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Transforming Sustainable Aquaculture by Applying Circularity Principles

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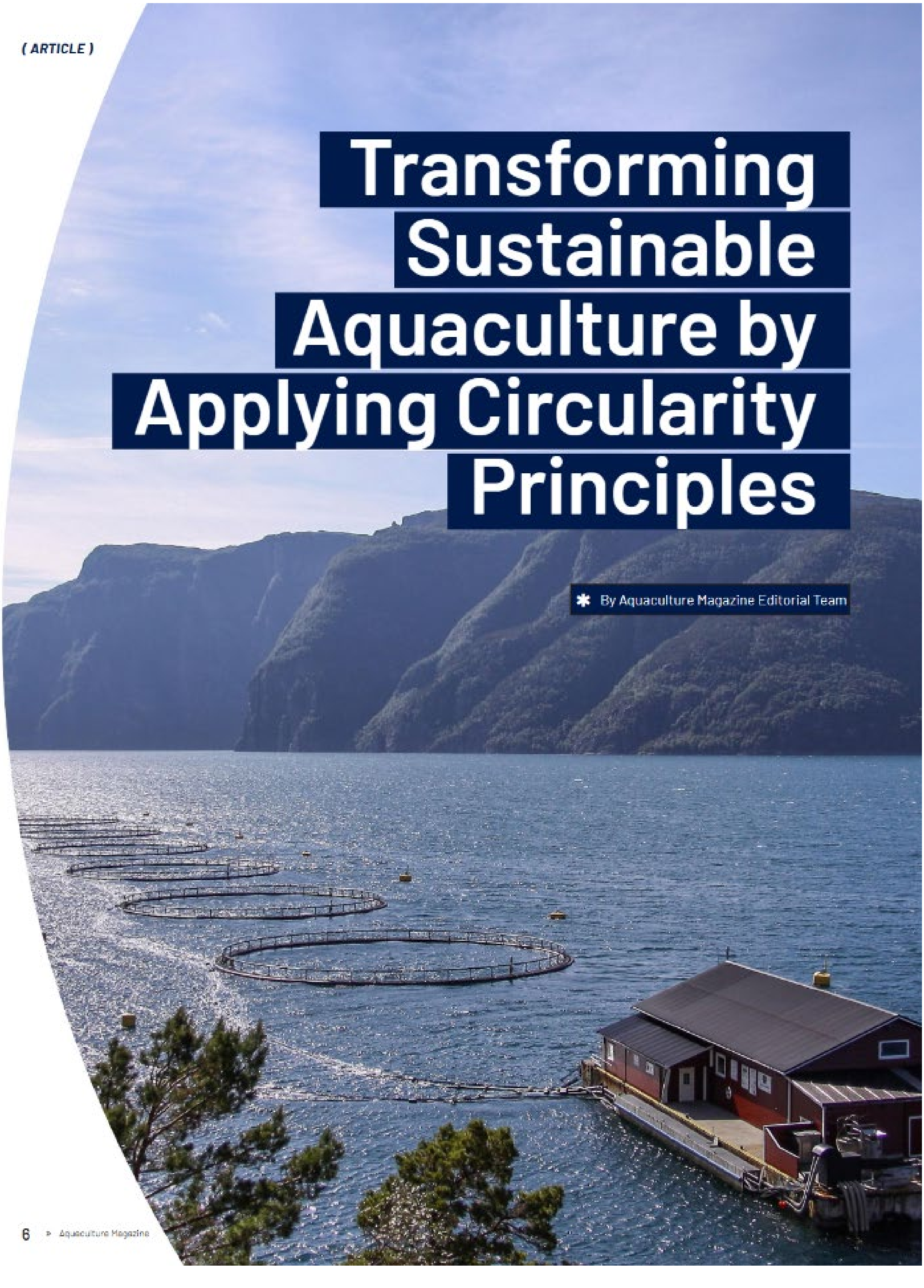


✱ By Aquaculture Magazine Editorial Team

A circular economy offers a promising approach to lessen the environmental impact of human activities through improved resource use and waste reduction. Five ecological principles, applied primarily to land-based food systems, have not yet been fully explored in aquaculture. This study adapts these principles to aquaculture, revealing key opportunities to enhance sustainability.

The environmental impact of global food systems has driven a shift towards a circular economy (CE), which focuses on efficient resource use, waste reduction, and emissions minimization. CE principles, including ecosystem regeneration, waste minimization, biomass prioritization, and renewable energy use, have been explored in agriculture and livestock but are less studied in aquaculture. This study extends Muscat et al.'s CE framework to aquaculture, addressing waste management, nutrient recycling, and feed ingredients. While some aspects of CE in aquaculture have been investigated, a comprehensive review of the framework's application across different aquaculture species and systems is lacking, highlighting the need for further exploration. This review translates Muscat et al.'s principles to aquaculture, examining their implications for species and production systems, and identifies pathways to enhance circularity.

First principle: Safeguarding and Regenerating the Health of Aquatic Ecosystems

The "safeguard" principle in aquaculture focuses on protecting and enhancing the health of aquatic ecosystems by operating within their carrying capacity. This involves using regenerative practices that prevent or reduce ecological damage and improve ecosystem services.

1.1 Production systems and their environmental impacts

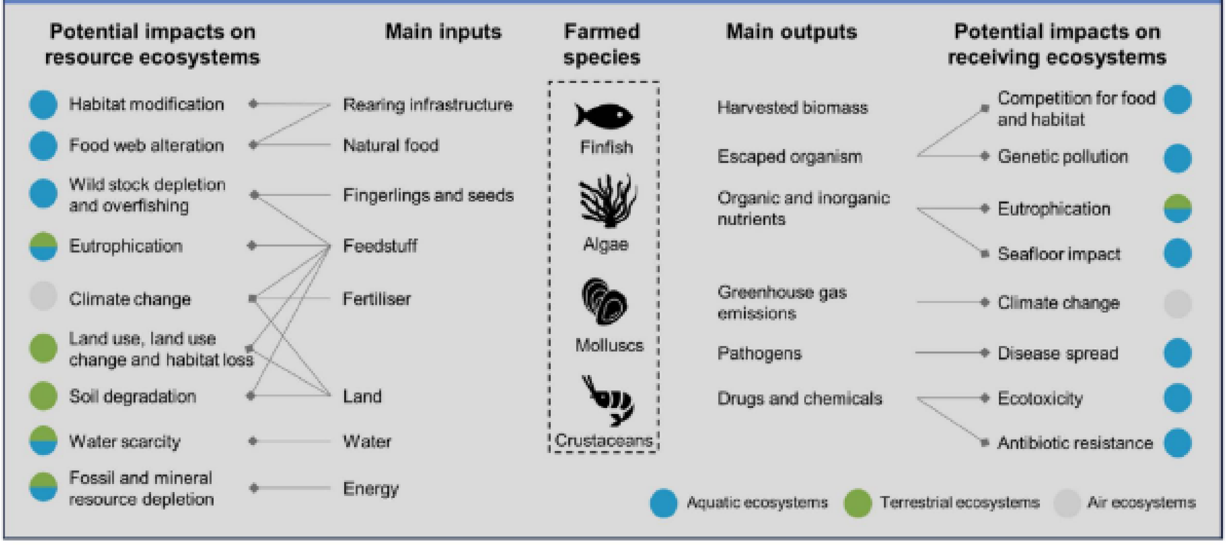
Aquaculture affects both resource ecosystems (inputs) and receiving ecosystems (outputs). The environmental impacts vary based on production systems—fed vs. unfed, intensive vs. extensive. For instance, high-quality feeds in finfish and crustacean farming can stress local and distant ecosystems through nutrient emissions and land use. Plant-based feeds for carnivorous fish further impact terrestrial ecosystems. Freshwater aquaculture increases competition for water resources. To alleviate these pressures, adopting water-efficient systems like recirculating aquaculture systems (RAS) and non-food-competing feeds can help mitigate environmental impacts (Figure 1).

1.2 Carrying capacity and resilience

Ecological carrying capacity is the ecosystem's ability to absorb aquaculture impacts without harm, in-

Figure 1

Main inputs and outputs of aquaculture systems and their potential environmental impacts on resource and receiving ecosystems.



cluding nutrient management and disease control. A broader approach is needed to consider impacts on distant ecosystems and long-term ecosystem services.

1.3 Regenerative practices

Regenerative aquaculture aims to enhance ecosystem services by reducing feed use, avoiding pollutants, and integrating mixed species systems like Integrated Multi-Trophic Aquaculture (IMTA). These practices aim to improve water quality, preserve habitats, and offer new ecosystem services while maintaining existing ones, potentially leading to restorative outcomes and innovative business models.

Second principle: Avoiding Producing Non-Essential Products and Wasting Those That Are Essential

The "avoid" principle emphasizes the need to minimize the extraction of natural resources and environmental impacts by producing only essential products and avoiding waste. This involves assessing the value and necessity of different aquaculture products and addressing waste throughout the value chain.

2.1 Nutritional and health benefits of fresh aquaculture products

Aquaculture primarily produces food that provides essential nutrients such as high-quality protein, omega-3 fatty acids, and bioavailable micronutrients. The nutritional value of these products varies among species and depends on their feed composition. Aquaculture products are particularly important for vulnerable populations in the Global South, where they can significantly impact health, especially during critical periods like the first 1,000 days of life.

2.2 Contribution to food security

Aquaculture's impact on food security should be evaluated by species. Species like carp, tilapia, and bivalves, classified as 'accessible commodities,' are crucial due to their affordability and availability. In contrast, 'luxury commodities' like Atlantic salmon and abalone are less accessible to low-income consumers due to high costs and intensive resource use. While luxury products like Atlantic salmon contribute economically, prioritizing accessible commodities like carp and tilapia is more beneficial for food security and resource efficiency.

2.3 Loss and waste in aquaculture value chains

Reducing loss and waste in aquaculture is critical for ensuring nutrition security. Aquatic food chains experience significant losses, with estimates ranging from 29% to 50%, higher than for terrestrial products. Effective strategies to minimize these losses, tailored to specific regional contexts, are essential for enhancing the overall efficiency and impact of aquaculture systems.

Third Principle: Prioritizing Biomass Streams for Basic Human Needs

The third principle emphasizes prioritizing the use of biomass and resources to meet basic human needs, avoiding feed-food competition. This involves using resources like arable land to produce human food rather than feed, and using non-food competing feedstuffs, such as byproducts from human food systems.

3.1 Efficiency of using land, fresh water, and feed at the product level

Optimizing land, water, and feed use involves directing resources to the most efficient food production systems. While aquaculture generally has lower land use compared to terrestrial animal farming, resource efficiency varies by species and system. Extractive species like seaweeds and bivalves are more resource-efficient than fed aquaculture species. Using byproducts from food systems as feed can further reduce land use. Aquaculture's feed-use efficiency, particularly in fish, often surpasses that of terrestrial animals due to their poikilothermic metabolism and buoyancy.

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3.2 Feed-food competition

Feed-food competition arises when food-grade ingredients are used in aquafeeds. Direct competition occurs when ingredients like fishmeal and soy are used in feeds. Although some of these ingredients could be used for human food, most are not. Indirect competition includes using arable land for feed crops instead of food crops. Reducing feed-food competition involves utilizing non-food competing feedstuffs, such as food waste and byproducts (Figure 2 and Figure 3). Balancing species production and increasing human-edible yields can also minimize competition and enhance overall resource efficiency.

Fourth Principle: Using and Recycling Byproducts of Agro and Aquatic Ecosystems

The "recycle" principle emphasizes the safe recycling of nutrients and carbon from byproducts into bio-based systems, ensuring environmental safety.

Figure 2

Novel and conventional protein sources used in aquafeed and examples of species that can use them best depending on their effective trophic level and the carbohydrate (orange) and crude protein contents (blue) of the ingredients. According to circularity principles, human food has the highest priority for all novel and conventional human-edible feedstuffs.

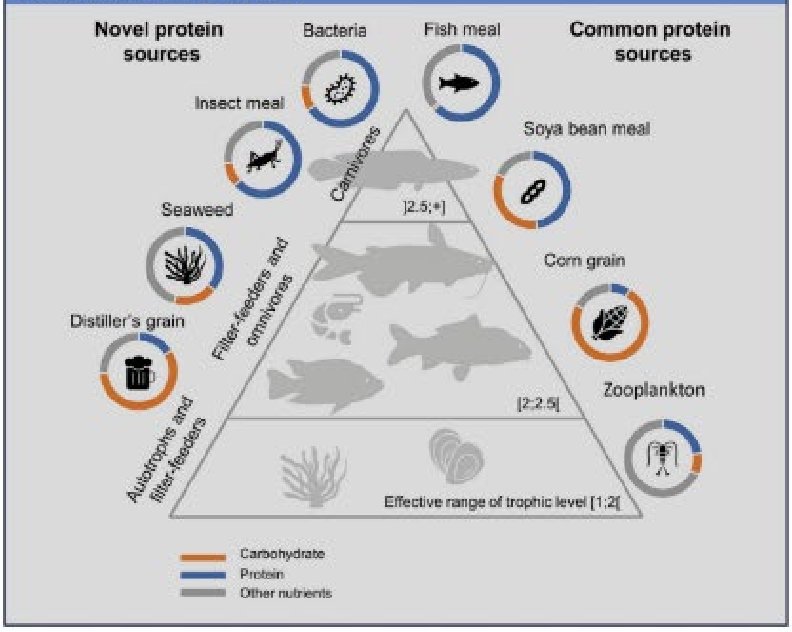
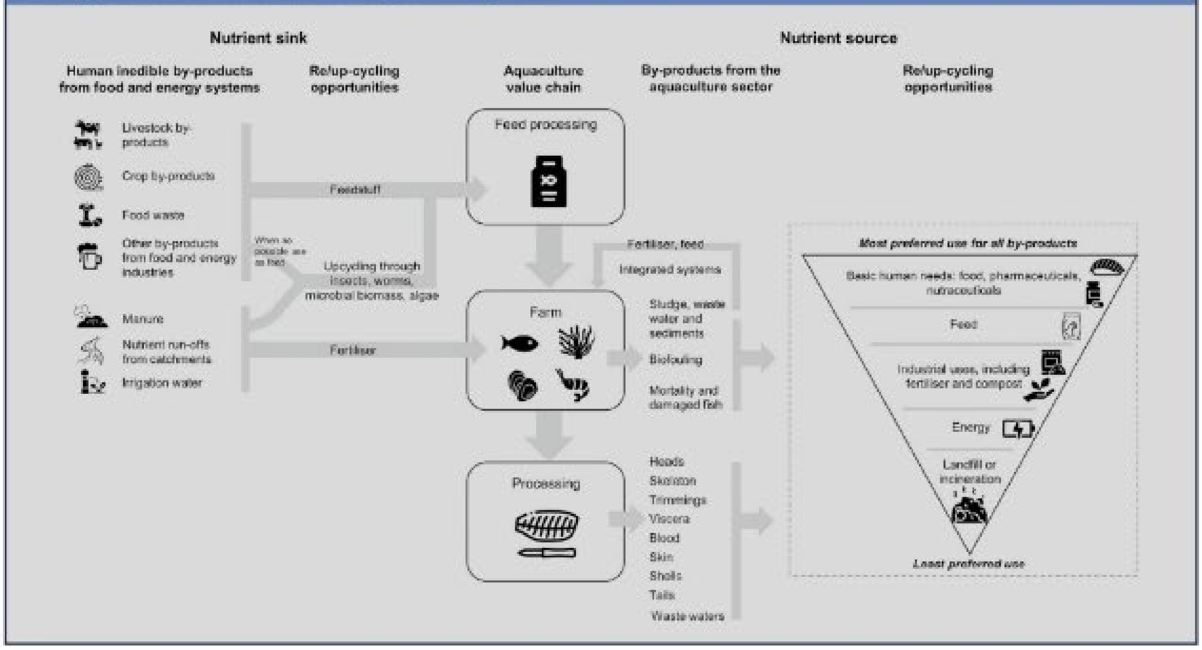


Figure 3

Recycling opportunities in the aquaculture value chain for food-system byproducts and in other sectors for aquaculture byproducts. A hierarchy of biomass recovery should be followed when recycling food-system byproducts in the aquaculture value chain (left side of the figure) and when recycling aquaculture byproducts (right side of the figure) to avoid food-grade ingredients ending up as feedstuff or fertilizer for aquaculture systems.



Regenerative aquaculture aims to enhance ecosystem services by reducing feed use, avoiding pollutants, and integrating mixed species systems like Integrated Multi-Trophic Aquaculture (IMTA).

4.1 Nutrient waste from aquaculture and opportunities to recycle it

Aquaculture generates nutrient-rich byproducts, including metabolic waste, uneaten feed, mortality, and biofouling. Uneaten feed often constitutes a significant portion of waste, with up to 6% of distributed feed remaining uneaten in well-managed systems. Advances in animal nutrition and management practices have reduced metabolic waste, but zero-waste systems are not yet achievable. Waste collection and recycling depend on the system; for example, freshwater ponds and RAS can utilize waste for fertilization or biogas production, though logistical challenges exist. Marine systems face difficulties in recycling due to salt content, and pond sediment recycling is limited by labor intensity and low profitability.

4.2 Recycling waste in Integrated Aquaculture Systems

Integrated Multi-Trophic Aquaculture (IMTA) and other circular systems recycle waste across various farming technologies. IMTA systems, theoretically adaptable to various environments, face barriers such as economic constraints, complexity, and lack of support. Integrated aquaculture can also involve interactions with terrestrial and urban systems, recycling nutrients from livestock and human waste. Although promising, large-scale studies are needed to fully assess the effectiveness and commercial viability of these systems.

Fifth Principle: Using Renewable Energy While Minimizing Overall Energy Use

The 'entropy' principle advocates for reducing overall energy demand, prioritizing renewable energy sources, and enhancing energy efficiency in aquaculture systems.

5.1 Hotspots of energy use

Energy analysis methods like Life Cycle Assessment (LCA) and emergy accounting reveal that feed production, on-farm operations, and juvenile production are major energy consumers

in aquaculture. Feed production is particularly energy-intensive due to the processing and transportation of raw ingredients. On-farm operations, including aeration, recirculation, and temperature control, also contribute significantly to energy use, especially in Recirculating Aquaculture Systems (RAS). Post-harvest processes, such as transport, further add to energy consumption.

5.2 Production system, species, and key drivers of energy efficiency

Energy use varies by aquaculture system: intensive systems like RAS and aquaponics use more energy than cage or extractive systems. Species also impact energy efficiency; carnivorous species typically require more energy than extractive ones. Additionally, the energy needed to maintain suitable water temperatures in different climates affects energy use. Transitioning to renewable energy sources and improving energy efficiency, such as through industrial symbiosis or on-farm renewable energy, are crucial for reducing the environmental footprint and managing energy costs in aquaculture.

Recommendations for More Circularity

Species Selection: Emphasize aquaculture of essential, resource-efficient species over luxury species. Nutrition-sensitive species, which support vulnerable populations, are more beneficial for global food security than luxury species that primarily serve wealthier markets. Shifting towards species with lower environmental footprints, like bivalves and carp, is advocated.

Feed Management: Address feed-food competition by reducing the use of food-competing feedstuffs. This shift could increase global food supply and reduce environmental impacts, though it may also decrease the scale of fed aquaculture.

Policy and Market Adjustments: Develop policies to promote the production of essential species and improve market conditions for omnivorous species. Support nutrient recycling and better waste management to enhance circularity in aquaculture systems.

Consumer Education: Improve consumer awareness about the benefits of low-trophic-level species and sustainable aquaculture practices.

Research Needs: Address gaps in understanding ecosystem resilience, food loss, and efficiency of feed conversion in aquaculture to support the transition to more circular practices.

Overall, implementing these recommendations can enhance sustainability and efficiency in aquaculture, benefiting both the environment and food security. aqm

This is a summarized version developed by the editorial team of Aquaculture Magazine based on the review article titled *"TRANSFORMING SUSTAINABLE AQUACULTURE BY APPLYING CIRCULARITY PRINCIPLES"* developed by: *KILLIAN CHARY, K, VAN RIEL, K and MUSCAT, A – Wageningen University & Research; WILFART, A. and HARCHAOUI, S. – Institut Agro, Rennes; VERDEGEM, M. – Wageningen University & Research; FILGUEIRA, R. – Dalhousie University, Institute of Marine Research, Bergen.* The original article was published, including tables and figures, on *SEPTEMBER, 2023*, through REVIEWS IN AQUACULTURE. The full version can be accessed online through this DOI: 10.1111/raq.12860