Sustainability Science in Ecological Aquaculture

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Introduction

The most popular definition of sustainable development is to ***meet present needs without compromising the ability of future generations to meet their needs*** adopted at a United Nations conference in 1987. Most definitions of sustainability are synonymous with environmental sustainability of air, water, and land systems. Sustainability is however a concept much broader than examining the site-specific environmental impacts and of the environmental externalities in planning for site-specific developments; it also accounts for systematic impacts to human (social)-economic-environmental systems for food, water, waste, energy, and shelter. The many definitions of sustainability all embody common the concepts of "stewardship", "design with nature," plus incorporate recent concepts of the "precautionary principle", and "carrying capacity". Sustainability science uses the wisdom from multiple disciplines in decision-making (e.g. it is "transdisciplinary").

There are many definitions of "sustainability" as the concept applies to aquaculture. Most aquaculture scientists define sustainability as synonymous with "environmental sustainability". Sustainability science in aquaculture is used to undertake more comprehensive planning for multiple impacts on multiple time and spatial scales to better understand and plan for the consequences of aquaculture development options.

The emerging fields of ecological aquaculture and before it, agroecology, recognize that the implementation of more sustainable aquatic food production systems require knowledge about how ecosystems are utilized, how conflicts among social groups are addressed, and how this knowledge results in viable economic aquatic farming ecosystems. The concept of sustainability and the methods to measure the evolutionary progress towards more sustainable systems are limited, but have become a necessity.

Wurts (2000) stated that "Whether the word sustainability has become overused or not, it has catalyzed a forum for oversight of the growth and development of aquaculture on a global scale."

A baseline of response to social ecological changes is the foundation for the implementation of more sustainable food systems, and the practice of adaptive management must be included as responses to changes in the condition of ecosystems in which new aquatic food production is conducted requires incorporation of an iterative learning process.

The use of sustainability science in aquaculture marks the path toward encouraging a long-term perspective and an appreciation of the roles played not only by ecologists, but also by civil societies, markets, and governments in adapting to food systems and ecosystems changes. The use of sustainability science in aquaculture is an approach that is fundamentally a knowledge-based enterprise that incorporates baseline information on natural and human ecosystems, then develops, evaluates, encourages, and communicates imagination, ingenuity, and innovation at both the individual and institutional levels.

Information obtained is typically cross sectoral as interdisciplinary groups are needed that are educated in such diverse fields as the natural and social sciences, law, design and planning, engineering, and business. This information is designed for use by teams of aquaculture professionals working to apply the principles of the ecosystems approach to aquaculture. Applying the notions of sustainability science in aquaculture is intended to inspire engagement of governmental agencies, businesses, and non-governmental groups with academics to achieve lofty goals such as:

"***to implement an aquatic farming ecosystem that would be a living example of the highest form of sustainable development of any known animal or plant protein production food system by using the concepts of ecological design and stewardship"***. At present, there is a paucity of information targeted specifically for those engaged in aquaculture programs and projects in places where the ability of government to regulate and direct the processes of ecosystem change is weak or severely constrained.

A Sustainability Science Approach to Implement Ecological Aquaculture

Sustainability is not a "black/white" phenomena; rather, it is many "shades of grey", an evolutionary process. To measure and evaluate progress along a trajectory requires: (a) establishment of baselines for the main issues of public concerns, then (b) developing a diverse but targeted set of resource and social indicators.

These indicators are then used to report progress on and analyze interactions between social, environmental, and economic impacts (both positive and negative ones). It is important to note that sustainability science as applied to aquaculture is driven as much by social as by environmental/ecological concerns; thus, a singular involvement of aquaculture technical experts in sustainability plans and assessments is insufficient.

Sustainable aquaculture integrates the best available science with a transparent, equitable, and democratic approach to planning and decision-making. Implementing the ecosystems approach to aquaculture needs to be carried out in a strategic manner that tailors principles of good practice to the culture and the needs of a specific place. Successful, sustainable aquaculture operations advance through linked cycles of planning, implementation, and re-assessment. These features of ecosystem management signal the transition from traditional sector-by-sector planning and decision-making to a more holistic approach based on the interactions between sectors and within and among complex social-ecological systems.

Developing an operational framework for how the sustainability of a planned aquaculture operation will evolve is the first step. Having such a social-ecological systems blueprint is rare for aquaculture businesses and management entities, and is very much needed. However, there are numerous aquaculture certification bodies that are vying for the opportunity to use their labels/logos to claim ownership of the sustainability rubric in aquaculture.

What is needed is not another certification scheme but a road map, an overall sustainability science approach to the implementation of the ecosystems approach to aquaculture which can step above the cacophony of certifications and assist in developing a common language that can be used for free! A sustainability science approach to aquaculture is a long-term perspective, and includes an appreciation of the roles played by civil society, markets and government, and offers a realistic means to development social-ecological stewardship.

The development of a sustainability baseline should be the responsibility of a lead aquaculture agency. Its full implementation may require alternative methods of governance and employ innovative management approaches.

There is a need to first facilitate an operational definition of aquaculture ecosystem boundaries for assessment (**the Area of Focus, AoF**) in order to set geographical limits to assess parameters such as carrying capacity or water management needs, and to understand the governance regime within which the Area of Focus is nested in order to understand and clarify such things as administrative and legal jurisdictions.

Once the AoF is defined and agreed upon, a sustainability science approach to implement ecological aquaculture is based upon the ***development of a baseline that has two parts, and then follows a sequence of five steps (after Costa-Pierce and Page, 2012)***:

(1) The <u>first part of a baseline</u> is an ecosystem audit of an area of focus (AoF) that defines the natural and social systems within which aquaculture is planned.

This involves the documentation and analysis of both natural and social systems, draws upon cases studies of other aquaculture systems in the region and how the governance system in those cases in that specific place has responded – or failed to respond – to the trajectories of change. It examines the long-term trends in both human well-being and the environmental conditions in the Area of Focus (AoF) as related to aquatic and terrestrial foods and examines responses to the issues raised by past and current expressions of aquaculture there.

(2) The <u>second part of the baseline</u> is the development of a designed aquaculture site specific ecosystem that addresses the specific aspects of the ecosystems approach to aquaculture adapted to the AoF in terms of economic, environmental, and societal benefits.

The baseline will be used as reference points against which future changes in this aquaculture ecosystem will be gauged. Baselines are not formulaic but are designed planning exercises with buy-in from key stakeholders such as the client, community, and regulatory community or identified group of people involved in the project. While not formulaic, baselines do include a set of common metrics to include:

- Ecological aquaculture design (or redesign) of production practices
- Health and quality control standards
- Social goals at both the individual and community levels for local food, job and regional development (e.g., "green jobs", "local foods")
- Governance goals.

The following five steps encompass some essential parts of any baselining process:

1. **Define the sustainability issues**. Aquaculture systems can use environmentally derived feeds, water, and energy, occupy land and water space, and generate wastes. There are at least eight issues of wide public and regulatory concerns regarding aquaculture development:

- Destruction of habitats
- No net gain to global seafood supplies
- Environmental impacts of discharged wastes
- Impacts of escapees
- Diseases in farmed fish
- Chemical use and discharge
- Impacts of coastal marine mammals
- Siting causes visual pollution

Once issues are defined, a baseline can be further developed which can measure progress over time by:

2. **Complete a sustainability assessment** of these issues by evaluating the status of current aquaculture practices that affect natural and social resource systems using available methods which also includes an assessment of governance systems (Table 1). Gibson et al. (2005) gives a complete analysis of all of the available tools for sustainability assessments, but the most widely available methods include:

Economic Sustainability

- Cost-benefit analysis: analysis of cost effectiveness of different uses to determine if benefits can outweigh costs US Department of Transportation (see reference web site).

- Triple bottom line or "full cost" accounting: costs considered for all environmental, economic, and social impacts; costs measured in terms of opportunity costs (the value of their best alternative use); guiding principle is to list all parties affected and place a monetary value on effects on welfare as valued by them (Savitz, 2006; McCandless et al., 2008).

Social Sustainability

- Stakeholder analysis: analysis of attitudes of stakeholders at the initiation of and throughout a project. Allows tracking of how stakeholders change attitudes over time with educational processes (Fletcher, 2003; Savage et al., 1991; Hemmati et al., 2002; Dalton, 2005; Dalton, 2006).
- ISO 26000 guidelines for corporate social responsibility (ISSD, 2004).
- ICLEI (International Council for Local Environmental Initiatives) provides ssoftware and tools to help local governments achieve sustainability goals (ICLEI.org).

Environmental Sustainability

- Life cycle analysis: complete assessment of products from raw material production, manufacture, distribution, use and disposal, including all transportation; used to optimize environmental performance of a single product or a company. A similar analysis called a MET (Materials, Energy, and Toxicity) Matrix is also used (American Center for Life Cycle Assessment; Bartley et al., 2007; Ayer and Tyedemers, 2009).
- Environmental impact assessment: the process of identifying, predicting, evaluating, mitigating biophysical, social, and other effects of development proposals prior to policy decisions (EAI Review; IAIA, 1995).
- ISO 14000 certification: norms to promote more effective and efficient environmental management and provide tools for gathering, interpreting and communicating environmental information (ISO).
- Environmental indicators: the use of quantitative indicators of resource use, efficiency and waste production in aquaculture (Boyd et al., 2007).

3. **Complete a detailed risk analysis** for all components of this comprehensive assessment (Fletcher et al., 2004; GESAMP, 2008).

4. **Complete a plan for ameliorating identified impacts** by incorporation of better (or best) practices and enhancing reuse or recycling pathways (National Research Council, 2010; Pullin, 1993; Tucker and Hargreaves, 2008).

5. **Complete a plan for communicating** the evolution of operations towards greater stewardship and sustainability (GESAMP, 2008).

To be effective, sustainable aquaculture initiatives must:

(a) be “profitable” over long periods of time – ideally many decades.
(b) be capable of being adapted to changing conditions.
(c) provide the mechanisms to encourage both wise resource use and collaborative behaviors.

Much of the challenge lies in achieving changes in the behavior of those who may be unaware of the benefits of sustainable aquaculture.

Aquaculture that is constructed upon principles that encourages high-energy consumption and the profligate use of natural resources must give way to new locally derived values and new forms of practice. As suggested by Daly (1996) qualitative development rather than quantitative growth is the path of future progress. If such ideas are to be made operational at the scale of an aquaculture operation, a trajectory can be established based on goals for profit as well as social and environmental benefit. Once the goals of an aquaculture program or project have been defined as expressions of the ecosystem approach much of the day-to-day work is concerned with the well-known best practices of aquaculture management.

For example, there has been much debate about the impacts of shrimp pond mariculture on mangrove forests through the Topics. Mangrove ecosystems provide essential goods and services to humanity, harboring an extraordinarily large biodiversity for the small areas of the planet that these systems occupy, and provide a sustainable source of timber and charcoal to coastal communities while protecting fragile coastlines from erosion and storms. Establishment of proper scientific baselines to measure the true impacts of mariculture on coastal ecosystems is essential. Pullin (1993) cautions that, "Analysis on depletion of mangrove cover in Asia point towards the fact that shrimp ponds have recently been and/or now being constructed either on former mangrove areas that were cleared long ago and considered degraded), or on more recently cleared areas for which the primary purpose of clearance was timber abstraction (logging, wood chip industries or charcoal production) or by adopting traditional trapping ponds…Aquaculturists in Asia are therefore more often than not the end users of already degraded or destroyed mangroves rather an the primary culprits of mangrove destruction".

Examples of Sustainability Science Approaches Used to Implement the Ecosystems Approach to Aquaculture

Good examples globally of an ecosystem approach to aquaculture at the watershed/aquaculture zone scale are found in both Israel and Australia. Both nations face severe land, water, and energy constraints. In Israel, highly efficient, landscape-sized integrations of reservoirs with aquaculture and agriculture have been developed (Hepher, 1985; Mires, 2009), as well as highly productive, land-based aquaculture ecosystems for marine species (Neori et al., 2000). These aquaculture ecosystems are productive, semi-intensive enterprises that are water and land efficient, highly, and are net energy and material gains to society which follow principles similar to the fields of agroecology and agroecosystems (Pimental and Pimental, 2003).

In Australia, an Ecologically Sustainable Development (ESD) framework approach to aquaculture development was used (Fletcher et al., 2004). This ESD framework identified important issues, developed comprehensive reports for each issue, and then prioritized each using risk assessments. The ESD process employed extensive community consultation that considered social and environmental values of all other marine users, and users' management plans for operations and administration as well as environmental administrative attributes, then proposed development and monitoring plans.

As a result of this ESD approach, nine marine aquaculture zones of 2,400 ha in Port Phillip Bay and Westernport, Victoria, Australia were permitted. The Australian ESD approach combined analytical and participatory methods and developed sustainability plans that considered both ecosystem and human well-being, then developed implementation strategies by designing and enhancing effective governance systems for the expansion of aquaculture.

Improved Governance of Aquaculture Ecosystems

To be effective, implementing an ecosystems approach to aquaculture initiatives must consider:

(1) sustainability over long periods of time – ideally over many decades,
(2) capability of being adaptable to changing conditions, and
(3) provision of mechanisms to encourage or require specified forms of resource use and collaborative behaviors among institutions and user groups that are stakeholders of the aquaculture ecosystem.

FAO (2006) found that one of the key trends towards more sustainable forms of aquaculture development and management is enhanced regulation and better governance.

Governance is defined as formal and informal arrangements, institutions, and mores that structure and influence how resources or an environment are utilized, how problems and opportunities are evaluated and analyzed, what behavior is deemed acceptable or forbidden, and what rules and sanctions are applied to affect how natural resources are distributed and used (Table 2, Olsen et al., 2006, 2009).

Much of the challenge lies in both understand and achieving changes in the behavior of the stakeholder groups and institutions associated with the aquaculture production systems. An ecosystems approach to aquaculture would integrate the best available science with a transparent, equitable and democratic approach to planning and decision-making. Management would need to tailor the principles of good aquaculture practices to the culture and the needs of a specific place (AoF). Successful aquaculture programs advance and change through linked cycles of planning, implementation, and reassessment. These features of ecosystem management signal the transition from traditional food production sector planning and decision-making to a more holistic approach based on the interactions between sectors and within and among linked social-ecological systems.

There are three mechanisms by which the processes of governance are expressed: the marketplace, the government, and the institutions and arrangements of civil society (Olsen et al., 2006). These mechanisms interact with one another through complex and dynamic interrelationships that are examined and contrasted and documented in a baseline. Each of the three governance mechanisms influence and can alter patterns of behavior through measures such as those identified in Figure 1.

It is important to distinguish between management and governance. Management is the process by which human and material resources are harnessed to achieve a known goal within a known institutional structure. Management is aquaculture business management, park management, personnel management or disaster management. In these instances the goals and the mechanisms of administration are well known and widely accepted. Governance, in contrast, addresses the values, policies, laws and institutions by which a set of issues are addressed. It probes the fundamental goals and the institutional processes and structures that are the basis for planning and decision-making. Governance sets the stage within which management occurs (Olsen, 2003).

The future of sustainable aquaculture is highly dependent on understanding the response by all three expressions of governance; markets, civil society, and government. For example, Kenya has fostered a participatory policy formulation for aquaculture, providing a legal and investment framework through government, establishing public–private partnerships to engage markets, providing basic infrastructure support, promoting self-regulation, providing a research platform for civil society to be engaged, undertaking zoning for aquaculture and providing monitoring and evaluation support (FAO, 2006).

Adaptation of sustainability frameworks used to evaluate the needs and progress of governance on coastal management plans are essential to evaluate progress towards an ecosystem approach to aquaculture and to build in adaptive learning and action. Governance frameworks recognize not only the importance of changes in practices such as changes over time in aquaculture ecosystems, but also recognize that for each change, there are correlated changes in the behavior of key partners and stakeholders within the sphere of influence of the management activity, and that these changes can be measured at local, regional and national levels (Table 1).

Sectoral agencies responsible for managing activities impacting aquaculture ecosystems (e.g. capture fisheries, coastal zone development, watershed management organizations, agriculture, forestry, industrial developments) will have to develop new ways of interacting to regularly communicate, cooperate, and collaborate. The need for innovative governance to implement an ecosystem based approach to aquaculture can be seen as an obstacle but can also be seen as an opportunity to increase the social benefits of aquaculture that are likely to develop through synergies among food production sectors.

Annotated Appendix of Definitions (modified from Costa-Pierce and Page, 2012)

Area of Focus: The area of focus (AoF) is the geographically defined area that an ecosystem-based aquaculture project or program has decided to address and that therefore is the focal point for a baseline. The term 'area of focus' is a geographic limit set to model the choices available to the aquaculture practitioner and allows for a dialogue between stakeholders as to the influence of the production. The AoF is a simplification of the far more complex concept of an "action arena" put forward by Ostrom (1986) to model the choices of individuals when studying the behavior of institutions.

Adaptive Management: A central feature of the practice of any form of ecosystem-based aquaculture is that it must respond positively to changing conditions within its AoF (and to its own experience). In other words, the practice of aquaculture must be grounded in a process of learning and adaptation (the "evolution of the blue revolution", Costa-Pierce, 2002). Adaptive management is not reactive management, but proactive thinking and acting. This does mean that the aquaculture practitioner simply responds to the unexpected. Adaptive management in aquaculture is a conscious process of examining the course of events as these are revealed by pre-selected indicators of changes in an aquaculture ecosystem (both its social and environmental components), and by events occurring at differing spatial scales.

Capacity Building: There is growing international recognition that the lack of human capacity to practice an ecosystem approach to aquaculture is a key factor in limiting forward progress in the conservation and sustainable use of aquatic systems (Costa-Pierce, 2008). To date, however, no accepted performance standards have been developed for assessing the effectiveness and impacts of aquaculture projects and programs that have adopted the ecosystem approach. We herein offer conceptual frameworks and methods for assessing the maturity of aquaculture development and management initiatives, and gauging their impacts upon the condition of coastal ecosystems. These are the core ingredients for an ecosystems approach to aquaculture that builds the capacity of local populations and leaders to identify forces that shape the coastal ecosystems of which they are a part, and to select the actions that can maintain and enhance qualities that are critical to a desirable future.

Carrying capacity: The carrying capacity is the number of organisms or farming operations that the environment can sustain indefinitely without environmental harm, given the food, habitat, space, water, and other requirements from the environment.

Nested Systems of Governance: Environmental and societal issues relating to sustainable aquaculture impact, and are impacted by, conditions and actions (at both higher and lower levels) in a governance hierarchy. Some issues can be addressed more effectively at one level, and less effectively at another. The choice of the issue or set of issues to be addressed within a given site must therefore be made in full knowledge of how responsibility and decision-making authority are distributed within a layered governance system. Planning and decision-making for aquaculture at one scale; for example, within a municipality or province, should not contradict or conflict with planning and management at another; for example, large scale aquaculture at the nation-state scale. The reality is that such contradictions and conflicts are common. A major challenge for the aquaculture practitioner is to recognize these differences and work to either change them or select goals and strategies that recognize that such contradictions must be accommodated or resolved. In practical terms this means that a central feature of ecosystem-based aquaculture is that all planning and decision-making must recognize and analyze conditions, issues, and goals in respect to the next higher level in a governance system. Thus, ecosystem-based aquaculture at the municipal scale must —at a minimum—be placed within the context of governance at the scale of the province.

Participation: One of the defining characteristics of the practice of the ecosystem approach to aquaculture is its emphasis on participation and its relevance to the people affected. The emphasis upon participation recognizes that if an aquaculture program is to be successful those whose collaboration and support is needed must be involved in the processes of defining the issues that the program will address, and in selecting the means by which goals and objectives will be achieved. Both individuals and members of communities and institutions are more likely to comply with a management program when they feel that that it is consistent with their values, and responds to their needs and to their beliefs of how human society should function. Voluntary compliance by a supportive population lies at the heart of the successful implementation of a program. A participatory approach helps stakeholders and the public to see the efforts of an aquaculture program as a whole.

Precautionary principle: A principle states that if an action or policy has a suspected risk of causing harm to the public or to the environment that in the absence of scientific consensus the burden of proof rests on those who advocate taking the action.

Stewardship: Ecosystem stewardship is an ethic practiced by aquaculture practitioners, organizations, communities, and societies who strive to sustain the qualities of healthy and resilient ecosystems and their associated human communities. Stewardship takes the long-term view and promotes activities that provide for the well-being of both this and future generations.

Sustainable development: The management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Sustainable development conserves resources, is environmentally non-degrading, and is technically appropriate, economically viable, and socially acceptable (FAO, 1995).

Transdisciplinary: A modern research strategy that crosses many disciplinary boundaries to create a holistic approach. Transdisciplinary research efforts are focused on problems that cross the boundaries of two or more disciplines, and develop new or reframe old concepts, methods and findings that were originally developed by one discipline, but are now used by several others.

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Table 1. A Framework of Indicators that Chart the Progress of Governance Applied to an Ecosystem Approach to Aquaculture (Olsen, 2003; Olsen et al., 2006, 2009; Costa-Pierce and Page, 2012)

Orders	Explanations	Indicators
First Order	Government at the national level commits to a plan of action designed to adopt an ecosystem approach to aquaculture (EAA) by issuing a formalized commitment to an EAA, thereby putting in place the ''enabling conditions"	New laws, programs, and procedures are initiated that provide the legal, administrative, and management mechanisms to achieve the desired changes in behavior by: (i) building constituencies that actively support EAA with the user groups that will be most affected; with government institutions involved; and with the general public; (ii) developing a formal government mandate for an EAA with the authority necessary to implement actions in the form of laws, decrees, or other high level administrative decisions that create an EAA as a permanent feature of the governance structure of aquaculture; creation of commissions, working groups, user organizations and non-governmental organizations (NGOs) dedicated to the advancement of an EAA agenda; designating EAA zones; (iii) devoting resources, especially sustained annual funding, adequate to implement an EAA; (iv) developing an implementation plan of action for an EAA that is constructed around unambiguous goals; (v) creating the institutional capacity necessary to implement the new EAA plan of action.
Second Order	Evidence of successful implementation of an EAA	(1) Changes in the behavior of institutions and interest groups have occurred such as collaborative planning and decision-making through creation of task forces, commissions, civic associations, etc.; (2) Successful application of conflict mediation activities; (3) Evidence of functional changes such as establishment of new public-private partnerships, new collaborative actions undertaken by user groups, implementation of new school curricula that incorporates an EAA; (4) Changes in behaviors directly affecting ecosystem goods and services, such as the elimination of socially and environmentally destructive aquaculture practices; (5) Investments in infrastructure supportive of EAA policies and plans.
Third Order	Evidence of sustained achievements in institutional and behavioral change due to an EAA as seen in the environment and indicators for the quality of life, incomes, or engagement in alternative livelihoods that have improved target communities	(1) Improvements in ecosystem qualities, such as sustained conservation of desired ecosystems and habitats, halting or slowing undesired trends such as nutrient releases, feed wastage, diseases, damaged benthic ecosystems, etc.; (2) Improvements in society as evidenced by monitoring of social indicators such as increases in indices of quality of life, reduced poverty, greater life expectancy, better employment opportunities, greater equity in access to coastal resources and the distribution of benefits from their use, greater order, transparency and accountability in how planning and aquaculture development decision-making processes occur, greater food security, or greater confidence in the future.

Table 2. Sustainability science assessments of aquaculture include an assessment of governance systems, which examine the three processes of governance: government, the marketplace, the government, and civil society (Olsen, 2003; Olsen et al., 2006, 2009).

Major Expressions of Governance
Government
Laws and regulations
Taxation and spending policies
Education and outreach
Marketplace
Profit seeking
Ecosystem service valuation
Cost-benefit analysis
Eco-labeling and Green Products
Civil Society: Organizations and Institutions
Product choices
Advocacy and lobbying
Vote casting
Co-management
Stewardship activities

Figure 1. The three mechanisms by which the processes of governance are expressed interact with one another through complex and dynamic interrelationships that are vital parts of sustainability science assessments of aquaculture as each alter behaviors and decision-making that determine human uses of ecosystems (Olsen et al., 2006).