (Radwan 2008). This system is currently prohibited due to its detrimental impact on the environment (El-Sayed 2007), and its inefficient utilization of water and land resources.

Despite the advancements in aquaculture systems in Egypt and their reliance on semi-intensive earthen ponds, some species are still cultivated by collecting seed from the wild, including mullets, European seabass (*Dicentrarchus labrax*), gilthead seabream (*Sparus aurata*), meagre (*Argyrosomus regius*), African catfish (*Clarias gariepinus*), European eel (*Anguilla anguilla*), marbled spinefoot (*Siganus rivulatus*), and bayad (*Bagrus bayad*). The contribution of mullets, seabream, seabass, and meagre collectively accounts for about 98% of the total capture-based aquaculture sector in 2021, as illustrated in Fig. 2.

Wild Seed Supply Estimation for Key CBA Species

There are no official estimates for the total number of wild-caught mullet seeds, only 50 million seeds are legally collected and recorded through the collection stations (LFRPDA 2024). According to our estimates, considering mortality rates at each stage of handling, acclimatization, incubation, and grow-out, the number of seeds collected from the wild is estimated to be 2.31 billion. This means that illegally collected mullet seeds

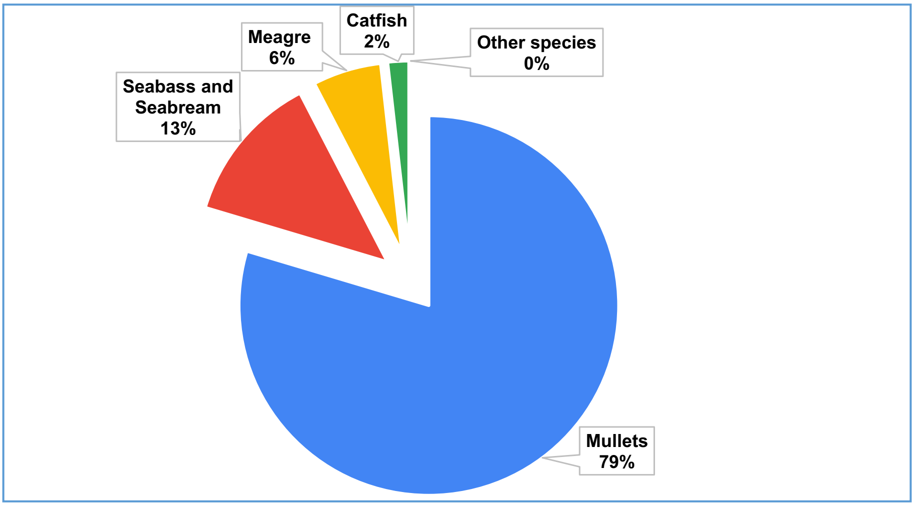


Fig. 2 Contribution of each species to the total Egyptian CBA industry in 2021 (FAO 2023)

represent 97.8% of the total catch. Our estimate slightly exceeds that of Goulding and Kamel (2013), which was 94.8%, indicating an increase in the prevalence of illegal catch operations.

The estimated supply of seabass seeds amounts to 83 million, comprising 3 million from hatcheries and 80 million from the wild. Consequently, wild resources contribute to 96% of the seabass seeds supply. Similarly, the total supply of seabream seeds is estimated at 263 million, with 6 million from hatcheries and 257 million from the wild, indicating that wild resources contribute to 98% of the seabream seeds supply. Notably, these estimates surpass those reported by Sadek (2000), who noted that 80% of seabass and seabream supplies originated from the wild. This indicates a significant increase in wild seabass and seabream seed collection over the past two decades. In contrast, the supply of meagre seeds is entirely reliant on the wild, totalling 35 million seeds, as Table 1 illustrates.

It is worth mentioning that these estimates did not account for the potential wastage of seed during the collection process for these species, which were considered unknown estimates, potentially leading to conservative estimates. Abdel-Hady et al. (2024) have raised doubts about the quantity of Egyptian aquaculture production of seabass, seabream, and meagre, arguing that the feeds required to sustain this level of the recorded production would necessitate a volume of trash fish equivalent to nearly twice the production of all the Egyptian fisheries production. This suggests that our estimates may be exaggerated. Considering these conflicting observations, our estimates may be deemed realistic and provide a foundational basis for planning the management of this important resource.

CBA practices

1) Mullets

Mullet's farming in Egypt primarily relies on the collection of wild seeds. Initially, the government established seed collection stations to supply fingerlings to licensed fish farms. However, this activity has evolved into a private enterprise with minimal government involvement (Dickson 2022). The main sources of mullets and other marine species seeds in Egypt include the Suez Canal, Northern Delta lakes, Nile tributaries, and drainage canals leading to the Mediterranean Sea (Sadek and Mires 2000). The seeds season for grey mullets runs from August to November, while other mullet species, such as thin-lipped grey mullets and golden grey mullets, have a season extending from December to March. In the 1960s and 1970s, grey mullet was the predominant species in fish farming (Radwan 2008).

The three most farmed mullet species in Egypt, namely grey mullet (*Mugil cephalus*), thin-lipped grey mullet (*Liza ramada*), and dotted grey mullet (*Valamugil seheli*), are favored due to their rapid growth and high market demand (Saleh 2008). Additionally, salt-fermented mullet is a traditional celebratory food widely enjoyed during Easter festivals in Egypt, reflecting cultural customs (Khalil et al. 2014).

Mullet fry, ranging from 12 to 20 mm in length, are caught as they reach the coast or enter coastal lakes, agricultural drainage outlets, or irrigation channels (Saleh 2008). Fishers utilize sturdy seine nets with a 1-mm mesh size to catch fry in coastal waters. These nets are prepared using cork, lead lines, wooden bars, and pulling ropes. Additionally,

Table 1 Estimation of seed supply for key Egyptian species used in capture-based aquaculture in 2021

Species	Metric	Magnitude	Source
Mullets	Production (kg)	378,885,000	FAO 2023
	Survival (%)	54	Saleh 1991; Kleijn and Dijkema 1988; Abdel-Gawad and Salama 2007
	Avg. marketing weight (kg)	0.304	Macfadyen et al. 2012
	Total seeds no.	2,308,022,661	Calculated[a]
	Hatchery seed no.	0	LFRPDA 2024
	Wild seed no.	2,308,022,661	Calculated[b]
	Wild seed (%)	100	Calculated[c]
Seabass	Production (kg)	33,245,000	FAO 2023
	Survival (%)	50	Haggag 2017
	Avg. marketing weight (kg)	0.8	Haggag 2017
	Total seeds no.	83,112,500	Calculated[a]
	Hatchery seed no.	3,353,000	LFRPDA 2024
	Wild seed no.	79,759,500	Calculated[b]
	Wild seed (%)	96	Calculated[c]
Seabream	Production (kg)	42,743,000	FAO 2023
	Survival (%)	50	Haggag 2017
	Avg. marketing weight (kg)	0.325	Haggag 2017
	Total seeds no.	263,033,846	Calculated[a]
	Hatchery seed no.	6,409,000	LFRPDA 2024
	Wild seed no.	256,624,846	Calculated[b]
	Wild seed (%)	98	Calculated[c]
Meagre	Production (kg)	27,688,000	FAO 2023
	Survival (%)	80	Eid et al. 2020b
	Avg. marketing weight (kg)	1	Haggag 2017
	Total seeds no.	34,610,000	Calculated[a]
	Hatchery seed no.	0	LFRPDA 2024
	Wild seed no.	34,610,000	Calculated[b]
	Wild seed (%)	100	Calculated[c]

[a]Total seeds no. = Production (kg) * 100 / Survival / Avg. marketing weight (kg)

[b]Wild seed no. = Total seeds no. − hatchery seed no.

[c]Wild seed (%) (%) = wild seed no. / Total seeds no.

scoop nets are utilized near pumping station outlets to gather fries from agricultural drainage canals (Sadek and Mires 2000). After catching the fry, they are kept in hapas or tanks for several hours. Then, they are sorted to remove unwanted or damaged fry, counted, and emptied into polyethylene bags for transportation by trucks to nursery units in grow-out farms to produce fingerlings (Saleh 2008).

These species are raised in polyculture systems, with an initial fingerling weight ranging from 10 to 15 g (Saleh 2008). The average stocking density ranges from 1850 to 4000 fish per hectare for grey mullet and thinlip mullet, respectively. At harvest, the average weight of grey mullet and thinlip mullet is 409 g and 216 g, respectively, after a growth period of approximately 8.7 months (Macfadyen et al. 2012).

Egypt's success in cultivating mullet is evident, as it emerged as the world's largest producer, achieving a production volume of around 351 thousand tonnes, representing 97% of the global production in 2021 (FAO 2023).

2) Seabream and seabass

In the Mediterranean, the production of seabream and seabass predominantly relies on hatchery-produced fingerlings. The use of wild-caught fingerlings is rare and is only practiced in a few locations, such as Egypt (Saleh 2008; Rothuis et al. 2013; Muniesa et al. 2020). However, Egyptian marine fish farmers have shown a preference for wild-caught over hatchery-produced European seabass fry (Salem et al. 2018). The reason for this may be attributed to the decrease in price, as farmers rely on feeding them with trash fish. Therefore, they do not face a specific problem with the adaptation of the juveniles to artificial feeds, in addition to its decreased deformities rate.

Fishers utilize specialized equipment such as mosquito nets, scoop nets, bagged dragnets, and beach seines to capture wild seeds. Once the seeds are captured, they are sorted and transferred to acclimation ponds filled with brackish water before being prepared for sale. The transportation of the seeds is accomplished using tanks or polyethylene bags that are inflated with oxygen (Sadek and Mires 2000). These seeds, ranging between 0.25 and 10 g, are collected (Sadek 2000).

Marine fish farming in Egypt began in 1976 with the cultivation of seabream due to its adaptability to brackish and marine water conditions (Eisawy and Wassef 1984; Sadek 2000). The species has a fast growth rate, tolerates various salinities, and has high demand in both domestic and export markets. Seabass can also be farmed in tanks using brackish groundwater or in cages located in brackish lakes (Rothuis et al. 2013). Seabream production in Egypt primarily relies on extensive and semi-intensive farming systems. In the extensive system, low stocking density is used, allowing fish to rely on natural food sources. In the semi-intensive system, farmers supplement tilapia feed and small shrimp from Northern Delta lakes to the fish's diet (Sadek 2000). Seabream and seabass are commonly raised in brackish-water ponds under polyculture conditions with mullets, mainly in Damietta. Fish are stocked at densities (2,500–20,000 fish\ha) in a ratio of 6:3:1 (seabass:seabream:mullets), and the production ranges between 7 and 8 t\ha in a significant production season extending to approximately 30–36 months (El-Sayed 2007; Haggag 2017). In Wadi Mariout in Alexandria, the seabass, seabream, and mullets fingerlings stocking density in earthen ponds is either 7,857, 2,619, or 1,190 fish\ha, with an initial weight of 40 g (Haggag 2017). Most farms depend on feeding seabass and seabream with trash fish, with a feed conversion ratio ranging between 10 and 12 kg:1. Meanwhile, farms using artificial feed achieve a ratio of 2.5–3 kg:1 (Haggag 2017). The most economically feasible methods for farming seabass and seabream are in ponds with trash fish feeding (Haggag 2017).

Egypt is the world's third-largest producer of farmed seabass, with a production of approximately 33,000 tonnes in 2021, representing 11% of the global farmed seabass production. Egypt also ranked third globally in seabream production, with a yield of approximately 43,000 tonnes, representing about 13% of the global farmed seabream production (FAO 2023).

3) Meagre

Meagre is cultured in brackish-water ponds using wild seed, and it has been identified as a promising candidate for Egyptian aquaculture since the private sector's initial adaptation efforts in 1996 (El-Sayed 2017b). A floating gill net is used mainly for collecting meagre seeds from coastal waters (El-Shabrawy 2009). After the seeds are caught, it is treated in the same way as is done for the acclimation and transportation of seabass, seabream, and mullet seed. Then, farmers purchase meagre from seed sellers in weights ranging from 5 to 15 g. Additionally, farmers reported that they rely solely on wild seed as a single source. They rear them in dedicated ponds before restocking them in grow-out or stocking ponds.

Meagre is highly sought after due to its fast growth rate, protracted spawning season, ability to tolerate different levels of salinity, and high demand in both domestic and export markets (Abou Shabana et al. 2012; Rothuis et al. 2013). Pastor et al. (2002) reported that meagre grows rapidly in cages and indoor tanks, while recent studies by Eid et al. (2020a) have identified meagre as a promising candidate for brackish-water pond aquaculture. At present, meagre farming operations in Egypt depend solely on trash fish and small shrimp as their primary feeds, The feed conversion ratio is 6–10:1, leading to a harvest of approximately 6.4–12 t/ha, with 1.25 kg as an average weight/fish in 12–14 months (Abdelhamid et al. 2013; Haggag 2017; Eid et al. 2020a, b). However, Eid et al. (2020b) indicated that in Egypt, meagre feeding with trash fish showed the best growth performance and economic evaluation compared to the use of artificial feed under current conditions. In 2021, Egypt's production of cultured meagre reached around 28,000 tonnes, representing 64% of global production (FAO 2023). This production makes Egypt the world's largest producer of meagre from aquaculture.

4) Other species

Except for African catfish, all fish seed used in freshwater aquaculture in Egypt is hatchery-produced. Information on the number of collected catfish seeds or the demand for them is unavailable (Saleh 2007; Nasr-Allah et al. 2014b). And this situation persists. Catfish seeds are collected from the wild (Saleh 2007), specifically from lakes in the Northern Delta using traps baited with dead chickens. They are then sold to fish farms at weights ranging from 250 to 1000 g, as reported by farmers.

Catfish polyculture with tilapia is a common practice in aquaculture to increase fish yield and control tilapia spawning in ponds, often with the use of stocked catfish (El Naggar 2007; Saleh 2007; Ibrahim and Naggar 2010; Macfadyen et al. 2012). El Naggar (2007) found that introducing catfish at 13% of the total tilapia stocked led to a 70% reduction in tilapia recruitment and an increase in total pond production. In Egypt, farmers typically culture catfish in polyculture with tilapia at a stocking density of approximately 800 fish\ha, with an average weight at harvest of around 1.481 g (Macfadyen et al. 2012).

Some Egyptian farmers choose for monoculture of catfish for marketing purposes, especially at the end of the winter season when prices rise due to low fish supply. Similarly, Poulsen et al. (2008) pointed out that CBA is also widely practiced in the Mekong River basin, where juvenile snakehead fish, caught from the wild, are raised in grow-out cages, ponds, and pens. African catfish farming in Egypt typically involves monoculture and relies on unconventional feed sources such as mill and slaughterhouse waste, poultry offal, and even dead chickens. As reported by Saleh (2007), the use of such feed sources may raise consumer concerns and explain the public's reluctance to accept African catfish as a food source. In 2021, Egypt achieved a production of 8,475 tonnes of farmed African catfish, solidifying its position as the world's third-largest producer. This accounts for 3.6% of global production, with Nigeria and Uganda leading the ranks (FAO 2023).

European eels and bayad are also cultivated in a limited manner using wild seed, with a production of approximately 48 and 3 tonnes, respectively, in 2021 (FAO 2023). These species are commonly grown in Egypt to control tilapia spawning and increase their economic value. Eels are found in the Nile River, the north Delta region, and the coastal lagoons of Egypt. Eel farming can be successful in Egypt due to the favorable climate and low production costs compared to other countries.

Socio-economic impact of CBA

The use of wild seed for aquaculture sparks controversy between capture fisheries communities and fish farmers. Fishing cooperatives oppose the practice, considering it an unjust government policy favoring affluent fish farmers over the larger, poorer fishing community (Saleh 2008; Goulding and Kamel 2013). Moreover, illegal seed collectors may encounter harassment, arrests, and fines, with drivers of seed vehicles facing similar challenges. These actions often lead to the mortality of some seeds during detention periods. Wild seed collection in Egypt is a year-round practice, targeting various species and often involving individuals from the same village or district, frequently within the same family. These groups typically consist of 6–10 people (Saleh 2008). The precise number of individuals engaged in the illicit seed fishery, transportation, and marketing is unknown, but those involved are considered elites in lagoon fishing communities due to their education and cultural background, despite being perceived as lower middle class by urban dwellers (Saleh 2008). This controversy primarily arises from the fact that the benefits primarily go to wealthy fish farmers and not to the broader fishing community. Therefore, these practices disproportionately affect the livelihoods of impoverished fishing communities.

The total production of the CBA industry in Egypt, including mullets, meagre, seabass, seabream, catfish, eels, and bayad, was estimated to be approximately 539,756 tonnes in 2021, accounting for roughly 34% of the entire aquaculture sector's total production. The CBA industry is valued at around 1.746 billion USD, representing about 57% of the production value of the fish farming sector, as shown in Table 2. The aquaculture industry in Egypt generates around 19.56 full-time equivalent jobs per 100 tonnes of produced fish across the entire value chain (Nasr-Allah et al. 2020). Based on this estimate, the CBA production in Egypt is expected to provide more than 106,022 full-time jobs (542,036/100*19.56). However, illegal, unreported, and unregulated (IUU) marine seed capture is unsustainable and poses a risk of recruitment collapse, as emphasized by Saleh (2007). With the increasing volume of this activity, the risk of this problem has significantly escalated, necessitating gradual actions, and providing alternatives when addressing this issue. These groups engage in illegal operations due to challenges in obtaining licenses, stemming from government bureaucracy, multiple seed collection sites, and the absence of a proper management plan by authorities. This exposes them to security risks, prompting them to operate at night. Occasionally, some members of the group get arrested, while the rest escape, leaving the seeds to go to waste. This results in a significant loss of seeds or forces them to pay bribes to security groups to avoid further complications.

Environmental impacts of CBA

The main issues surrounding wild fry supply include availability, transportation infrastructure, and the effect on fisheries stock (El-Gayar 2003). Therefore, Egypt's CBA has faced criticisms for its reliance on collecting seeds from the wild. This practice can lead to overfishing and negatively impact natural stocks (El-Sayed 2017b). In addition to its ecological impact, using wild-collected seeds in aquaculture can also lead to the transmission of

Table 2 Production and value of Egyptian capture-based aquaculture (CBA) species in 2021 (FAO 2023)

Species	Production (tonnes)	Value (USD 1000)
Mullets	378,885	894,799
Seabass and seabream	73,803*	427,359*
Meagre	27,688	115,038
Catfish	8,475	8,077
Eels	48	292
Bayad	3	10
Total CBA	542,036	1,759,477
Total aquaculture	1,576,189	3,086,168
CBA as % of total	34%	57%

*According to our estimates in Table 1, 96% of seabass production and 98% of seabream production depend on wild seeds

diseases, presenting a problem for farmers (Megahed and Aly 2009). For example, large-scale mortalities of farmed marine fish at Deeba Triangle during the summer of 2019 were linked to the use of wild-caught fish seeds (Eissa et al. 2021). Furthermore, the polyculture of tilapia with mullets may pose a significant risk for "summer mortality" of tilapia, as wild-sourced mullet fingerlings may carry diseases (Ali et al. 2020). To minimize the spread of infectious diseases among cultured fish, it is recommended to use hatchery-reared fish seeds rather than wild-sourced ones (Eissa et al. 2021). In addition, cultivating marine finfish and shellfish aquaculture solely with wild seed introduces uncertainty and diminishes seed quality reliability. Ensuring timely seed availability through effective production planning becomes challenging (Megahed and Aly 2009).

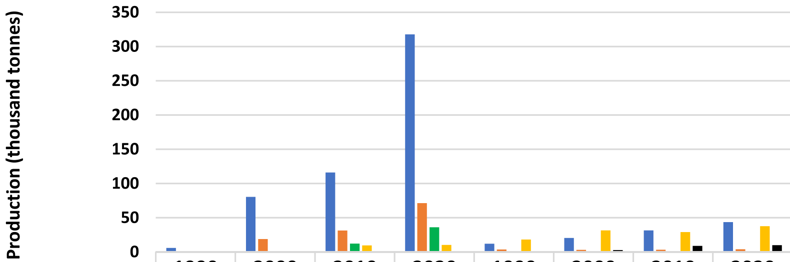
In the mid-1990s, concerns were raised by environmental groups and capture fisheries about the increasing rate of seed collection for aquaculture, which they believed could reduce stock replenishment (Saleh 2008). This practice also results in high mortality of the collected seeds, primarily attributed to poor conditions during harvest, transportation, and storage (El-Gayar 2003; Goulding and Kamel 2013). However, authorities claimed that the impact of collected seed on wild mullet populations would be negligible, citing the high fecundity of mullets and stating that losses of seed for aquaculture are lower compared to those caused by natural predation (Saleh 2008). According to Collins (1985), the fecundity of striped mullets ranges between 0.5 and 2 million eggs per female, depending on the size of the female. Despite concerns about the impact of seed collection on natural stocks, Egyptian experts have gained extensive experience in the large-scale handling of mullet fry, significantly reducing losses during the handling process. Additionally, the stability of mullet captures over more than a decade amidst a growing aquaculture industry has lessened opposition to the practice (Saleh 2008).

The long-term sustainability of wild resources to support the sector's growth is uncertain due to limited scientific data (Saleh 2008). Despite the long history of mullet seed collection in Egypt, there is no published scientific study on its impact on wild stocks. The available information is limited to comparisons of mullet catches and record numbers of collected seeds, but landing estimates are not accurate enough to evaluate possible impacts due to the exclusion of illegal catches (Saleh 2008). Therefore, comparing production trends between capture fisheries and CBA based on the species used in CBA provides a clearer measure than relying on the count of seed collected. The absence of an accurate count of illegal mullet seed collection and the unreported collection of seed from other species, such as seabass, seabream, meagre, catfish, eels, bayad, and Marbled spinefoot, makes this comparison more reliable. Analysis of this measure reveals that the species used in CBA experienced an increase in catch from 1990 to 2020. Concurrently, aquaculture production of these species has also risen (Fig. 3). This suggests that opposition to CBA lacks evidence of negative effects on fish stocks resulting from seed collection. However, it is not conclusive evidence and raises doubts about the accuracy of official fish statistics, particularly as fish farmers are not obligated to report production data to authorities. Production estimates, as indicated by Dickson (2022), are calculated by multiplying the aquaculture area by the average estimated productivity, adjusted based on industry communications.

Management of CBA

The dependence on wild seed hampers long-term planning in the sector, necessitating a comprehensive understanding of the subject matter and a decision-making process involving various stakeholders (FAO 2006; Saleh 2008; Sadovy de Mitcheson and Liu 2008). Successfully managing CBA requires recognizing and documenting activities, as well as monitoring impacts for a cost-benefit analysis. However, managing these practices presents challenges, including limited institutional capacity, enforcement issues, conflicts of interest, and corruption (Pomeroy 2008; Asche 2008).

Previous attempts to manage seed capture have generally failed due to inadequate enforcement, illegal fishing practices, and a lack of scientific data guiding decision-making (FAO 2006). In Egypt, statistics reported a decline in seed collection despite an increase in production for species relying on seed collection. Additionally, a study by Nasr-Allah et al. (2014a) revealed the average production of fry is 10 million annually for each hatchery. However, official statistics from the General Authority for Fish Resources Development (GFARD) indicate an average production of only 750 thousand fry. The lack of accuracy



	1990	2000	2010	2020	1990	2000	2010	2020
	Aquaclture				Capture			
Mullet	6	81	116	318	12	20	32	44
Seabass and Seabream	0	19	31	71	4	3	3	4
Meagre	0	0	12	36	0	1	1	1
Catfish	0	1	10	10	18	32	29	38
Other	0	0	0	1	0	3	9	10

Fig. 3 Production trends of capture and CBA of selected species in Egypt (FAO 2023)

in the statistics highlights the need for a critical reassessment of fish production data as a crucial first step toward improving the management of this activity.

To ensure the long-term viability of Egypt's aquaculture industry, immediate government action is required, addressing the illegal fry trade, enforcing regulations, and promoting sustainable practices (Saleh 2007). The presence of a black market and illegal fishing undermines these efforts, posing a significant threat to the sustainability of the aquaculture and fisheries sector. In response, Egypt has enacted Law No. 146/2021 for the Protection and Development of Lakes and Fish Resources. The Lakes and Fish Resources Protection and Development Agency (LFRPDA), formerly known as GAFRD, is responsible for managing the sector's resources. Article 31 prohibits unauthorized fishing and seed collection. Violating this law can result in imprisonment and fines, emphasizing the need for regulatory enforcement.

Challenges

Identifying and addressing the challenges facing hatcheries is of paramount importance for transitioning from CBA to HBA. The key issues include:

1) Legislation disadvantage

Private sector hatcheries are disadvantaged by legislation prohibiting the use of fresh water, except in state-established hatcheries (Saleh 2007). This puts private hatcheries in an unfavorable competitive position.

2) Quality of fish seed

Aquaculture development is hindered by the lack of regulations to maintain the quality of fish seed during production (Brummett 2007; El-Sayed 2017a, b). This affects the production efficiency and profitability of the farms.

3) Selective breeding hurdles

Some Egyptian hatcheries produce common carp fry with deformities and poor growth due to potential long-term inbreeding (Saleh 2007). The use of supplies from the wild hinders selective breeding hurdles, impacting the commercial development of enhanced hatchery technology for mullets (Saleh 2007). If we look at the growing volume of global trade in seafood and increasing competition, this means that the competitive ability of aquaculture in Egypt will decline soon, especially with significant advancements in hatchery techniques and selective breeding in competing countries.

4) Challenges faced by tilapia hatcheries

Egyptian tilapia hatchery operators encounter oversupply, falling prices, delayed payments, poor water quality, financing constraints, brood fish shortage, high fuel costs, limited knowledge of best practices, and a ban on seed transport (Nasr-Allah et al. 2014a). These numerous challenges will undoubtedly undermine any opportunities for improvement in the near future.

5) Shortage of consultants and veterinarians

There is a shortage of consultants and veterinarians to provide guidance and support to hatchery workers (Nasr-Allah et al. 2014b). This leads to an increased likelihood of disease incidence and mortality rates in hatcheries, as well as a heightened risk of disease transmission to farms. Consequently, this affects the profitability of both hatcheries and farms.

6) Leasing and restrictions

Hatcheries under GAFRD supervision are leased for a maximum of 25 years, subject to specific terms. Private sector hatcheries face more restrictions than government operators, creating an uneven playing field (Saleh 2007). This regulatory situation also limits research and development opportunities.

7) Live feeds and micro diets challenges

Inadequate live feeds and micro diets negatively affect the quality and productivity of marine hatchery larvae. The lack of appropriate feed often leads to early disposal of production due to high mortalities during transport and stocking (Salem et al. 2015). The issue becomes more critical, particularly with import restrictions due to foreign currency shortages. This is because essential feeds, such as *Artemia* and shrimp feeds during early stages, depend on imports.

8) Disease prevalence

Disease prevalence in hatcheries, with mass mortality events reported among hatchery-reared European seabass due to bacterial infection (Ragab et al. 2022). Tilapia and shrimp hatcheries are not immune to this problem either. The lack of disease-resistant strains and deficiencies in biosecurity measures exacerbate this issue.

9) Seasonal shrimp production

Shrimp production in Egyptian hatcheries is seasonal, influenced by demand and winter temperatures, necessitating advancements in hatchery systems and technologies for cost reduction (Sadek 2010). They are encouraging investors to establish more hatcheries to increase the available quantity at the beginning of the season.

10) Challenges in the Ghalyoun project

Despite government support, the Ghalyoun project, including a marine hatchery, has not achieved its planned production targets (Feidi 2018; LFRPDA 2024). If the obstacles facing this hatchery are resolved, it will contribute significantly to increasing the supply of seabass, seabream, and shrimp seeds, given its substantial production capacity.

11) Wild capture competition

Wild capture of fish seed directly competes with private sector hatcheries, hindering investment in marine hatcheries due to the lower prices offered by the government and illegal suppliers (Saleh 2007). This situation may subject private marine hatcheries to losses, and perhaps this is one of the main reasons for their limited expansion over the past three decades.

Sustainable management strategies

To promote sustainable aquaculture and capture practices in Egypt, the government can undertake several measures, which include:

1) Wild Seed collection licenses and regulations

Management and best practices for CBA are only possible when activities are recognized, acknowledged, and documented (Sadovy de Mitcheson and Liu 2008). Furthermore, granting licenses for the collection of wild seeds will put an end to illegal practices. It is of paramount importance to consider that licenses should be issued through specific fees via public auction (Goulding and Kamel 2013). And should be based on several criteria, such as species, quantities, and location. Regarding species, bass and bream fry are currently hatcheries spawned commercially. However, existing hatcheries cannot meet the market demand. In this context, short-term licenses are issued to existing seed fishers, with their numbers gradually decreasing as hatchery production rises. As for mullets and meagre, these species are not commercially hatchery spawned at present. Consequently, licenses are issued for seed collection under specific controls to ensure sustainable fisheries management and promote responsible aquaculture practices (Goulding and Kamel 2013). Special attention must be devoted to identifying appropriate techniques for each species involved in wild seed collection, as the fishing gear could cause environmental and ecological damage, such as habitat destruction and biodiversity loss among non-target species, largely due to bycatch (Sadovy de Mitcheson and Liu 2008; Pomeroy 2008). An immediate prohibition on collecting catfish fingerlings is crucial due to the current capacity of hatcheries to meet the existing demands of aquaculture.

2) Facilitating licensing procedures and offering incentives

Simplifying licensing procedures for both existing and new hatcheries and providing incentives, such as allocating suitable sites at nominal rates for extended periods, contingent upon compliance with relevant conditions (Saleh 2008; Goulding and Kamel 2013). Attracting new investors by offering appropriate investment sites for establishing additional marine hatcheries.

3) Promoting hatchery seed preferences

Raise awareness about the advantages of using seabass and seabream hatchery-produced juveniles over wild-caught seeds, emphasizing safety, size, adaptability, and transportation standards. Goulding and Kamel (2013) suggest providing incentives for farmers, such as discounts on annual rental fees, to farmers committed to purchasing juveniles from hatcheries, reducing reliance on wild-caught seeds.

4) Selective breeding programs

Selective breeding programs for fish began in the 1990s (Chatain and Chavanne 2009). The development of current hatcheries to adopt selective breeding programs is essential. These technologies aim to enhance selected traits such as growth, disease resistance, feed efficiency, environmental tolerance, and product quality for the species being bred (Megahed and Aly 2009; Griot et al. 2021; Megahed 2020). This necessitates increased investment in research and development, involving universities, research centers, and attracting specialized foreign companies in marine selective breeding to invest in this sector in partnership with Egyptian investments.

For example, tilapia raised in Egyptian farms still grows slower compared to other strains. The GIFT strain, raised in Brazil and imported from GenoMar Philippines, reaches about 1300 g per fish after 8 months of culture, starting from 8 g (Dos Santos et al. 2019). This strain not only grows rapidly but also demonstrates high disease resistance and yields more fillets. Meanwhile, tilapia farmed in Egypt begins at approximately 9 g, reaching 265 g per fish after 8.7 months (Macfadyen et al. 2012). In current selective breeding programs, genetic improvement in the harvest weight of seabass can range from + 50 to + 150% (Vandeputte et al. 2014). Studies on seabream (Knibb 2000) have shown a 5–10% increase in growth rate per generation. The expected genetic gain in harvest weight can reach up to + 100%. In 2016, approximately 50% of farmed sea bass came from selective breeding efforts (Janssen et al. 2017). However, Egypt still has progress to make in this area.

5) Training on best management practices

Providing training for hatchery staff on the best management practices to enhance human resource performance and their ability to utilize modern technology (Nasr-Allah et al. 2021). Additionally, guiding farmers to rely on hatchery seeds based on clarifying their advantages compared to wild seeds will significantly contribute to reducing the demand for wild seeds. Additionally, Sadovy de Mitcheson and Liu (2008), as well as Pomeroy (2008), recommend that training and outreach are necessary to reduce mortalities associated with various capture, transfer, and culture practices, as well as wasteful bycatch. Furthermore, raising awareness about the issue of resource wastage is essential.

6) Implementation of biosecurity measures

Implementing biosecurity measures in hatcheries to mitigate the spread of diseases and to promote the use of vaccines, especially those developed using advanced molecular technologies, as a preventive measure against fish diseases and to reduce the use of antibiotics (Ragab et al. 2022; Can et al. 2023). This will also contribute to reducing the risk of disease incidence on farms and providing an advantage for hatchery seeds compared to those collected from the wild.

7) Incentivizing investment and research in live feeds and micro diets

Providing incentives for investment, research, and development in the field of live food and micro-diet systems is of paramount importance (Salem et al. 2018; Ashour 2020). These incentives may include financial incentives, such as tax exemptions and interest-free loans for an extended period, or in-kind incentives, such as providing free sites or granting exploitation rights for an extended period, for both local and foreign investors. This will lead to a reduction in dependence on imports, and lower prices, and contribute to the utilization of local resources, such as high-quality *Artemia* strains available in various locations in Egypt. Additionally, supporting research and development in this field is likely to make a significant contribution.

8) Specialized management for monitoring and control

The interconnected nature of this sector requires an organizational structure capable of accommodating its complex nature and the substantial interactions between aquaculture and fisheries (Clavelle et al. 2019). Therefore, the unique and specialized collective fishing sector within the fishing industry should be recognized, necessitating integrated management tailored to its specific characteristics, despite being a type of fishery that is not fully understood (Sadovy de Mitchison and Liu, 2008). Hence, allocating dedicated management within LFRPDA, formerly known as GAFRD, is crucial for overseeing this vital sector. This agency comprises specialized management for aquaculture and another dedicated to fisheries. This administration is supposed to implement the plans and legislation deemed sufficient according to Saleh (2008), but their execution requires further control over fishing activities.

With a particular focus on establishing closed areas and seasons, which is essential to allow mullets, seabass, seabream, meagre, and eel broods to migrate to their spawning grounds and spawn successfully. Additionally, there should be a commitment to monitoring and evaluating the mechanisms to ensure the enforcement of penalties against violators of laws and regulations regarding the collection and trade of wild seeds.

9) Providing incentives to hatcheries

Providing incentives, through simplified access to low-interest loans can encourage investment in establishing marine hatcheries. This investment should be contingent upon the utilization of modern technology to enhance technological localization in the sector. By implementing these measures, we can promote sustainable growth in aquaculture while fostering innovation and efficiency in the industry.

10) Alternative livelihood options for fishermen

Given the necessity of providing alternative livelihood options for fishermen engaged in wild seed collection, they could indeed be retrained to work in hatcheries, where activity is expected to increase while simultaneously reducing seed collection. Pomeroy (2008) also suggests that governments provide assistance, whether in terms of incentives or low-interest loans, to enable this group to enter the aquaculture sector.

11) Statistical system

Accurate statistics are crucial for effective planning of the aquaculture industry's development in Egypt and the sustainable management of fishery resources. This requires addressing issues such as unreported CBA production data, and uncontrolled collection of seeds from wild sources illegally by the private sector. Efficient producer organizations can assist in the registration and data collection process, improving the availability of official data on unregistered or unlicensed hatcheries (Goulding and Kamel 2013; Nasr-Allah et al. 2014a; Froehlich et al. 2022; Abdel-Hady et al. 2024).

12) Collaboration and partnerships

Encourage collaboration between the government, research institutions, and direct stakeholders, to address weak institutional context (Haylor and Bland 2001). And to develop a comprehensive plan for the development and management of HBA and CBA activities. These strategies, when effectively implemented, will contribute to the sustainable development of aquaculture while simultaneously alleviating the environmental burden on fisheries.

13) Sustainable aquaculture certification

Encouraging and supporting the adoption of aquaculture products based on sustainability standards (Pomeroy 2008; Osmundsen et al. 2020). This ensures high-quality production and enhances the global marketability of Egyptian aquaculture products.

14) Government marine hatcheries exiting competition

Government hatcheries should not compete with the private sector due to unequal competitive conditions. This is exemplified by the K21 marine hatchery. Established in 1993 with funding from the United States Agency for International Development (El-Gayar 2003), it was further developed in 2010 under the Italian grant within the MADE project. This hatchery primarily produces seabream and seabass fry, directly competing with private hatcheries. Therefore, it needs to cease competing with the private sector and redirect its activity towards spawning species like mullets and meagre. Additionally, it should focus on training industry workers and transferring spawning technology from abroad to Egypt.

Upon initiating the implementation of this strategy, it is expected that within the first 2 years, a mapping of the characteristics of capture-based aquaculture practices will be conducted. This includes documenting the physical, biological, social, and economic characteristics, such as areas and seasons for seed collection, types of nets, seed numbers and species, bycatch species, income, seed collection expenses, number of workers, their roles, and formal engagement through licensing. Alternative livelihood options will also be identified and proposed to reduce pressure on wild stocks accompanying the gradual reduction in collected seed numbers. Additionally, precise data will be recorded on hatchery production to determining its maximum capacity, suitable economic incentives, and identifying sites for presentation to potential investors interested in marine species breeding and induced spawning. Moreover, the plan includes removing obstacles, providing worker training, and offering low-interest loans to both existing and prospective hatchery owners. These actions will be taken subsequent to determining the required number of hatcheries to meet future demands and ensuring they are equipped with broodstock.

Following these proposed measures, the number of seeds to be collected will be progressively reduced. By the eighth year of strategy implementation, the collection of seabass and seabream seeds is expected to be completely halted, while in the tenth year, the numbers of meagre and mullets will be reduced by 85% and 25%, respectively. It is expected that the contribution of seabass and seabream fingerlings will increase by 160% from the seed supply to meet market demand in the tenth year, considering that the first year is the base year. By the tenth year, 85% of the demand for meagre fry and 10% of the demand for mullet fry will be met, as indicated in Table 3. The strategy will be continually refined through periodic updates to ensure optimal utilization of this resource.

Conclusion

The practice of CBA constitutes a fundamental aspect of the aquaculture industry in Egypt, but it has numerous interactions with fisheries. Therefore, responsible management is of paramount importance to ensure its sustainability. To promote aquaculture and sustainable fishing practices, the government can seek to eliminate illegal practices by granting licenses for the collection of the seed of certain species not expected to be commercially spawning in the short term, including mullets, meagre, and eels. Licenses for other species currently spawning commercially but not adequately meeting market demands, including seabass and seabream, should gradually be reduced. Simultaneously, restrictions on collecting fingerlings of catfish should be tightened due to their current ease of induced spawning. This approach should be accompanied by supporting hatcheries through financial incentives, training, and assistance in adopting modern technology.

Accurate data are essential for monitoring, surveillance, and sustainable planning. Additionally, collaboration between the government, research institutions, and direct stakeholders is necessary for regulating and planning activities sustainably. Furthermore, ongoing studies and continuous monitoring are vital for adapting strategies to evolving challenges. Therefore, future studies should focus on assessing the potential impact of climate change on the availability of wild seeds. Developing improved strains that significantly differ in growth and disease resistance between hatchery and wild-collected seeds can alleviate pressure on fisheries, ensuring their sustainability, while simultaneously fostering growth in the aquaculture sector.

Table 3 Forecasting the transition from wild seed collection to hatcheries seed production based on the proposed strategy

Species	Resources	Year									
		1	2	3	4	5	6	7	8	9	10
Mullets	Hatcheries	0%	0%	0%	2%	4%	7%	10%	14%	18%	25%
	Wild	0%	0%	−2%	−5%	−8%	−11%	−15%	−20%	−25%	−30%
Seabream and seabass	Hatcheries	5%	10%	25%	45%	60%	80%	100%	125%	150%	160%
	Wild	0%	−10%	−10%	−20%	−40%	−65%	−90%	−100%	−100%	−100%
Meagre	Hatcheries	0%	0%	0%	5%	10%	20%	30%	45%	65%	85%
	Wild	0%	0%	0%	−5%	−10%	−20%	−30%	−45%	−65%	−85%

Author contribution M.M.A.: Conceptualization, methodology, validation, formal analysis, investigation, data curation, writing—original draft, writing—review and editing, visualization, supervision. A.F.K.: Methodology, formal analysis, review, and editing. A. Md. S.: writing—original draft, writing—review and editing, visualization S.M.H.: Methodology, data collection, validation, formal analysis, investigation, visualization, review, and editing.

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Data availability No datasets were generated or analyzed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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