

Is water productivity relevant in fisheries and aquaculture?

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Abstract

We present a critical analysis of the application of the water productivity concept in fisheries and aquaculture, defining the scope of application of the concept and limitations. A revised framework is presented and potential issues raised, highlighting areas for further research. A pluralistic approach including socialecological assessments and the explicit consideration of trade-offs between the objectives of increased food production, ecosystem conservation and poverty alleviation is proposed. This may set the scene for further developments of the water productivity concept beyond fisheries and aquaculture.

Media grab

Water productivity can essentially be applied when water is a limiting factor to aquatic resource production and in confined water bodies. Beyond these conditions, the concept must be further developed to fully reflect the social and ecological dimensions of fisheries and aquaculture.

Introduction

The identification of issues raised by the concept of water productivity in fisheries and aquaculture will help define the scope and limitations of its application. Issues range from the assessment of both fisheries output (or value) and quantities of water used, analysis across spatial and temporal scales, and the multiple objectives assigned to increased water productivity.

The multiple benefits of fisheries and aquaculture and the multiple functions of water

Water productivity is defined by the Comprehensive Assessment of Water Management in Agriculture as 'the ratio of the net benefits from crop, forestry, fishery, livestock, and mixed agricultural systems to the amount of water required to produce those benefits' (CAWMA, 2007; Molden et al., 2007). Benefits from fisheries and aquaculture include the production of food, livelihood improvement, nutrition and health (<http://www.fao.org/focus/e/fisheries/nutr.htm>, Dugan et al., 2007), and the contribution of fisheries to ecosystem resilience. A wide range of fish and crustaceans of very different nutritional value and with different ecosystem requirements is thus included.

Assessment of fisheries value has proved difficult because the valuation of ecosystem nonprovisioning services (e.g. MEA, 2005) and sociocultural benefits of fisheries have received insufficient attention. Fisheries plays a variety of roles in rural livelihoods, ranging from a specialist occupation for wealth accumulation to a safety net for the poor (Smith et al., 2005). Access, property rights, and control over common aquatic resources are of fundamental importance especially to the landless poor and to women. Thus in some situations (e.g. crop production failure) modest production of aquatic resources by vulnerable communities may have disproportionate social benefits to livelihoods.

The definition of the water unit also presents difficulties. In fisheries and aquaculture, water plays roles as a supportive medium, as a habitat providing food, and shelter and as a medium to facilitate migration with many species needing to move between spawning, nursery, and feeding areas within a river basin (Lorenzen et al., 2007). Aquatic habitats and the ecological services they provide result from specific geomorphological and hydrological conditions.

Water requirements for fisheries and aquaculture are both qualitative and quantitative in nature. Direct consumption for the accumulation of aquatic resources biomass is negligible and water requirements are therefore essentially nonconsumptive. Water may, however, be consumed indirectly in the production of aquaculture seed or via percolation, seepage, and evaporation from ponds or reservoirs. Water requirements are characteristically highly dynamic (e.g. seasonality and timing of river flow), especially in tropical floodplains.

Issue of scale: from local to river basin, from rapid change to long-term trend

The benefits (output, value) delivered by fisheries and aquaculture depend on social and ecological factors that occur at different spatial (local-regional) and temporal (short-term—long-term) scales. The challenge is to derive measurable and verifiable indicators of the social-ecological processes underlying the delivery of benefits, and to identify where and when water becomes a critical determinant of these processes.

The following indicates important water-related issues at different spatial and temporal scales. Important issues related to spatial scales are as follows:

- Local aquatic resource biodiversity and ecological integrity are strongly influenced by ecoregional factors occurring at the scale of one or several river basins.

- While individual species may be sensitive to subtle changes in water resource availability and quality, communities may be highly resilient thanks to compensatory mechanisms (e.g. change in species composition to compensate for the reduction of one species).
- To complete their life cycle, migratory species require connectivity between aquatic habitats within watersheds.
- The socioeconomic benefits of fisheries and aquaculture may be distributed across the ecosystem, for example the 'winners' benefiting from increased production in an irrigation reservoir vs. the 'losers' in the impacted delta downstream of the dam.
- National policies that encourage increased water productivity may conflict with existing local governance (e.g. customary rights).

Important issues related to temporal scales are as follows:

- Different species or life-stages have different water resource requirements, for example migrant vs. resident species, daily feeding vs. seasonal spawning.
- Annual and inter-annual variations of water availability are crucial in the assessment of water productivity. When water becomes scarce, temporarily or long-term, its value often changes dramatically, and fisheries and aquaculture water requirements may conflict with other users (agriculture, livestock, domestic use).
- Fisheries production can vary greatly with water fluctuations. For example, excessive drawdown of reservoir water levels may deplete fish stocks, taking years to rebuild.
- Long-term changes in ecosystems value need to be accounted for (e.g. through discounting factors of economic assessments) because degraded ecosystems are likely to have less capacity to produce and sustain aquatic resource production.
- Livelihoods change at different rates. For example irrigation development may decrease the importance of fishing in livelihood strategies, whilst the cultural importance of fishing may persist despite developmental change.

Therefore rather than a diagnostic assessment, a dynamic analysis of fisheries and aquaculture at different spatial scales is required.

The multiple objectives of increased water productivity

The objectives of increased water productivity are increased food production, poverty alleviation, and ecosystem conservation (CAWMA, 2007). Although linked, the objectives are not always congruent. The concept of water productivity reflects the objective of food production, but is poorer at capturing the water-related issues of ecosystem conservation and poverty alleviation.

The concept also does not sufficiently capture inherent trade-offs between different uses of water. Increased food production may be at the expense of other ecosystem services, e.g. water for aquaculture versus water used to sustain capture fisheries; environmental flows versus reservoir fisheries. In turn, losses to a crop may be a gain for ecosystems, e.g. seepage from irrigation canals feeds groundwater. Where access or property rights are not considered, increased water productivity may adversely affect the poor. For example, auctioned village ponds in India have generally increased the water productivity through aquaculture while limiting access of poor villagers through the introduction of barriers to entry or the creation of incentives for wealthier people to compete for water and fish resources.

Last, who determines the objectives? Increasing water productivity worldwide needs the contribution of local stakeholders. The objectives promoted at international levels primarily by policymakers and scientists do not necessarily translate well at the local level and stakeholders have little incentive to contribute to the objective (see CAWMA, 2007).

Scope for application

Our recommendation is to limit applications of water productivity in fisheries and aquaculture, as currently defined, to the following conditions:

- Diagnostic assessment.
- At the use level essentially.
- For managed and controlled production systems in confined water bodies.
- Where water is a limiting factor to aquatic resources production, such as seasonal or durable water scarcity.

Care must also be taken in applying the concept. Because ecosystem services and sociocultural values are not adequately represented implications must be carefully considered.

Revising the water productivity framework

Given the limitations of the current concept, we propose revising the water productivity framework proposed by Molden (1997) and adapted by Peden et al. (2007) for application to livestock. We first elaborate the concept at the use level; at the service and river basin levels, we incorporate these uses into a multiple use and user framework (Figure 1).

Use level

At the use level, we base fisheries and aquaculture water productivity on the livestock water productivity framework and modify the latter to provide a standardized and integrated methodology. Peden et al. (2007) define livestock water productivity as 'the ratio of net beneficial livestock-related products and services to the water depleted in producing them.' This acknowledges the importance of competing uses of water but focuses on livestock-water interaction (Peden et al., 2007). Fisheries water productivity cannot be defined in the same way because hardly any water is depleted in fish production (process depletion), and the ratio of fish production to water depleted in production becomes exceedingly high.

There are also important differences in focus between the definition as applied to livestock and fisheries. Water and fish are part of the same system, and their 'interactions' have been well-studied (Kolding and van Zwieten, 2006). Fisheries and aquaculture water productivity can be expressed as 'the ratio of net beneficial fish-related products and services to the volume of water in which they are produced.' The volume of water is analogous to a unit of land on which, say, crops are produced. The area of land, unless flooded, does not reduce, but crop productivity can change as land properties change. Similarly, water productivity of fisheries is directly related to surface water inflow, water quality, and water conserving strategies. Competing uses of water and their impacts on water inflow and quality are much more critical in applying the concept to fisheries.

Water productivity of aquaculture can be increased through system design, good management—appropriate stocking densities, good water quality, disease control—and enhancement of productivity. Strategies include stocking good strains of fish, enhancing natural food production, and using supplementary or nutritionally complete formulated feeds. Peden et al. (2007) state that the production of livestock feeds is one of the world's largest uses of agricultural water. They argue that use of crop residues and by-products provides a unique opportunity to improve crop water productivity, because they are potential feed sources requiring no additional evapotranspiration. Similar strategies can be important in aquaculture water productivity.

The bulk of global aquaculture production is of omnivores or herbivores, reliant on natural food or supplementary, plant-based diets. The culture of aquatic animals from higher up the food web, such as trout, is more reliant on fishmeal of marine origin, although fishmeal is also important in livestock, especially poultry, production. Peden et al. (2007) refer to water used in the production of imported feed as 'virtual' water, which takes no water from within the farming system. Estimates of 'virtual' water in aquaculture feeds are hard to make, particularly if feed inputs are of largely marine origin.

Nondepletive uses of water occur where benefits are derived from an intended use without depleting water (Molden, 1997). Using water for fisheries and aquaculture is broadly a nondepletive use. Intensity of water use in aquaculture, however, increases as production intensifies. Although aquaculture effluent discharges can contribute to 'non-productive' water depletion, aquaculture can also make productive use of water that is not readily utilizable for other purposes (e.g. saline water, wastewater). Moreover, when incorporated in agricultural systems, water productivity of aquaculture can be considered complementary to other productive water uses (van der Zijpp et al., 2007). Much of the water may also be reused, e.g. in supplemental crop irrigation. Such 'complementary' productivity can greatly increase net economic returns.

Water productivity can be measured against gross or net inflow. Gross inflow refers to the total amount of water flowing into the domain from precipitation and surface and subsurface sources. Net inflow is the gross inflow plus any changes in storage. If water is added to storage, net inflow is less than gross inflow. Water added to storage can be used for fish production and water productivity of fish grown in dams, ponds, etc., being expressed in a simplified form as:

$$1. \quad PW_S = \frac{P_{fish}}{|I_{Gross} - I_{Net}|}$$

where PW_S = Water storage productivity, P_{fish} = fish productivity, I = Inflow

Reservoir storage water is usually committed to uses other than fish production (e.g. irrigation, power generation). Here, fisheries and aquaculture can be considered nondepletive users of water. The *Process Fraction (PF)*, relating process depletion to either total depletion or the amount of available water (Molden, 1997), is therefore negligible in fish production.

$$2. \quad PF_{Depleted} = \frac{D_{Process}}{D_{Total}} \quad \text{and} \quad 3. \quad PF_{Available} = \frac{D_{Process}}{W_{Available}} \quad (\text{Molden 1997})$$

where $PF_{Depleted}$ is the process fraction of depleted water, D is Depletion, $W_{Available}$ is available water.

Service level and river basin level

At the service level, water productivity of fish is considered alongside other productive uses in the same multiple water use system (MWUS). In aquatic ecosystems, fisheries often provide by far the largest productive use of water. Fish derive their feed directly from the aquatic food web and capture fisheries production varies

widely across aquatic ecosystems. Aquatic ecosystems provide fundamental regulating and support services to fisheries production, and therefore cannot be considered in isolation from each other. Aquatic ecosystems can also provide important regulating services to aquaculture, (e.g. in the biological treatment of effluents).

The negligible process depletion of water in fish production implies that huge overall productive gains can be made even when the MWUS are primarily providing other productive services (e.g. irrigation). Almost all storage water is used in a nonconsumptive way for fish production (PW_s) and can be diverted to other uses. If an irrigation command area includes within its boundary fish, crop, and livestock productive uses, overall water productivity can simply be expressed as:

$$4. PW_{Tot} = \sum (PW_s + CWP + LWP)$$

where PW_{Tot} = total (overall) water productivity, PW_s = water storage productivity, CWP = crop water productivity, and LWP = livestock water productivity. Total water productivity (PW_{Tot}) is higher than the sum of its components, as most storage water after fish productive use is diverted for crops, and crop residues are used as feed inputs for livestock.

At the river basin level, water uses can be compartmentalized by use category and domain. The area drained by the system can be subdivided into catchment areas and the main stem and tributaries identified and sorted by drainage area size. Outflows from upstream catchment areas become inflows to areas downstream. In an open basin there may be uncommitted utilizable outflows available for use downstream. With additional storage, uncommitted outflow can be transferred to a process use such as irrigation or aquaculture. In a fully committed basin, there are no uncommitted outflows. The net inflow less the amount of water set aside for committed uses represents the water available for use at the basin, service, or use levels (Molden, 1997). One way to compartmentalize water uses at the basin level is to apply the water accounting framework of Molden (1997) at the individual agroecosystem level (including systems for domestic and industrial water use). Committed water uses in each domain can be prioritized according to costs and benefits of different uses and indicators of system performance can be developed, relating water productive outputs to water inputs.

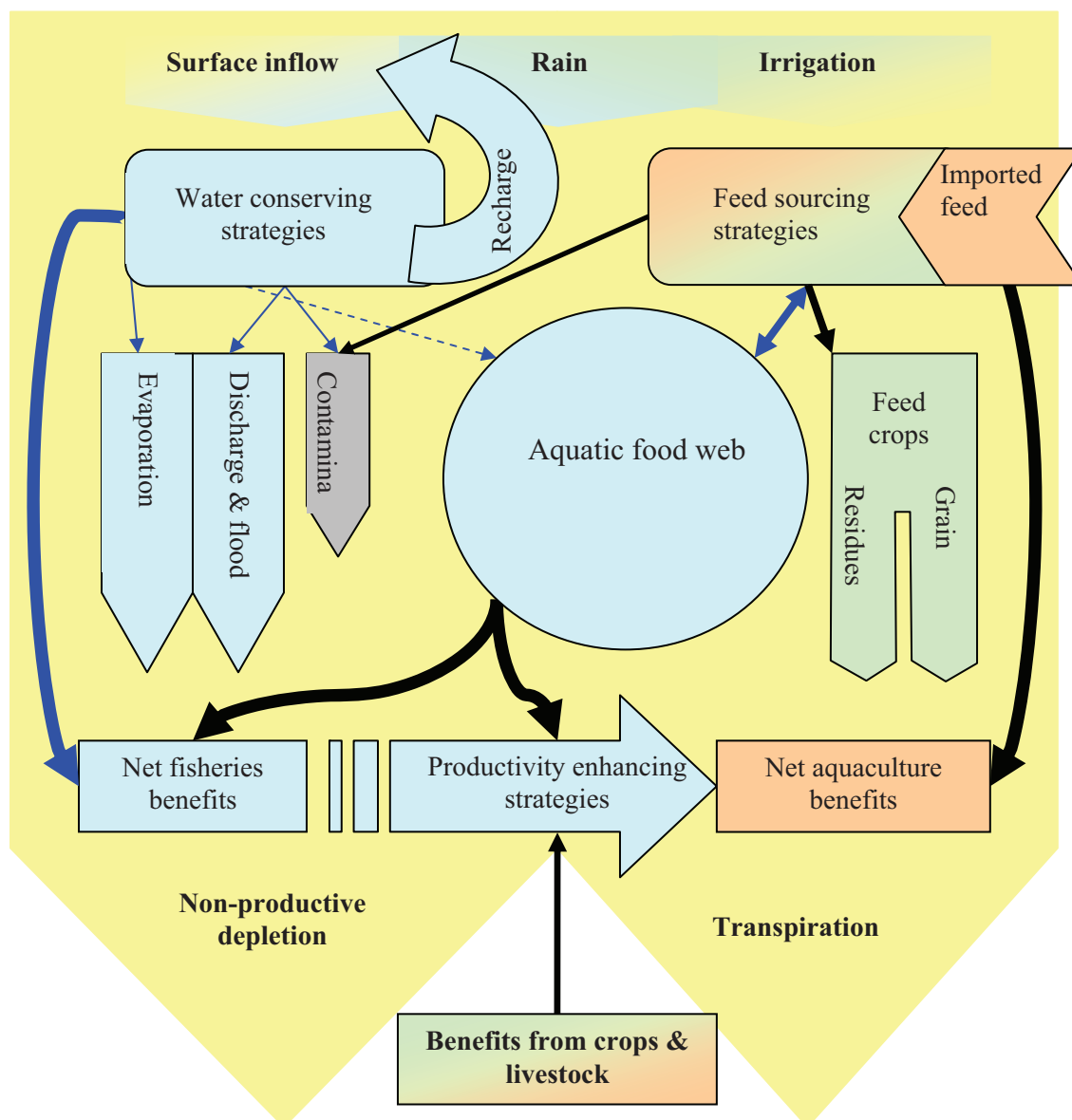


Figure 1. Fish water productivity scheme (modified from Peden et al., 2007).

Conclusions

This paper establishes the benefits and limitations of the use of the water productivity concept in fisheries and aquaculture, defining the scope and conditions of its application, and highlighting further research requirements. Water productivity can essentially be applied when water is a limiting factor to aquatic resource production and in confined water bodies.

Beyond these conditions, it is critical that the water productivity concept be developed to fully reflect the social and ecological dimensions of fisheries and aquaculture. This approach implies the evaluation of the social-ecological trade-offs inherent in the water productivity concept between increased food production, ecosystem conservation, and poverty alleviation. Further research is needed in the following key areas:

- Social-ecological assessment of water productivity.
- Assessment of water productivity of multiple uses.
- Participation of stakeholders (across sectors and levels) in the assessment.
- Analysis at basin and landscape scales.
- Trade-offs between and complementarities among multiple water productivity objectives.

A pluralistic approach is recommended so that a range of assessment and valuation tools (including consumption, ecosystem and human health, poverty, governance) can provide a comprehensive and holistic

assessment of fisheries costs and benefits in a context of multiple uses of water. This may set the scene for a broader revision of the concept beyond fisheries and aquaculture.

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