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NEEDS AND COMPROMISES OF OFFSHORE AQUACULTURE

COMPROMESSI E NECESSITÀ: ACQUACOLTURA IN MARE APERTO

Abstract *– Fish aquaculture has always been practiced in human history but was only regarded as the main production of aquatic species until after the 1990s. Aquaculture production drastically increased, due to the growing demand for fish as a cheaper and more sustainable protein source for human populations. Most marine fish farms are sited in sheltered, shallow, and nearshore areas, which led to environmental concerns and competition for common sea space. The solution for the fish farming industry is to move installations from nearshore sites to offshore sites. The offshore environment reduces the environmental impacts and offers more space for fish farms with a reduction of contest with other sea space users alongside better conditions for fish welfare.*
Nevertheless, offshore fish farming introduces many biological and physical challenges. The offshore cage design should consider the environmental features of the selected site to minimize risks and running costs, while maximizing productivity and fish welfare.

Key-words: *Marine aquaculture, fish cage design, maritime spatial planning*.

Introduction – The fishery industry has so far represented the largest share of aquatic organism consumption, causing overfishing and depletion of fish stocks. The 90% of fished species are already overfished, with null growth potential in global production. For this reason, aquaculture must take over to cope with the world's demand for valuable aquatic proteins. The production and consumption growth of aquaculture products predicted for the following years is sustainable and desirable for FAO (Marino *et al.,* 2020). Aquaculture represents one of the most efficient and sustainable animal production systems, both in terms of human food production and environmental impact. In the '90s, aquaculture was responsible for 7% of the total fish production, while since 2016, aquaculture production achieved about 50% of the total production. The predicted aquaculture production share for 2030 is 60%: such a projected increase requires appropriate economic support, investments in research, and maritime spatial planning.
Most farms are in sheltered areas, shallow waters, and close to the shoreline. These features guarantee safe running and maintenance operation and easy access to the cages for feeding and harvesting but may lead to higher environmental impact from fish wastes. Additionally, closeness to the shoreline implies more conflict with other marine uses (*e.g.*, ports, tourism, and shipping). Therefore, many farmers have increased fish density in their cages (Huguenin, 1997; Stickney, 2002) to increase production for unit area of the concession. These farming conditions have harshened conflict with local communities and environmental groups, which are concerned about animal health and environmental degradation due to the input of organic matter and chemical compounds near the cages.
In response to these problems, the aquaculture industry began to explore areas that could support sustainable fish aquaculture: sites far from the coast characterized by high depths, high availability of surface, and constant sea currents.

Aquaculture in exposed sites implies cage design difficulties; an appropriate cage design should consider environmental risks related to the selected site, enough space to guarantee good fish health, and a good compromise between distance from the coast (to guarantee offshore conditions) and distance from support structures (to minimize time and management costs).
In this paper, we synthesize available information on the aquaculture technologies already used in this industry with a focus on the farms operating in the Mediterranean Sea and in Italy

Materials and methods – Preliminary literature and web research were conducted to determine the state of the art of aquaculture. At first, we searched for technologies used in the whole world and for the breeding of all finfish species. Gradually, we focused on the Mediterranean Sea and Italy. We looked for all kinds of marine aquaculture techniques (aquaculture in sheltered and exposed sites), analyzing the structural features of the cages and the environmental characteristics of the sites. We identified the main environmental challenges for offshore and sheltered aquaculture for an appropriate design of the cages: framework, shape, size, volume, and materials.
We classified all the cage systems currently on the market and looked for companies working in the industry in the Mediterranean Sea, especially in Italy.

Results - ***Cage design*** - One of the main aspects to consider is the wave force acting on the structures. The most traditional anchoring system is the gravity system, which includes four components: the floating collar, the net, the sinking system, and the mooring system. The floating ring provides stability, while the ballast ring keeps the conformation of the entire cage stable. The framework can be rigid, but the wave forces are entirely transferred to the cage. It can be composed of movable joints; in this case, the cage follows the wave action, or flexible structure, and adapts very well to the wave action.

The cages are built in circular, rectangular, and square shape. Circular cages have the best surface/perimeter ratio and low weight, which is very important for the mooring system resistance. Besides, circular cages are very resistant to wave action stress, which makes them suitable for exposed sites. Rectangular and square cages are subject to high forces in the corners; polygonal cages are more resistant than square cages to the wave action because they distribute the wave force on more corners, reducing the force acting on each corner (Piccolotti and Lovatelli, 2013). These cages are easily constructed, and they can be built in big and modular structures; all these features make them suitable for sheltered areas.
During the design process, it is crucial to keep in mind the size of the cages in connection to the site; the cage resistance is strictly related to the size. Big cages can be used in sheltered areas where wave forces are insignificant, while the production cost decreases as the size increases.
Generally, the used materials are galvanized steel, high-density polyethylene, polyvinyl chloride, aluminium, steel, wood, and plastic. Nowadays, the most widely used, especially for circular cages, is HDPE for its mechanic resistance, flexibility, lightness, and easiness of repair/maintenance.

Cage systems - Aquaculture cages are divided into two categories: open-net systems (1) and closed containment systems (2).

Floating flexible cages (1) are the most widely used worldwide. The framework of the cage is generally circular and made of HDPE pipes from which the net hangs. This

kind of cage is very resistant (not to storm) (Scott and Muir, 2000), but they present net deforming issues in case of strong currents, reducing available space for fish.
E.g., Bridgestone cage, Dunlop cage, Tubenet cage (Akva group).

Floating rigid cages (1) strongly resist to the wave force (also intense storms); they oppose the wave action. They are usually huge and include other support structures, such as feedstocks, fishing areas, and fuel stocks. However, these cages are costly and need big ports for support.
E.g., Pisbarca system (Marina Systems iberica) (Chu *et al.,* 2020).

Semi-submersible flexible cages (1) can be lowered under the sea surface in case of storms. They are light and simple in structure. However, if they are left for long periods in submerged conditions, they may need an automatic feed distribution system.
E.g., TLC cage, Ocean spar cage, Oceanis 1 and Oceanis 2 cages (Badinotti).

Semi-submersible rigid cages (1) are big platforms like the floating rigid systems; they usually include enough space for feed and fuel stocks, fishing areas, and monitoring systems. The cage can be lowered in case of storms, and the net volume is maintained thanks to the rigid framework. They take long time for construction and are very expensive.
E.g., Ocean farm 1 cage (Farmocean International).

Submersed cages (1) have the primary operating mode underwater. They can be temporarily brought to the surface for maintenance and fishing. Low landscape impact and moderate production costs.
E.g., Sadco cage (Sadco shelf), AquaPod and SeaStation cages (InnovaSea).

Closed containment systems (2) allow the control of water quality and the entire production cycle. They are not susceptible to storms, algal blooms, and pathogens. Such systems have high production costs and need a power energy support system in case of offshore conditions.
E.g., The Egg system (Hauge Aqua), Container ship system (Marine Harvest ASA).

Focus on Italy - Italian finfish marine aquaculture is mainly based on two species: gilt-head bream (*Sparus aurata,* Linnaeus 1758) and seabass (*Dicentrarchus labrax*, Linnaeus, 1758). Aquaculture is very important in the agri-food industry; however, most of the aquaculture products comes from shellfish and freshwater farms. Sea bream and seabass production represent approximately the 7% of the total production in the EU (EUROSTAT, 2020). In 2019, the total number of enterprises involved in aquaculture was 521 for 691 installations: 250 for freshwater aquaculture, 54 for marine water aquaculture, 386 for shellfish aquaculture and one installation for crustacean aquaculture (Capoccioni *et al*., 2020). Marine aquaculture represents the smallest percentage of the industry; particularly in regions like Liguria, Sicilia, Calabria, and Campania (Fig. 1).
We identified 27 out of 54 farms. We found information about the cage system for 16 of them. The most used cage system is the floating flexible because most installations are in sheltered areas. Floating flexible cages are also used offshore (2-4 miles from the coastline), but in large embayment partially protected by strong waves. Considering the level of exposure to waves of the Italian coastline, to move offshore and reducing the overlap with other uses of the sea, farmers must introduce semi-submersible and submerged systems, which better face extreme marine conditions, although requiring more maintenance cost.

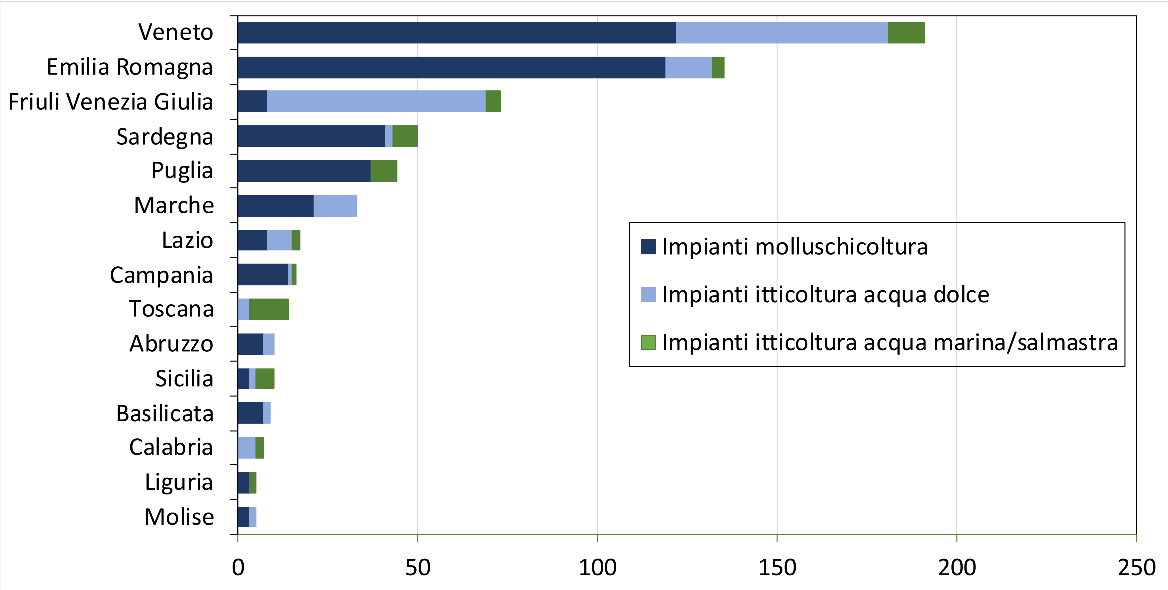

Fig. 1 – Aquaculture farms for sector (adapted data from Marino *et al.,* 2020 and Capoccioni *et al.,* 2020).
Impianti di acquacoltura per settore (dati adattati da Marino et al.*, 2020 e Capoccioni* et al.*, 2020).*

Conclusions - Italy appears to lag behind other countries in the EU and the rest of the world, due to bureaucracy (i.e., the issuance of the maritime state concession) and different laws on animal welfare, such as the use of feed adjuvants and drugs. In response, Italy is already pursuing some macro-objectives in the National Strategic Plan for Aquaculture 2020-2021: simplify administrative procedures, develop sustainable aquaculture through maritime spatial planning and increasing sites potential, promote aquaculture competitivity and conditions of fair competition for aquaculture owners (Capoccioni *et al.,* 2020). Italy needs to invest in those regions potentially suitable for marine aquaculture currently underutilized. For instance, the Ligurian Sea area offers much space for aquaculture activities; however, lousy sea conditions and hostile public opinion make aquaculture a real challenge. For this reason, we need to invest time in research activities and awareness campaigns for the growth of the sector.

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