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Ecosystem services from aquaculture: Valuing the hidden benefits of aquatic farming systems

A.K. Prusty*, Poonam Kashyap and N. Ravisankar

ICAR-Indian Institute of Farming Systems Research, Modipuram, Meerut, Uttar Pradesh 250 110

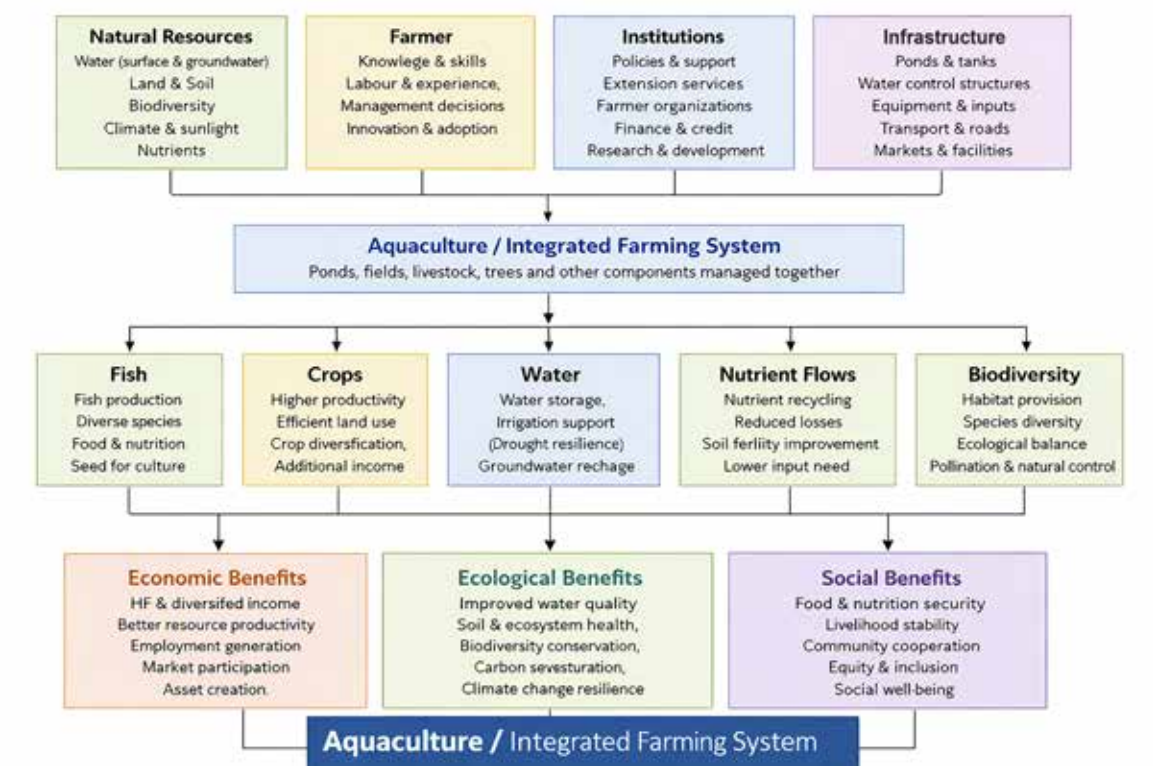
Aquaculture is generally evaluated in terms of fish production, farm income, employment and input output efficiency. However, ponds, wetlands, rice-fish systems and other aquaculture-based farming systems also interact with soil, water, biodiversity, farmers, institutions and rural infrastructure, generating a much wider range of benefits. These include nutrient recycling, water storage, flood regulation, carbon sequestration, habitat provision, livelihood diversification, knowledge generation and cultural values. Such benefits are often poorly reflected in conventional farm accounting because many of them are not traded in markets. A four-capital perspective comprising natural, human, social and produced capital provides a useful way of organising these interlinked contributions. In this approach, the capitals are considered as the underlying stocks, while ecosystem services and farm products represent flows arising from their interaction. The article discusses the major ecosystem services associated with aquaculture-based farming systems and describes practical methods for their biophysical and economic valuation. An evaluation matrix is proposed for Indian aquaculture and integrated farming systems to support more comprehensive assessment of their economic, ecological and social contributions.

Keywords: Container farming, Economic analysis, Frontline demonstration, Lucrative venture, Sustainability

AQUACULTURE is a rapidly growing source of fish, food, employment and rural income. However, its contribution extends beyond fish production. Ponds, wetlands, rice-fish systems and integrated farms interact with water, soil, nutrients, biodiversity, labour and local institutions, generating a range of provisioning, regulating, supporting and cultural services. This broader role is particularly relevant in Indian farming, where aquaculture is often integrated with crops and livestock. Farm ponds can store water and support irrigation, rice-fish systems improve resource use, and pond sediments and organic residues contribute to nutrient recycling. Wetland-based systems can additionally support flood regulation, carbon storage and biodiversity. Many of these benefits, however, have no direct market price and therefore remain largely invisible in conventional farm economics. Assessment of aquaculture consequently needs to consider not only its marketed outputs but also the ecological, human, social and physical resources that support production and generate wider benefits. A four-capital perspective of natural, human, social and produced capital provides a useful framework for understanding these interconnections and assessing the ecosystem services and well-being generated by aquaculture-based farming systems.

Aquaculture as a multifunctional farming system

The conventional assessment of an aquaculture farm normally focuses on stocking density, feed, survival, fish yield, production costs, gross returns and net returns. These indicators remain essential for farm management, but they become incomplete when aquaculture is part of a larger farming landscape. A pond may retain runoff, reduce nutrient and sediment movement, and provide water for irrigation or livestock. Aquatic organisms can convert nutrients into biomass, while pond vegetation can provide habitat, reduce erosion and contribute to carbon storage. At the same time, aquaculture can enhance farmers' knowledge and skills and strengthen access to markets, inputs and technical information through collective action. These interactions show that aquaculture functions as an integrated ecological and socio-economic system, rather than simply as a fish-production unit. In India, systems such as *Pokkali* and *Kaipad* demonstrate how aquatic farming can simultaneously provide food and income while supporting wider ecological functions. Therefore, ecosystem-service assessment should complement rather than replace conventional aquaculture economics, extending farm accounts to recognise important



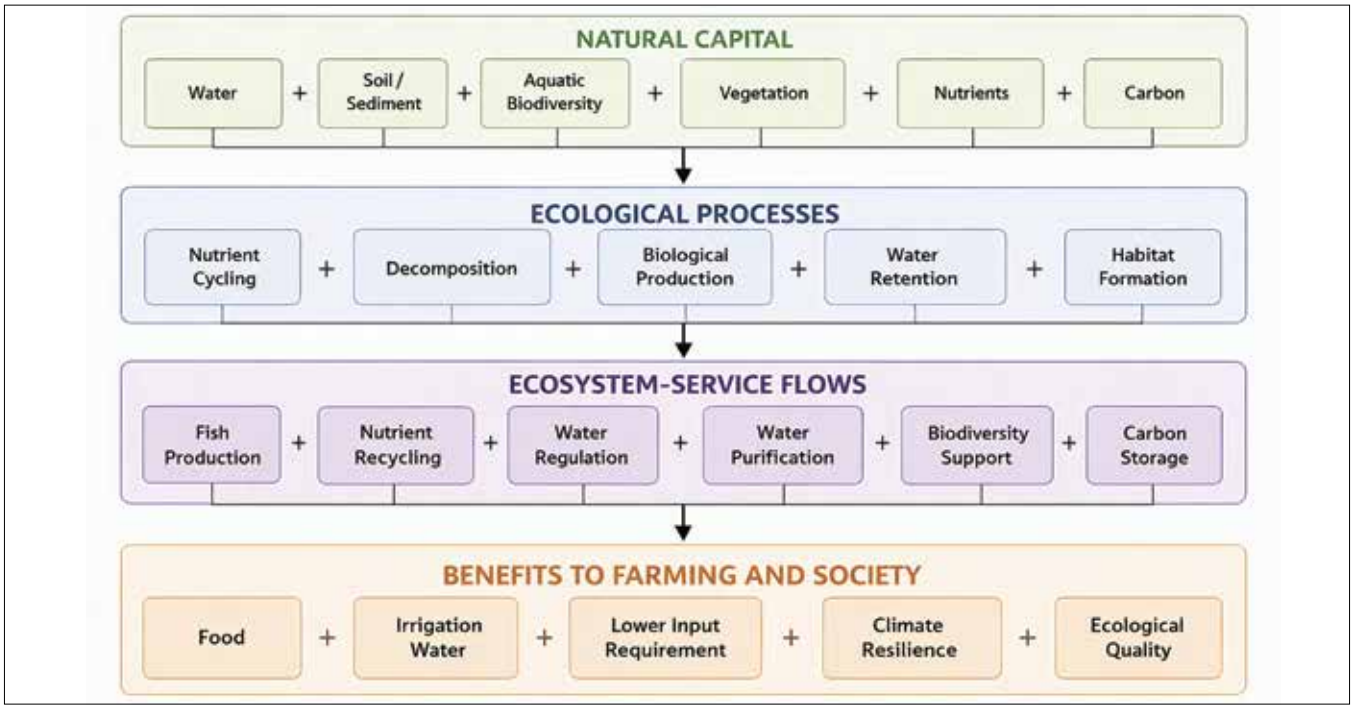
Aquaculture as a multifunctional farming system

ecological and social benefits and costs that are not reflected in market transactions.

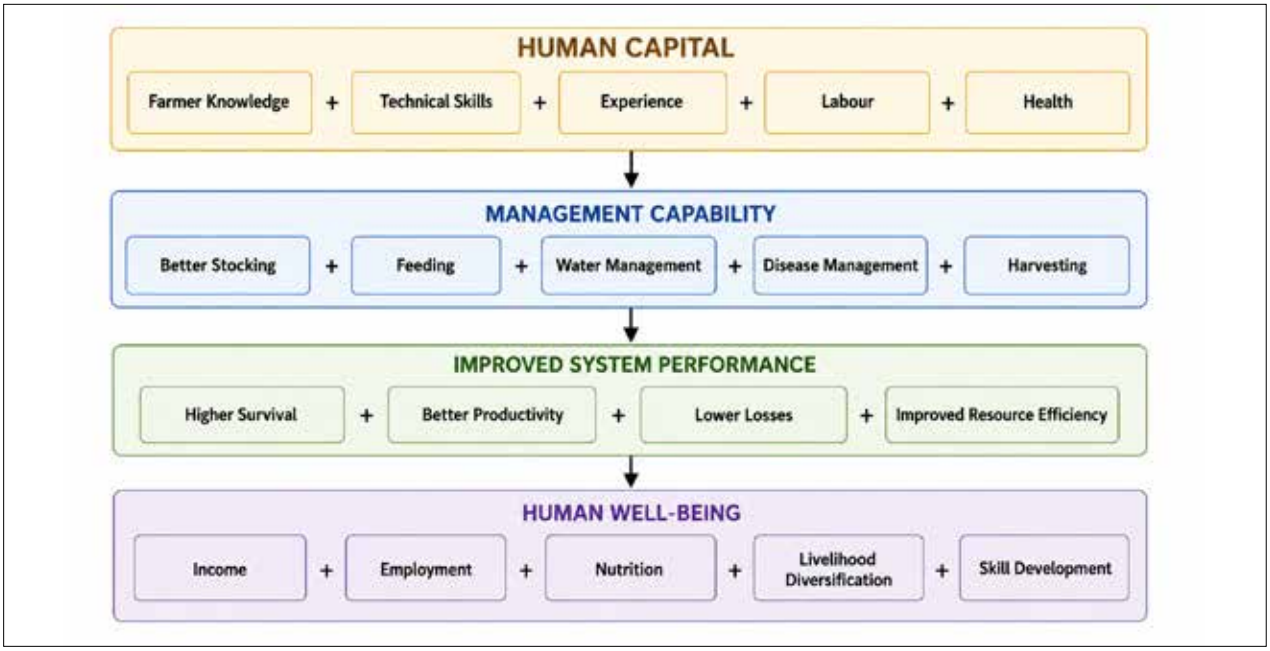
Four capitals approach

The four capitals can be considered the foundation from which the different functions and benefits of an aquaculture-based farming system arise. They are strongly interdependent. A healthy pond ecosystem may increase fish production; farmer knowledge may improve management of the pond; social institutions may facilitate collective water management; and physical infrastructure may make it possible to harvest, store and market fish.

***Natural capital*:** Natural capital represents the ecological foundation of the aquaculture system. In a farm pond or integrated aquaculture system, it includes water, soil and sediment, aquatic organisms, microorganisms, vegetation, biodiversity, nutrients, stored carbon and the ecological processes through which these components interact. The natural capital



Natural Capital conceptual flow pathway in aquaculture

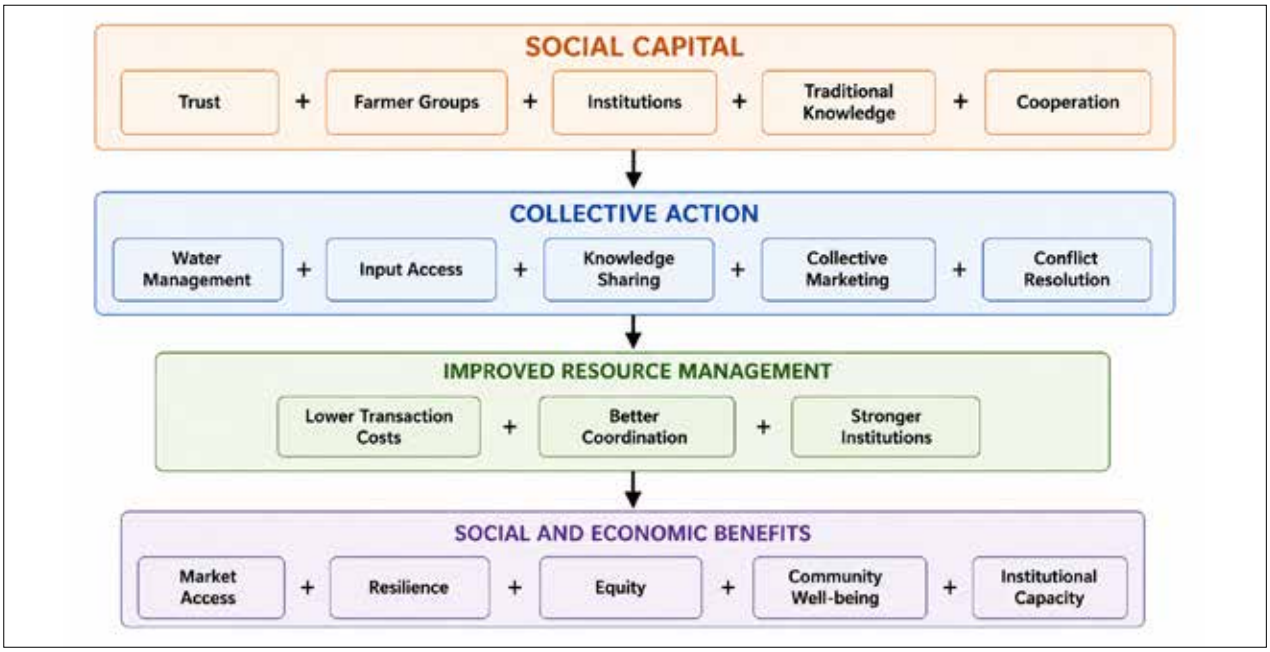


Human capital conceptual flow pathway in aquaculture

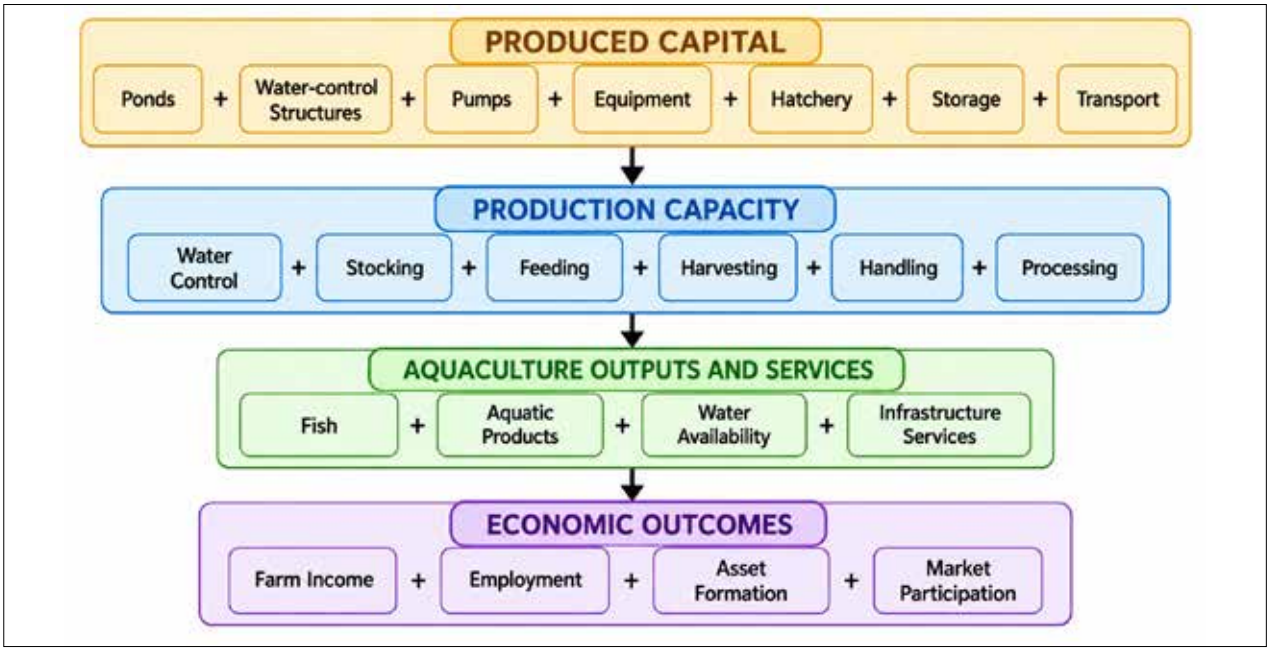
component is particularly important because the condition of the ecological resource determines the capacity of the system to continue supplying services. If water quality deteriorates, biodiversity declines or excessive nutrient loading occurs, the natural-capital base can decline even when short-term fish production remains high. Aquaculture provides broad range of services associated with pond fish farming and those perceptions differed among farmers, institutional stakeholders, pond users and local residents. Regulating and supporting services were particularly important to several stakeholder groups.

Human capital: Human capital refers to the knowledge, skills, health, labour capacity and experience of people participating in the farming system. Aquaculture depends substantially on farmer capability because stocking, feeding, water-quality management, disease prevention, harvesting and marketing require knowledge and timely decisions. Human capital can therefore be assessed through indicators such as labour generated, training, technical knowledge, adoption of improved practices, managerial capability, employment continuity and nutritional contribution.

The value of human capital should not be confused with the wage paid for farm labour alone. Skills acquired through aquaculture may improve the farmer's future earning capacity and ability to manage other enterprises. In this sense, aquaculture can generate a longer-term livelihood asset in addition to current income.



Social capital conceptual flow pathway in aquaculture



Produced capital conceptual flow pathway in aquaculture

Social capital: Social capital represents the relationships, institutions, norms, trust, cooperation and collective arrangements that allow people to manage resources and undertake economic activities. It becomes particularly important where ponds, irrigation structures, wetlands or water resources are collectively managed. Community institutions can determine who has access to water, who participates in management, how maintenance is financed and how benefits are distributed. Social capital also facilitates knowledge sharing, collective decision-making, access to inputs and markets, conflict resolution and coordinated resource management. Strong social networks can reduce transaction costs and improve the capacity of farmers to respond collectively to production risks, environmental changes and market fluctuations. For Indian integrated farming systems, social-capital assessment may therefore include farmer-group participation, collective management arrangements, access to extension and markets, knowledge exchange, institutional support and community participation. These factors can strengthen resource-use efficiency, improve livelihood resilience and enhance the capacity of farming communities to sustain ecosystem services over time.

Produced capital: Produced capital consists of human-made assets that support aquaculture and associated farming activities. These include ponds, embankments, channels, pumps, aerators, hatcheries, nets, storage facilities, roads, transport equipment, processing infrastructure and other physical assets. Produced capital also interacts with natural capital. A properly designed pond can increase water storage and provide habitat, while embankments and drainage structures can influence water movement. Consequently, the value of the physical infrastructure should be assessed together with the ecological functions it enables.

Ecosystem services emerging from the four capitals

The four capitals should not be interpreted as four separate categories of ecosystem services. Rather, they represent stocks that interact to generate multiple flows and outcomes. This distinction is important for avoiding conceptual and monetary double counting. For example, a pond's natural capital may provide habitat and nutrient-cycling capacity; farmer knowledge may determine whether those functions are maintained; social institutions may govern water access; and produced infrastructure may determine the pond's ability to retain water. The resulting ecosystem services may include fish production, water regulation, nutrient recycling, biodiversity support and flood mitigation. In this way, the same aquaculture system can generate several classes of services.

- ***Provisioning services*** include fish, shellfish, aquatic plants, seed material, water and useful biomass.
- ***Regulating services*** include water regulation, flood moderation, nutrient retention, water-quality improvement, erosion control and carbon sequestration.
- ***Supporting or maintenance services*** include nutrient cycling, primary production, habitat formation and maintenance of biological diversity.
- ***Cultural services*** include recreation, landscape amenity, environmental education, traditional knowledge and cultural heritage.

These categories should be interpreted according to the characteristics of the individual farming system. Not every aquaculture system will generate every service, and some systems can simultaneously produce ecosystem disservices, such as nutrient pollution, excessive water consumption, habitat alteration or greenhouse gas emissions.

Table 1. Evaluation matrix for ecosystem services and the four capitals in aquaculture-based farming systems

Capital/service dimension	aquaculture-based farming	Possible indicators	Appropriate valuation approach
Natural capital	Water, soil, biodiversity, nutrient stocks, carbon, habitat	Water storage, water quality, soil organic C, biodiversity, nutrient retention, carbon stock	Market price, production function, avoided cost, replacement cost, benefit transfer
Provisioning services	Fish, shrimp, shellfish, aquatic plants, water, biomass	Production, quantity harvested, water supplied	Market price, net-factor income
Regulating services	Flood moderation, water purification, erosion control, nutrient retention, carbon sequestration	Water retained, nutrients removed, sediment retained, CO_2-equivalent stored	Avoided damage, replacement cost, production function, carbon valuation
Human capital	Skills, knowledge, labour, health and nutrition	Training, labour days, skill acquisition, employment, nutritional contribution	Wage/factor-income approach, productivity approach, cost-based indicators
Social capital	Cooperation, farmer groups, institutions, traditional knowledge	Group participation, collective action, market linkages, institutional performance	Participatory valuation, contingent valuation, choice experiment, social indicators
Produced capital	Ponds, embankments, pumps, hatcheries, equipment, storage	Asset value, infrastructure capacity, investment, depreciation	Market value, replacement cost, investment appraisal
Cultural services	Recreation, landscape, heritage, education	Visitors, recreational use, cultural participation, WTP	Travel cost, contingent valuation, choice experiment
Cross-capital outcomes	Livelihood resilience, food security, climate adaptation	Income stability, dietary diversity, risk reduction, resilience indicators	Cost–benefit analysis, multi-criteria assessment, stated preference

Evaluation and valuation of ecosystem services

The economic value of an ecosystem service is not necessarily the same as the market price of the aquaculture product. Fish has a market price because it is traded, whereas flood regulation or biodiversity conservation may have no direct market. Consequently, valuation should normally proceed in two stages. First, the biophysical quantity of the service should be estimated, and then an appropriate economic or social valuation method should be selected.

The choice of method should depend on the service, data availability, scale and purpose of the assessment. Global review of ecosystem service valuation suggest that provisioning services are most commonly valued using direct market pricing, whereas regulating services frequently require avoided cost or replacement cost approaches while cultural services may require travel cost or other non-market approaches.

The choice of valuation method should correspond to the type of ecosystem service being assessed. Market-based approaches are suitable for marketed provisioning services such as fish and other aquatic products, while production-function, replacement cost and avoided damage approaches can be applied to regulating and supporting services. Travel cost, contingent-valuation and choice-experiment methods are useful for recreational, cultural and other non-market benefits. Thus, benefit transfer is best used as a supporting approach within a broader ecosystem service valuation framework rather than as a substitute for site-specific assessment.

From valuation to better farm and policy decisions

The principal value of ecosystem service assessment is not simply to arrive at a single monetary estimate, but to make visible the benefits and costs that remain outside conventional farm accounting. For example, two ponds may produce similar fish yields but differ substantially in their overall contribution to the farming system. One may depend heavily on purchased feed and external inputs, discharge nutrients and provide limited habitat, whereas another may recycle nutrients, retain runoff, support biodiversity, provide irrigation water and contribute to flood protection. Although conventional gross-return analysis may consider these systems broadly similar, a broader assessment can reveal important differences in their natural, human, social and produced capital and the services generated from them.

This wider perspective is particularly relevant to integrated farming systems, where aquaculture can convert underused nutrients and biomass into marketable food while supporting crop and livestock enterprises. Consequently, the value of an aquaculture-based system cannot always be represented by fish sales alone. Similarly, ecosystem services may extend beyond the farm and benefit the wider community without generating a corresponding financial return to the farmer. Recognising these benefits can help inform conservation-oriented management, ecosystem-service incentives and targeted public investment. At the same time, monetary valuation should be supported by sound ecological measurement, as monetary estimates may create a false sense of precision when underlying biophysical information is weak. A robust assessment should therefore combine biophysical indicators, monetary valuation and qualitative or social indicators to provide a more complete picture of the contribution of aquaculture-based farming systems.

Challenges in ecosystem service valuation

- The same ecosystem process may support more than one service, creating a risk of double counting. Nutrient cycling, for example, should not be valued

independently if its contribution is already included in the increased crop or fish production attributed to it.

- Many services occur outside the farm boundary. Flood regulation, biodiversity conservation and water-quality benefits may be received by neighbouring farms or downstream communities. Consequently, the spatial scale of valuation is important.
- Ecosystem service values vary with ecological condition, local prices, household income, population density and institutional arrangements. Values obtained from another region should therefore be transferred cautiously.
- Not all values should be monetised. Cultural identity, traditional knowledge, community cohesion and biodiversity may be better represented by quantitative or qualitative indicators rather than forcing them into monetary terms. The wider evaluation literature recognises the importance of combining monetary and non-monetary approaches when assessing complex food systems.

SUMMARY

Aquaculture-based farming systems produce far more than fish. Their interactions with water, soil, biodiversity, farmers, institutions and infrastructure generate diverse ecosystem services, including food, income, nutrient recycling, water regulation, biodiversity support, climate resilience and social benefits. A four-capital perspective helps organise these relationships. Natural capital provides the ecological base; human capital contributes knowledge and skills; social capital enables cooperation and institutions; and produced capital provides infrastructure and productive assets. Their interaction generates products and ecosystem services that contribute to human well-being. For Indian aquaculture, ecosystem service assessment should complement conventional measures of fish yield and profitability. Market prices, production function, avoided damage, replacement cost and suitable non-market valuation methods can help capture these wider benefits.

*Corresponding author email: aasiana143@gmail.com

