Prospects of Marine Aquaculture in the Adriatic Sea: comparison of sheltered and open-sea areas within Montenegro coastal zone

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ABSTRACT

Montenegrin coastal zone lacks sheltered areas suitable for traditional aquaculture technologies except for the Boka Kotorska Bay. However, this semi-enclosed area is affected by human impacts and has limitations for large scale and intensive fish-farming activities. Combining cage systems with mussel and seaweed farms could solve the problem of fish-farm waste conversion. In comparison with sheltered areas, multiple open-sea sites are available for intensive offshore aquaculture, but they involve engineering and biological aspects that have to be considered as risk factors. Submersible cages could be a solution for risk elimination in offshore aquaculture.

Key words: Fish farming, multitrophic aquaculture, submersible cages, offshore aquaculture

INTRODUCTION

Despite a great potential for development, mariculture production in Montenegro remains diminutive. Due to the limited availability of fish-farming sites in sheltered locations, marine aquaculture is currently not an important activity in Montenegro, both in the context of yield and its economic effect. The aquaculture production of Mediterranean mussel (*Mytilus galloprovincialis*) increased from 156t in 2007 up to 200t in 2011; within the same period, the production of sea bream (*Sparus aurata*) increased from 38t up to 60t (EUNETMAR…, 2014), similar to the European sea bass (*Dicentrarchus labrax*) farming production (from 38,5 to 60t). Mariculture activities are currently carried out exclusively in the Boka Kotorska Bay (87 km ^{2}), which has sheltered sites and suitable space primarily for the cage fish farming and bivalve farming on floating (suspended) plantations. Currently, there are 16 farms rearing Mediterranean mussel and oysters using the long line production system and two farms rearing sea bass and sea bream using the cage farming system. The mariculture sector in Montenegro employs about 40 people, so that one worker produces only 8 tons of farmed seafood annually (EUNETMAR…, 2014).

While research of the Institute of Marine Biology in Kotor showed that the Montenegrin coastal area has good conditions for natural development and great mariculture opportunities (Mandić *et al.*, 2014), the development of these activities is stagnant, and no locations have been identified for large-scale aquaculture in the open sea off the Montenegrin coast. Existing farms are located only in the protected area of the Boka Kotorska Bay, where the maximum amount of farmed fish cannot exceed 100 tons per farm to ensure environmental protection from eutrophication (Mandić *et al.*, 2014). Due to this limitation and a limited space, marine aquaculture cannot provide a large-scale production within sheltered areas. As the principal reserves for industrial aquaculture development in Montenegro, we consider the multi-trophic farming and the use of offshore zones, which requires the employment of new technologies.

MATERIAL AND METHODS

This paper is based on the material collected in various marine areas, such as the Black Sea, Caspian Sea, Tyrrhenian Sea, and Adriatic Sea (Montenegrin coast), using traditional methods of ichthylogical and hydrobiological research, including SCUBA diving, underwater observation, and laboratory experiments(Antsulevich and Maksimovich, 1990; Bugrov, 1992, 1994, 2006; Mandić *et al.*, 2014). Statistical and environmental data on the modern state of Montenegrin aquaculture were compiled from our own data and a number of scientific papers and official reports (Bugrov, 1992; Simović, 2006; FAO, 2007; Case study report: The Adriatic Sea, 2011; EUNETMAR, 2014; Mäkinen *et al.*, 2013; Kljajić *et al.*, 2014; Mandić *et al.*, 2014).

RESULTS AND DISCUSSION

Environmental aspects of marine aquaculture

The Institute of Marine Biology (Kotor) identifies the Boka Kotorska Bay to be within the parameters safe for local environment (Simović, 2006). However, intensive mariculture may cause environmental impact on underwater ecosystems. The impact depends primarily on the rate of water renewal in the area. If the rate of water renewal is too low to enable clean-up of fish wastes from the soil below the cages, the soil becomes polluted. A report by the Croatian Ministry of Environment (2003) states that tuna farming is likely to negatively impact the environment primarily because fish farms are often located in shallow waters near the coast, where water renewal is low. In addition, excessive fish feeding contributes to the environmental impact (Case study report.., 2011). It is well known that fish farming causes the drift of 5-25% feed mass from the net cages. The average emission of eutrophying substances from 1,000 kg of farmed fish is 23 kg PO_4-equivalents (Mäkinen *et al.*, 2013). Even with good farming practices and accurate fish feeding procedures, the eutrophication can be a serious problem for semi-enclosed sea areas. The water renewal rate is a natural phenomenon, which cannot be controlled by humans, but fish farmers are able to select a proper site with optimal parameters for water exchange (i.g., in the open sea areas).

An additional solution for intensive fish-farming development could be provided by polyculture production systems, which enable increasing production volume and utilizing the biodiversity of marine ecosystems. For example, combining the cage system with mussel and seaweed farms could solve the waste conversion problem. The Integrated Multi-Trophic

Aquaculture (IMTA) combines the cultivation of fed species (e.g. finfish) with extractive species including seaweeds, suspension and deposit feeders, which utilize inorganic and organic excess nutrients, respectively, from the fed aquaculture. Studies have shown that the condition index of mussels farmed in the same location with sea bream and sea bass is slightly higher throughout the year in comparison with mussels farmed in a monoculture (Peharda *et al.*, 2007). Research on mussel growth near fish farms in the Tyrrhenian Sea has shown that bivalves recycle allochthonous organic matter and contribute to the reduction of environmental pollution, thus increasing the profitability of farming (Sara *et al.*, 2009 – citation from Mandić *et al.*, 2014). Despite this knowledge of the IMTA advantages, there is only one fish farm located in the Boka Kotorska Bay, where mussels and oysters are farmed along with sea bream and sea bass (Mandić *et al.*, 2014).

Combining the cage system with an artificial reef is another way of solving the problem of the waste conversion. The reefs installed around the cage become inhabited with various filtering organisms. Waste products from the cage can be used as food for these organisms and contribute to the strengthening of the bio-filtration belt, thus increasing the self-cleaning capability of the affected sea area. Long before the IMTA concept was formulated, the first artificial reef-and-cage complex "SADCO-SHELF" (Fig. 1) was built in 1987 near an offshore oil platform in the Caspian Sea (Bugrov, 1994). Studies of benthos, periphyton and zooplankton showed the positive impact of submersible cage and artificial reef complex on increasing biodiversity and productivity in the impacted area (Antsulevich, Maksimovich, 1990). Underwater research demonstrated that cages have a leading role in the artificial habitat complex as a primary attractive center for residential and transient fishes. Fishing near the complex had a supporting role by providing the cage farm with fish of low market value as a feed for cultured species (salmon and sturgeon), and thus lowering the overall costs of feeds twofold (Bugrov, 1994). This prototype of the IMTA scheme exemplifies a possibility of achieving a nutrient loop, where all ingredients of the fish feed originate from the same area (Fig.1).

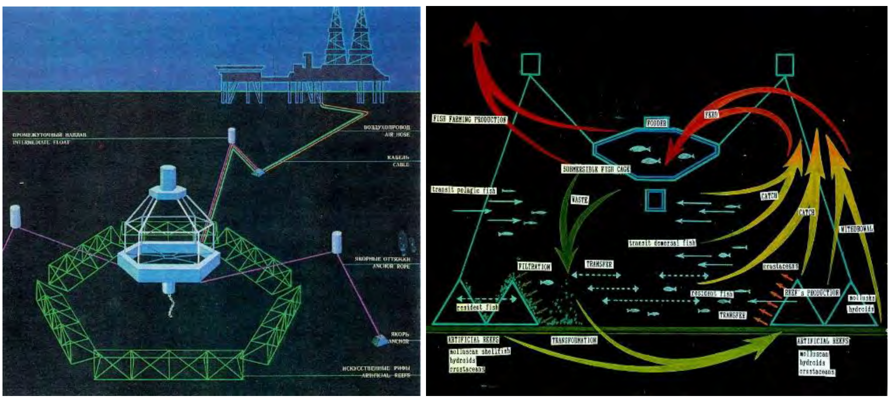


Figure 1. Artificial reef and cage system near an offshore oil rig (left) and the IMTA concept (right) (from Bugrov, 1992; 1994)

In the typical maricultural practice, the majority of raw materials and associated nutrients for the fish feed is imported from the outside areas. The goal of environmental management tools such as IMTA is to increase the share of ingredients caught or cultivated in the catchment area, and thus to decrease the overall eutrophication loading. The removal fishing, which is used only on a small scale, has been discussed as an environmental solution to remove nutrients from sensitive water areas such as lakes (Mäkinen *et al.*, 2013). A similar approach would be useful for the semi-enclosed Boka Kotorska Bay, where regular removal of mussels (farmed in a short 1-2 year cycle) could be used as a fish-feed raw material for cage farming.

The IMTA principles provide positive effect and feedback for open sea areas as well. In order to analyze various aspects of onshore and offshore aquaculture, a sea bream model has been developed and integrated with existing shellfish models in the Farm Aquaculture Management System (FARM) model. Clear benefits of IMTA can be seen both for ponds and offshore culture. In food-poor offshore areas, IMTA can significantly improve shellfish production (Ferreira *et al.*, 2012).

An additional problem, typical for near-shore aquaculture, is the so-called "visual pollution" that causes conflicts between sea farmers and the tourist industry, while tourism development has the priority in the Montenegrin economy. Overall, further seafood production growth in the Boka Kotorska Bay does not appear possible, so that mariculture has to find new, ideally "invisible" forms of development in open waters.

Offshore aquaculture systems may avoid a number of the challenges faced by near-shore systems, such as visual impacts, local environmental impacts, and space constraints. In most cases, predation issues and disease risks could also be substantially reduced. Expansion of the offshore aquaculture would allow for an increase of the scale of sea farms, and could therefore improve the financial efficiency. Competition and conflicts with other business interests, such as touristic infrastructure and coastal management, would be reduced as well.

Expansion of the scope of marine aquaculture leads to the inevitable development of exposed (open) water areas, which have better water exchange than coastal areas and are free of strong competition for ownership and users conflicts typical of coastal areas. According to long-term scientific research, open South Adriatic is the least polluted area of the whole Mediterranean (Regner *et al.*, 2002). This area differs from the other parts of the Adriatic in the largest volume content of sea water, the largest average depth, the highest water transparency, and the permanent water exchange within the Mediterranean Sea. On the basis of previous studies conducted by the Institute of Marine Biology (Kotor), a number of potential locations have been proposed for aquaculture in the open part of the Montenegrin coast (Fig. 2).

In order to ensure a more definitive site selection, it is necessary to perform additional studies of the sediment, benthic fauna, water quality, oceanographic conditions (wave height, current direction and speed), sanitary control, and monitoring of biotoxins. Besides these environmental characteristics, it is important to take into account the administrative and socio-economic data such as underwater cables, administrative areas, marine protection areas, military zones, etc. (Mandić *et al.*, 2014).

Figure 2. Potential aquaculture sites, according to Mandić *et al.*, 2014

(◘ - shellfish, ● - fish farming, ▲ - tuna farming, ★ - hydrographical stations)

Biological and engineering aspects of offshore aquaculture

While open sea areas can provide ample sites for intensive aquaculture, but they involve engineering and biological aspects that need to be considered as risk factors. Among engineering aspects, the main factor is a risk of cage damage as conventional floating cages at the water surface cannot withstand storm waves. Key biological aspects are wave impact on fish and overheating in the summer season.

The modern technical arsenal of aquaculture includes various cage system variants. According to the hydrostatic positioning, they can be classified as follows (Bugrov, 2006):

- floating cages; these are traditional fish-farming systems which are permanently disposed on the water surface and have a constant water line;

- semi-submerged cages that have a variable water line and are capable of operating in a partially submerged state, thereby reducing the wave load on the basic pontoons below the water level (the upper part of the cage structure is permanently above the water surface);

- submersible cages of the first generation ("diving" cages) that have a system enabling a cage to be fully submerged under water in the case of an undesired situation (for example, a storm); otherwise they always remain on the surface;

- submersible cages of the new generation (underwater fish-farming systems); the underwater position is their main working state, and they are raised to the surface only periodically for servicing and fish-farming operations performed as in traditional cages.

Floating and semi-submerged cages may have storm resistant constructions. However, in solving the problem of preservation of a cage structure, the engineering approach prevails, whereas the biological aspects are ignored. For example, floating cages with a flexible structure (plastic, rubber, or rope) can well withstand storm waves owing to their damping properties. In semi-submerged cages, the storm resistance can be provided by an increased rigidity of the threedimensional skeleton structure. However, the fish in such cages remain unprotected from the wave action, experience a higher stress, are susceptible to “sea-sickness" (their vestibular apparatus also suffers from naupathia), and may be injured by the material of a net bag. Many cases are known, when a cage moored reliably on the sea surface was turned into a “washing machine” during a storm and fully damage the fish contained in it.

The common disadvantage of the floating cages is that they are “attached” to the sea surface where the fish are exposed to overheating and enhanced insolation in summer. In addition, the cages themselves can be damaged by ships, floating logs or garbage. One can also mention the risk of vandalism, drift of toxic algae clouds, and oil spills.

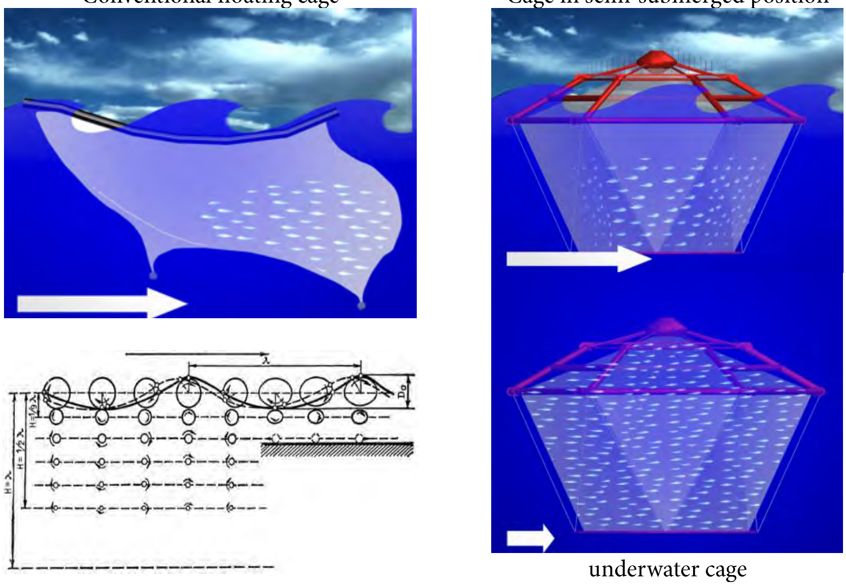
Submersible cage system could be the solution for offshore aquaculture with an exception of “diving” cages that are not fully reliable. In occasion of operational mistake or malfunction, such cages may remain at the surface during storm and be totally destroyed by waves. Only underwater technology of cage farming can reduce the risks and provide the guarantee for investors. This is also the way to avoid conflicts between users, especially in tourist areas, reduce a risk of fish overheating and cage damage by storms. The net bag of underwater cage keeps the effective volume without any reduction even in strong storms. The net does not move and does not traumatize or even disturb fish. As a result, it is possible to double fish stocking density and harvesting output per volume unit (Fig. 3). Overall, underwater approach can enable successful fish farming in open sea areas of Adriatic within Montenegro coastal zone.

Deep underwater position reduces the possibility of net fouling and the risk of net damage from solar radiation. Modern submersible cages (underwater fish-farming systems: Fig. 4) can be supplied with self-contained underwater feeders with automation and remote control (for example, SADCO-D; -E) or with a simple system for manual feeding as well as centralized feeding system (SADCO-SG). Reliable protection of these cages is achieved by their lowering under water, which is the normal operating position for the system. This position reduces the risk of damage by waves, drifting rubbish or oil spills, and enables successful fish-farming in stormy areas with waves up to 15 m (Bugrov, 2006).

According to the opinion of Food and Agricultural Organization of the United Nations (FAO) experts, advantages of SADCO cages are: suitability for a variety of sea areas (including strongly exposed sites), resistance and durability, low visual impact, and no reduction in the culture volume even under strong current conditions (FAO, 2007). One sea farm based on 12 submersible cages (with 3000m^3 volume each) can produce 1500t of sea bream or sea bass annually. The minimal quantity of cages for an optimal layout is 6 units, which can share common mooring anchors. A fish farm with a reduced number of cages is less profitable, because the anchorage and infrastructure expenses (farm design, land-based constructions, boat employment, additional equipment and services) remain at the same level with a bigger farm. For open sea sites in Montenegro we recommend a pilot installation of underwater farms for experimental-and-production fish farming, along with a research of biological and commercial potentials of various fish species.

Conventional floating cage

Cage in semi-submerged position



underwater cage

Figure 3. Comparison of different types of cages under impact of currents and waves oscillations (from Bugrov, 2006)

SADCO-D; -E

SADCO-SG

Figure 4. Submersible cages of "SADCO" series on sea surface and under water (photos by Leonid Bugrov)

Candidate fish species for marine aquaculture in Montenegro

The effects of temperature on biochemical and physiological processes of fish, an ectothermic organism, are well known as a key factor for successful fish farming. Physiological characteristics of fish, such as growth, food consumption, and activity, increase with temperature rising to a critical level, after which the rates of these processes rapidly decline. Extreme temperatures (both low and high) can lead to fish death. Thermal regime of the Adriatic Sea in Montenegrin zone is characterized by an overall insufficient heat for warm-water fish farming and seasonal overheating for cold-water fish species. These thermal features compromise conventional fish-farming practices.

According to the data from hydrographical stations "Bar" (located in the open sea at 100m depth: Fig. 2) and "Bojana" (near shore at 8m depth), the average annual temperature is 16,2°C and 17,1°C, respectively. The average monthly temperature varies between 13,4 - 24,1°C at "Bojana" and 14,6 – 19,4°C at "Bar". Inside the Boka Kotorska Bay summer temperatures at the sea surface can reach 25 - 26°C. In winter temperatures vary between 10,2 – 11,6°C at the surface but have higher values of 15,6 – 13,6°C at 8m depth due to the effect of inverted thermal stratification (Kljajić *et al.*, 2014).

Sea bream and sea bass are warm-water fish species. The optimal temperatures for their farming are about 24 - 26°C. Sea bream can tolerate temperatures of up to 30°C, but it is not tolerant of cooler waters, unlike sea bass. The daily growth rate of sea bream can double with a temperature increase from 12°C to 22°C. Sea bream farmed in submersible cages SADCO installed in open sea areas of South Italy (Sicily and Calabria) reached the market size in 9-10 months, while the same cages installed farther north (Campania and Toscana) require 12-15 months for the growth cycle. Under thermally stratified conditions in Boka Kotorska Bay, deep cages (or submersible cages) are likely to create better thermal environments for sea bream during the winter season.

Tuna and seriola are also prospective candidate species for marine aquaculture in Montenegro. There is a rising interest by various investors for growing not only sea bass and sea bream, but also tuna (*Thunnus thynnus*) (Mandić *et al.*, 2014). Several hundreds of wild-catch seriola (*Seriola sp.*) were successfully farmed in submersible SADCO cages in the Italian Mediterranean Sea (in Sicily and Basilicata: Bugrov, personal observation) and this experience could be applied to the Adriatic Sea as well.

Sturgeon fish has a widest range of thermal tolerance: they can live in near-freezing waters and can tolerate temperatures up to 30°C. Sea water temperatures in Montenegro are ideal for sturgeon farming, more optimal than in the native sturgeon areals (Caspian and Azov Seas). The average annual total of water heating in the Adriatic Sea is 6900 degree-days, much higher than ~5000 degree-days in the middle part of the Caspian Sea. This condition can improve the growth rate and time period of sturgeon maturation in Montenegro by 38%. The local Adriatic sturgeon (*Acipenser naccarii*) is a good candidate for sea-cage farming trials that could be implemented on the base of successful experiments on offshore farming of Caspian beluga (*Huso huso*) (Bugrov, 1999). Submersible cages protect sturgeon (demersal fish and poor swimmers) against the wave impact, which is very important for sturgeon's adaptability in the exposed sea conditions.

Sea trout farming also has a potential for Montenegrin aquaculture development after additional research. The "Montenegro's Fisheries Development Strategy..." states that the country has very favorable conditions for the production of trout. Presently there are 21 trout farms using the race ways and one farm on the Lake Piva using the cage culture. The total annual production of trout in fresh waters is around 450 tones (Simović, 2006). Farming in sea cages requires less investment than land based farms, which could be specialized for fingerlings.

Sea farming of rainbow trout (*Oncorhynchus mykiss)* in floating cages is applicable in the area of Boka Kotorska Bay. According to Kljajić *et al.* (2014), it is possible to obtain more than one production cycle of marketable fish (> 300 g) during the late autumn to early spring period by stocking rainbow trout fingerlings > 50 g. Deep (or submersible) cages may enable all-year-round trout farming by providing better thermal conditions during the summer season. The cage position depends on vertical thermal stratification and makes it possible to ensure cultivation of cool-water salmonid fish during the hot summer in southern seas (Fig. 5). All-year-round cultivation of rainbow trout has been realized in the Caspian and Black Seas for the first time in 1987-1991 (Bugrov, 1992).

The optimal temperature range for rainbow trout farming is about 14 - 18°C (preferred temperature 16,5°C). Until recently it was not possible to obtain a detailed data on the vertical temperature distribution in the Montenegrin zone of the Adriatic Sea, but diving observations with temperature measurements "in situ" have shown 18°C at 22m depth in the summer season (end of September, 2014), while the surface temperature at the same site (St. Nikola island near Budva) was 23°C (Bugrov, personal observations).

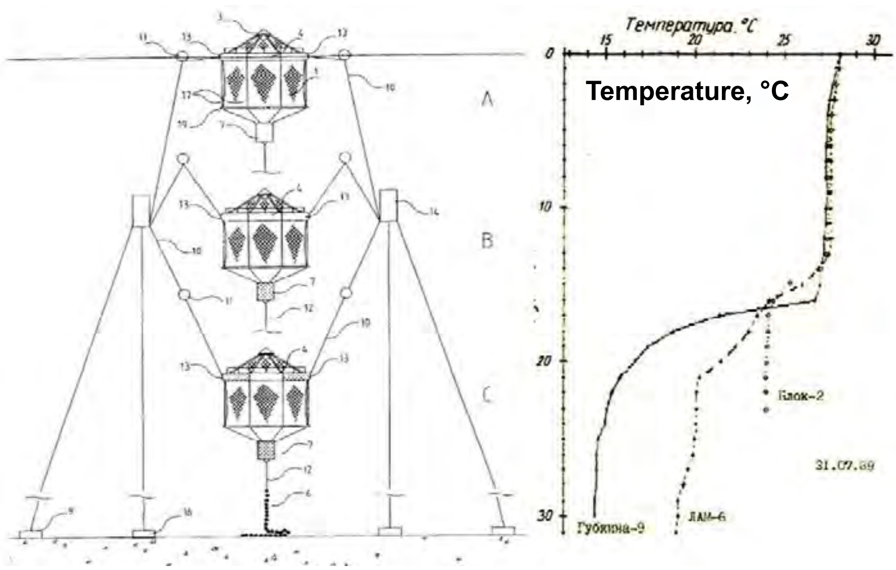


Figure 5. Thermal stratification in the summer season in the Caspian Sea (left) and vertical positioning of submersible cages for trout farming (right)

Another argument for the possibility of trout farming in the open-sea cages is provided by periodical catch of "wild" trout in the Adriatic Sea. Unidentified salmonids, generally named "sea trout", have been spotted occasionally in the north Adriatic Sea, although autochthonous salmonids have not been reported in the Mediterranean Sea. Based on mtDNA and nuclear DNA analysis, it was concluded that Adriatic `sea trout' belongs to the species *Salmo trutta* and is most likely derived from hatchery-reared brown trout populations (Snoj *et al.*, 2002).

CONCLUSIONS

Shallow-water areas, sheltered harbors, and wave- and wind-protected beaches along the coastal line of Montenegro are the most valuable and most expensive sites for tourism and recreation infrastructure development. This environment does not leave convenient sites for a traditional coastal aquaculture based on conventional floating cages. An employment of offshore submersible fish-farming technologies will enable the use of numerous, seemingly unconvenient locations. These locations are also cheaper for renting and allow farmers to avoid well-known conflicts between the aquaculture and environmental tourism.

The primary needs for sustainable aquaculture development in Montenegro include: evaluation of risk factors, consideration and assessment of limiting factors, application of innovative technologies for IMTA and offshore aquaculture, new R&D methods for fish farming in open-water areas with storm hazards, common strategy for aquaculture development with an environmental impact assessment, and spatial maritime planning of prospective sea sites for cage farming in open-water areas. New candidate fish species (native) for sea farming also need to be also studied for biological requirements and economical efficiency

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