

Defining an ecosystem approach to aquaculture (EAA) for federal waters of the United States

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Abstract: The increase in world population, along with increased demand for seafood as a source of human nutrition, and stagnant wild fisheries catches, will necessitate the growth and diversification of marine aquaculture globally. However, marine aquaculture development in many countries, including the United States, lags behind that of freshwater aquaculture. The United States (U.S.), despite having the world's largest Exclusive Economic Zone (EEZ), imports about 90 percent of the seafood consumed domestically (by value). One solution to the seafood import deficit is to pursue the development of marine aquaculture including offshore aquaculture in the EEZ, also known as federal waters.

Various laws and regulations give the National Oceanic and Atmospheric Administration (NOAA) oversight of fisheries in federal waters. NOAA's National Marine Fisheries Service (NMFS) has long recognized the importance of implementing ecosystem-based fisheries management in order to explicitly account for environmental changes and make trade-off decisions for actions that affect multiple species; however, this approach needs to be investigated for American aquaculture. In many respects, US marine aquaculture may already be managed with an ecosystem approach owing to the various environmental laws which underlie its regulation and management.

If marine aquaculture is to grow in accordance with US laws and social values there need to be guidelines and a framework for this effort, just as there is for capture fisheries. In order to benefit from marine aquaculture opportunities that are in line with these laws and values, the NOAA Office of Aquaculture is exploring an Ecosystem Approach to Aquaculture (EAA). The NOAA EAA is based on the definition of Ecosystem Based Fishery Management as defined under the US fisheries laws (Magnuson-Stevens Act). This exercise may also serve to guide research, and as the first step in articulating a more detailed approach for implementation of ecosystem-based management of marine aquaculture. This paper provides an overview of NOAA's Ecosystem Approach to Aquaculture, including a definition of EAA, rationale for development of the document, and some of the expected benefits of EAA.

Key words: ecosystem approach, offshore aquaculture, federal waters

Introduction

Marine aquaculture as it is now practiced in other countries, is a relatively recent development in the United States (Knapp and Rubino, 2016). The top marine species cultured and harvested in the US are: oysters, clams, mussels, shrimp, and salmon (NOAA, 2017); and much lesser amounts of yellowtail, moi,

seabass, and seabream (Fig.1). Marine aquaculture production has incrementally increased in both volume and value since 2009. Marine aquaculture production in 2015 was 96.6 million pounds, a 6.6 % increase over 2014 production and a \$7.9 million (2.1 %) increase in value (NOAA, 2017).

There is a huge potential to increase and expand marine aquaculture globally and in the US. In their

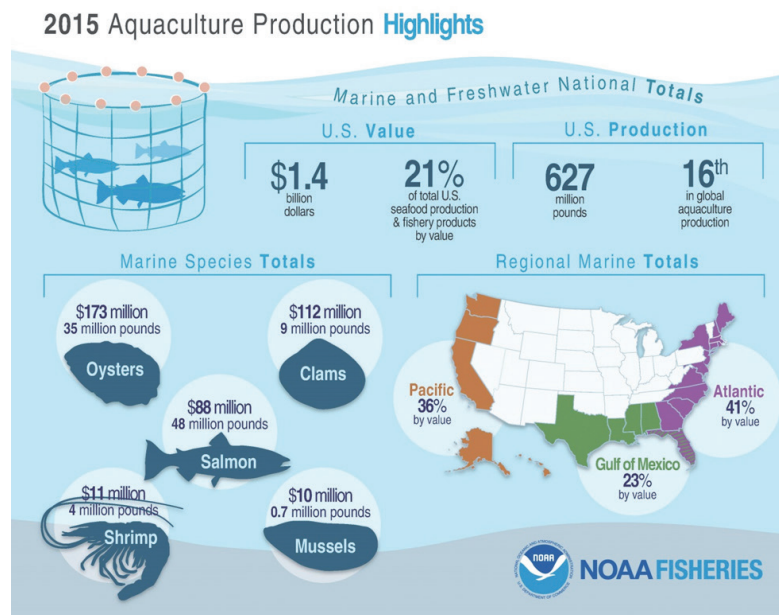


Fig. 1. U.S. Aquaculture production statistics for 2015. (NOAA, 2017)

studies, Kapetsky *et al.* (2013), Gentry *et al.* (2017), and Oyinlola *et al.* (2018) found that, even with many constraints, there are vast areas in the world's oceans that are suitable for offshore marine aquaculture. For example, Gentry *et al.* (2017) estimated that marine aquaculture could produce the equivalent of current wild-capture fisheries using less than 0.015 % of the global ocean area – a “surface area less than Lake Michigan”. Kapetsky *et al.* (2013) also calculated that most countries would only need to have aquaculture in less than 1 % of their EEZ to produce all the seafood they currently require. In the U.S., production could be vastly increased by utilizing more offshore, or federal, waters (Kapetsky *et al.*, 2013). Indeed, there are many factors driving the development and expansion of marine and offshore aquaculture¹, as explained below. However, doing this in an environmentally sound and sustainable way requires a balance that

allows for the production of more seafood, while also protecting native species, maintaining a healthy, productive, and resilient ecosystem, fish habitats, and a viable seafood industry. One option to account for the attainment of such diverse goals may be initiated through the articulation of an Ecosystem Approach to Aquaculture (EAA).

What is an ecosystem approach to aquaculture?

Based on a similar NOAA definition for an Ecosystem Approach to Fisheries, we define an Ecosystem Approach to Aquaculture as follows:

An ecosystem approach to aquaculture is a systematic method of managing aquaculture that:

- is in a geographically specified area;
- contributes to the resilience² and sustainability³ of the ecosystem⁴;

¹ “Offshore Aquaculture may be defined as taking place in the open sea with significant exposure to wind and wave action, and where there is a requirement for equipment and servicing vessels to survive and operate in severe sea conditions from time to time. The issue of distance from the coast or from a safe harbor or shore base is often but not always a factor” (Drumm, 2010).

² Resilience can be defined as the capacity of a(n) (ecosystem) to persist or maintain function in the face of exogenous disturbances. That is, the capacity of an ecosystem to tolerate disturbance (e.g., such as intensive fishing) without collapsing into a different state that is controlled by a different set of processes. This is primarily encapsulated by two elements, resistance to and recovery from pressure (NOAA, 2016).

³ FAO defines sustainability (as synonymous with sustainable development) as “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. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable” (Welcomme and Barg, 1997)

⁴ In the NOAA Fisheries context, the term “ecosystem” means a geographically specified system of fisheries resources (including aquaculture), the persons that participate in that system, the environment, and the environmental processes that control that ecosystem's dynamics (Murawski and Matlock, 2006). Aquaculturists, fishermen and the associated support communities are understood to be included in the definition.

- recognizes the physical, biological, economic, and social interactions among the affected aquaculture-related components of the ecosystem, including humans;
- seeks to optimize benefits within a diverse set of environmental and social constraints;
- is adaptive over time.

Our definition of EAA adheres closely to some others, such as that of the Food and Agriculture Organization (Soto *et al.*, 2008a), which defines EAA as follows: “*The ecosystem approach to aquaculture is a strategic approach to development and management of the sector aiming to integrate aquaculture within the wider ecosystem such that it promotes sustainability of interlinked social-ecological systems*”.

Our EAA definition fits within this more general FAO definition, and is consistent with the specific mandates and guidelines in the U.S.’s aquaculture law (National Aquaculture Act [NAA]) and fisheries law (Magnuson-Stevens Fishery Conservation Act [MSA]). It also respects other environmental laws under which the US operates and manages aquaculture to fulfill its mission (see the section on “Major Laws” below for more information on these).

EAA includes considerations of interactions among aquaculture, fisheries, protected species, habitats, and other ecosystem components, including the human communities that depend upon them and their associated ecosystem services. EAA examines not only the broader suite of factors that affect aquaculture efforts, but also considers the potential impacts (positive and negative) of aquaculture on other parts of the ecosystem (e.g., on nutrients, plankton, fish species, habitats, marine mammals and so on). “Societal goals” consider and include any relevant economic, social, and other factors valued by society in the context of, or relating to aquaculture. EAA is cognizant of both human and ecological considerations and seeks to optimize returns to both as much as possible. This is an attempt to create a common framework that leads to ecosystem resiliency.

In many ways EAA is similar to the Japanese concept of “*Sato-Umi*” which is defined as “*a coastal*

area with high productivity and biodiversity due to human interaction” (Yanagi, 2005), or “*a seascape where human-ecosystem interaction has resulted in increased biodiversity and productivity, thus improving the health of the environment and its ecosystem services*” (Mizuta and Vlachopoulou, 2017).

Purpose

The purpose of this paper is to articulate principles of marine aquaculture development and activity within the context of the National Oceanic and Atmospheric Administration’s (NOAA’s) multiple stewardship missions and broader social, environmental and economic goals. Meeting this objective will help NOAA to integrate environmental, social, and economic considerations in management decisions concerning aquaculture. The EAA will also serve to reaffirm that aquaculture is an important component of NOAA’s efforts to maintain healthy and productive marine and coastal ecosystems while providing seafood. Implementation of the EAA involves balancing competing uses of the marine environment, creating employment and business opportunities in our communities, and enabling the production of safe and sustainable seafood.

Why have an ecosystem approach to aquaculture?

Although aquaculture is considered a “fishery” under the US fisheries law (MSA), marine aquaculture is also farming and adheres to all the other environmental laws and regulations pertaining to all marine activities and all farming activities. A separate ecosystem approach is needed for marine aquaculture because it differs from capture fisheries in several important structural aspects. First of all, the potential impacts from aquaculture on wild fisheries stocks are indirect⁵ (habitat, stress, genetics), while capture fishing deals with direct (harvest) and indirect impacts (habitat destruction, genetic impacts, stress and so on). Some of the indirect effects of aquaculture can be managed to be positive and produce enhanced environments for wild stocks and

⁵ None of these directly remove members of wild populations from the ecosystem. This is in contrast to harvest from wild capture where the whole point is to remove members of the wild populations from the ecosystem.

other forms of aquaculture. For example, nutrients in the marine environment either provided by, or taken up by, aquacultured organisms can be used to mitigate oligotrophication or eutrophication, respectively. Aquaculture structures can be designed to provide habitat. Hatcheries may produce organisms for release to rebuild wild stocks. Second, the management options for marine aquaculture are greater, and of a different nature than for fisheries. The main control for wild fisheries is management of harvest and habitat. Control over the harvestable biomass in wild fisheries is largely by acts of nature. Control over the harvestable biomass in aquaculture is much more in the hands of people. Recruitment in aquaculture is controlled by a hatchery, but even more so, the quality of recruits in terms of growth and survival to harvest are determined by genetics, nutrition, environmental conditions and husbandry, which are all at least partially under the control of humans. Because of the greater number and diversity of control points, the application of an ecosystem approach to aquaculture is more complex and differs in priorities from an ecosystem approach to fisheries.

For NOAA, this is not a new way of thinking, but just the adaptation of an ecosystem approach to a different endeavor that is not specifically resource

extractive. It is time to define a NOAA ecosystem approach for aquaculture –and explore the same way of thinking the agency has advocated with regard to capture fisheries and other NOAA efforts.

Major laws and mandates governing aquaculture in the US

US marine aquaculture is arguably already managed with an ecosystem approach owing to the environmental laws which underlie its regulation and management (**Table 1**). There are laws in the United States that compel NOAA to manage marine fisheries and aquaculture so that the environment is considered and impacts minimized. Two of these are the Magnuson-Stevens Act⁶ (MSA) and the National Aquaculture Act (NAA). In terms of ecological considerations, the MSA essentially states that fisheries will be managed in a way that:

- integrates ecosystem considerations into fishery conservation and management actions,
- minimizes the impacts of fishing on ecosystem components, and
- conserves important ecosystem components from non-fishing threats.

Similarly, the National Aquaculture Act (NAA) dictates that aquaculture will be conducted to:

- promote and support the development of private aquaculture;
- promote coordination among the various federal agencies that have aquaculture programs and policies;
- Provide a legal mandate for NOAA Fisheries to support the development of the U.S. marine aquaculture industry.

The NAA also allows for the use of aquaculture to enhance and restore species. The NAA is primarily administered by the U.S. Department of Agriculture (USDA), which is the lead Federal agency for aquaculture in the U.S., along with the U.S. Department of Commerce (of which NOAA is a part) and the U. Department of the Interior. NOAA is specifically directed to support the development of

Tables 1. Federal permits required for offshore aquaculture operations in federal waters of the Gulf of Mexico⁷

Agency	Statutes/Authorities	Purpose
U.S. Army Corps of Engineers (USACE)	Section 10 of the Rivers and Harbors Act and some sections of Clean Water Act	Required in navigable waters of the U.S. to protect navigation for commerce
National Oceanic and Atmospheric Administration (NOAA)	Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act)	Required for operating offshore aquaculture facility in Federal waters of the Gulf and other areas of federal waters
U.S. Environmental Protection Agency(EPA)	Sections 402 and 403 of the Clean Water Act	Required for the discharge of pollutants into waters of the U.S.

⁶ Although the term “aquaculture” is not mentioned specifically in the MSA, NOAA has a legal opinion that equates aquaculture to fisheries; therefore, aquaculture endeavors in federal waters are also required to follow the same standards.

⁷ In the Gulf of Mexico, federal waters begin at 3 nautical miles from shore in Louisiana, Mississippi and Alabama and 9 nautical miles from shore in Texas and Florida, and extend to approximately 200 nautical miles from the coast. (NOAA, 2017)

the U.S. marine aquaculture industry, an increasingly important economic component of marine ecosystems, and use of aquaculture to enhance and restore species for commercial, recreational and restoration purposes. In addition, some types of aquaculture in federal waters are regulated under MSA in the Gulf of Mexico, and are under consideration by other Councils.

In addition to the MSA and the NAA, there are many other statutes and authorities that govern marine aquaculture permits and operations in the U.S. Some of the federal laws are listed in the **Tables 1 - 3**. Taken together, these laws, along with other regulations, enable federal oversight and enforcement to help protect the marine environments and the biota inhabiting them (e.g., endangered species, fish and wildlife, and essential fish habitat). Others pertain to navigation and fossil fuel extraction activities, as well as historic and cultural artifacts.

In addition to these federal laws, individual states and local government within states may also have others that are applicable to state waters.

The Coastal Zone Management Act (CZMA) was passed by Congress in 1972 and is administered by NOAA. It provides for the management of the nation's coastal resources, including the Great Lakes. The goal is to "preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone."

One of the programs of the CZMA is the National Coastal Zone Management Program (NCZMP), which comprehensively addresses the nation's coastal issues through a voluntary partnership between the federal government and coastal and Great Lakes states and territories. The program provides the basis for protecting, restoring, and responsibly developing the nation's diverse coastal communities and resources.

Currently 34 coastal states participate in the NCZMP. While state partners must follow basic requirements, the program also gives states the flexibility to design unique programs that best address their coastal challenges and regulations. By leveraging both federal and state expertise and resources, the program strengthens the capabilities of each to address coastal issues, including aquaculture activities.

Thus, aquaculturists wishing to obtain permits to

Tables 2. Federal authorizations required for offshore aquaculture operations in federal waters of the Gulf

Agency	Statutes/Authorities	Purpose
Authorizations		
U.S. Coast Guard (USCG)	33 U.S.C. 1221 <i>et seq</i> 33 CFR §66	Ensure safe navigation Authorize Private Aids to Navigation
Authorizations for Aquaculture Operations Co-Located with OCS		
Bureau of Ocean Energy Management (BOEM)	Outer Continental Shelf Lands Act; Energy Policy Act of 2005; 30 CFR	Required for any offshore aquaculture operations that utilize or tether to existing oil and gas facilities
Bureau of Safety and Environmental Enforcement (BSEE)	Outer Continental Shelf Lands Act	

build and operate aquaculture facilities in coastal and federal waters must go through an arduous process, designed primarily to protect the environment, to obtain them. Once their projects are operational, they must still adhere to federal and state laws governing water pollution, threatened and endangered species, marine mammals (i.e., entanglement in gear), and others. This legal landscape helps ensure that aquaculture in U.S. marine waters is conducted in accordance with the environmental aspects of the principles of an ecosystem approach to aquaculture. The current system does not consider broad scale social and economic considerations in permit decisions for aquaculture. An EAA might help to provide for a more diverse set of considerations in permit decisions.

What are some of the benefits of EAA?

As interest in aquaculture in the U.S. has increased, so too has the debate about the potential economic, environmental, and social effects of aquaculture. There are environmental challenges posed by aquaculture when it is done poorly (e.g., habitat destruction, excess nutrient discharges, water use demands, invasive species, genetic impacts and effects on protected species). There are also socioeconomic challenges, for example, competition for the use of marine space and potential effects of increased aquaculture production on prices of wild caught fish. However, aquaculture practiced in consideration of the ecosystem can result in many

Tables 3. Required federal consultations and reviews. Agencies with permitting decisions for aquaculture facilities including NOAA, EPA and USACE, will apply the relevant and applicable provisions of the laws identified below to their federal actions. Many of these consultations and reviews may occur in tandem with the permit application review process

Consultation or Review	Description of the Requirement
Endangered Species Act	Section 7 of the Endangered Species Act (ESA) requires any federal agency that issues a permit to consult with NOAA's National Marine Fisheries Service (NMFS) and/or the U.S. Fish and Wildlife Service (USFWS), <i>if</i> issuance of the permit may adversely affect ESA- listed species and/or the designated critical habitat for ESA-listed species. The Section 7 consultation process requires an analysis of the effects of the proposed action on ESA-listed species and designated critical habitat based on the best available science. The analysis must determine if the proposed action is likely adversely affect an ESA-listed species and/or designated critical habitat. If the analysis determines the issuance of a proposed permit will adversely affect an ESA-listed species, but will not jeopardize its continued existence, then reasonable and prudent measures and implementing terms and conditions that minimize the adverse impacts must be developed.
Essential Fish Habitat	The Essential Fish Habitat (EFH) provisions of the Magnuson-Stevens Act requires federal agencies to consult with NMFS when activities they undertake or permit have the potential to adversely affect EFH.
National Historic Preservation Act	Section 106 of the National Historic Preservation Act (36 CFR Part 800) requires any federal agency issuing a permit to account for potential effects of the proposed aquaculture activity on historic properties, <i>e.g.</i> , shipwrecks, prehistoric sites, cultural resources. If a proposed aquaculture activity has the potential to affect historic properties these details must be provided by the applicant as part of the application packages.
Fish and Wildlife Coordination Act	The Fish and Wildlife Coordination Act requires any federal agency issuing permits to consult with USFWS and NMFS if the proposed aquaculture activities could potentially harm fish and/or wildlife resources. These consultations may result in project modification and/or the incorporation of measures to reduce these effects.
National Marine Sanctuary Resources Act	Section 304(d) of the National Marine Sanctuaries Act (NMSA) requires that any federal agency issuing permits to consult with NOAA's <u>National Marine Sanctuary Program</u> (NMSP) if the proposed aquaculture activity is likely to destroy or injure sanctuary resources. As part of the consultation process, the NMSP can recommend reasonable and prudent alternatives. While such recommendations may be voluntary, if they are not followed and sanctuary resources are destroyed or injured in the course of the action, the NMSA requires the federal action agency(ies) issuing the permit(s) to restore or replace the damaged resources.

environmental, economic, and social benefits while avoiding the challenges listed above.

Resilience and sustainability

Aquaculture can contribute to the resilience and sustainability of seafood. NOAA defines resilience as the capacity of a system to persist or maintain function in the face of exogenous disturbances. That is, the capacity of an ecosystem to tolerate disturbance without collapsing into a different state that is controlled by a different set of processes. This is primarily encapsulated by two elements: resistance to, and recovery from, pressure. (NOAA, 2016)

NOAA defines fisheries sustainability as a

“characteristic of resources that are managed so that the natural capital stock is non-declining through time, while production opportunities are maintained for the future. Fishing is sustainable when it can be conducted over the long-term at an acceptable level of biological and economic productivity without leading to ecological changes that foreclose options for future generations” (Sutinen *et al.*, 2000; Blackhart *et al.*, 2006). This definition somewhat applies to aquaculture, but is not a perfect fit due to aquaculture's ability to scale with seafood demand versus capture fisheries' dependence on a fixed supply. There is no “natural capitol stock” to manage. The World Bank (The World Bank 2014) puts it this

way:

Aquaculture is projected to be the prime source of seafood by 2030, ...for an aquaculture system to be truly sustainable, it must have:

- **Environmental sustainability** — *Aquaculture should not create significant disruption to the ecosystem, or cause the loss of biodiversity or substantial pollution impact.*
- **Economic sustainability** — *Aquaculture must be a viable business with good long-term prospects.*
- **Social and community sustainability** — *Aquaculture must be socially responsible and contribute to community well-being.*

Sustainable aquaculture is a dynamic concept and the sustainability of an aquaculture system will vary with species, location, societal norms and the state of



Fig. 2. Example of Olympia oyster (*Ostrea lurida* Carpenter 1864) restoration plot in Puget Sound, WA. (Photo credit: NOAA Fisheries)



Fig. 3. A diver surveys coral pieces being cultured for coral reef restoration. (Photo credit: NOAA Fisheries).

knowledge and technology.

More efficient use of resources and feed

Aquaculture is one of the most efficient agricultural systems, and is typically better than terrestrial farming in terms of feed conversion (Hall *et al.*, 2011; Brummett, 2013), greenhouse gas emissions, land use, energy efficiency and freshwater use (Nijdam *et al.*, 2012). Aquaculture as practiced in the US provides food at a smaller global environmental cost than agriculture, while developing an EAA could produce this food with even a smaller negative environmental cost, or potentially while providing environmental benefits.

Restoration

- Aquaculture plays a prominent role in restoring populations of marine fish and shellfish. Hatcheries provide organisms to rebuild oyster reefs (**Fig.2**), coral reefs (**Fig.3**), enhance wild fish populations (e.g., salmon, red drum, flounder), and rebuild populations that are threatened or endangered (e.g., salmon and abalone, **Fig.4**).
- Fish hatcheries have long been used to augment both freshwater and marine fish populations. Many salmon runs in the U.S. are supplemented by salmon hatcheries in an effort to rebuild natural salmon populations that have declined due to various limits to natural recruitment, or to provide catch in excess of what would be available naturally

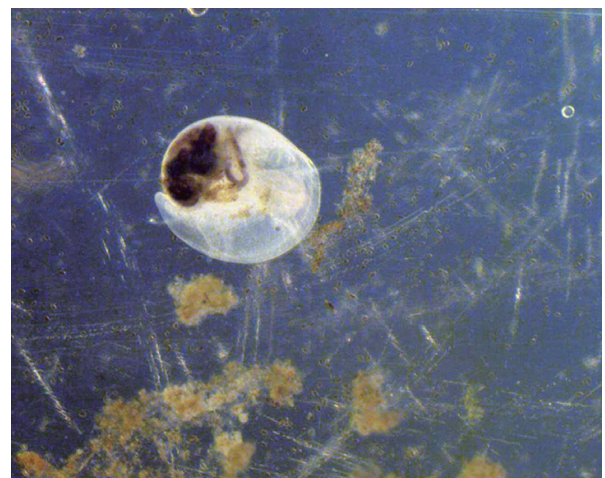


Fig. 4. Two month old white abalone larva cultured in a hatchery. Photo credit: Kristin Aquilino, NOAA

(Hess *et al.*, 2012). In addition, aquaculture can be used to restore physical and ecosystem function.

For example, one use of hatchery-reared oysters in the U.S. is in the creation of “living” or “green” shorelines to reduce erosion and wave action in vulnerable coastal areas (Fig.5). In these projects, oyster reefs are built using hatchery-reared oysters (set on shell) in conjunction with seagrass or submerged aquatic vegetation (SAV), marsh grass, and sometimes other structures to increase habitat



Fig. 5. Volunteers restoring marsh grass in a coastal “living shorelines” restoration project. (Photo credit: NOAA Fisheries)



Fig. 6. Rock Point Oyster Company Shellfish Farm in Quilcene, WA. (Photo credit: Jenifer Rhoades, NOAA IOOS Program). Bagged spat on shell like this can also be used in oyster restoration as well as living shoreline restoration projects.

and vegetation along shorelines and help prevent erosion. In some subtidal oyster reef restoration projects, hatchery-reared oysters are placed as an outer layer on mounds of clean shell (Fig.6).

Ecosystem services

There is growing recognition of the ecosystem services provided by aquaculture in the U.S. and other countries. Restoration practitioners have increasingly pursued bivalve, sea grass and kelp restoration as a component of restoring historical baseline water quality conditions and functioning of ecosystems (Rice, 2000). For example, restoration of oyster reefs (Fig.7) can restore water clarity, help reduce phytoplankton blooms caused by excess nutrient loading and decrease turbidity (Everett *et al.*, 1995; Carroll *et al.*, 2008). Like bivalves, seaweed also removes and sequesters carbon and nitrogen; and the structures of all types of aquaculture (cages, ropes, buoys, rafts, etc.) may provide habitat for aquatic animals (North, 1987; Phillips, 1990; Zhen-hua and Wei-ding, 2007).

Aquaculture of filter feeders (e.g., oysters and mussels) and macro-algae can enhance resilience of the estuarine ecosystem to eutrophication (Jackson *et al.*, 2001; Lotze *et al.*, 2006) and help enhance habitat functions. (Carroll *et al.*, 2008; Wall *et al.*, 2008). Conversely, much of the ocean is oligotrophic, and the addition of nutrients from fed aquaculture in these types of areas may lead to enhanced ecosystem services, biodiversity, and greater resiliency (Machias



Fig. 7. Oyster reef in the southeast U.S. (Photo credit: NOAA Fisheries)



Fig. 8. Flounder in seagrass bed. (Photo credit: NOAA Fisheries)

et al., 2004; Machias *et al.*, 2005; Diana, 2009). There has been much work on attempting to balance nutrient inputs from fed aquaculture with nutrient extraction by filter feeders and macro-algae on a local scale (Chopin *et al.*, 2001; Chopin *et al.*, 2008; Neori, 2008; Barrington *et al.*, 2009; Troell *et al.*, 2009; Chopin, 2015). This approach has been called Integrated Multi-Trophic Aquaculture (IMTA). EAA benefits from the mass balance nutrient relationships illuminated by IMTA studies, but differs by considering the nutrient (trophic) background of the host environment and its ability to benefit from additions or reductions in ambient nutrients from aquaculture at various ecosystem scales and under different temporal patterns.

When marine organisms of all types are cultured by using structures (long lines, cages, net-pens) the structures themselves may also provide habitat and attachment surfaces for many other organisms such as ascidians, sponges, anemones, and mollusks. It is well known that natural and enhanced oyster reefs are habitat for many different species (Bahr and Lanier, 1981; Breitburg and Miller, 1998; Coen *et al.*, 1999; Posey *et al.*, 1999). However, gear used in all types of aquaculture may also provide similar habitat benefits. For example, Powers *et al.* (2007) found that plastic mesh used in bottom clam culture had significantly greater macroalgal/epifaunal biomass per unit than sandflats and were similar to that provided by natural seagrass. Also, the kinds of invertebrates and juvenile fishes utilizing the clam

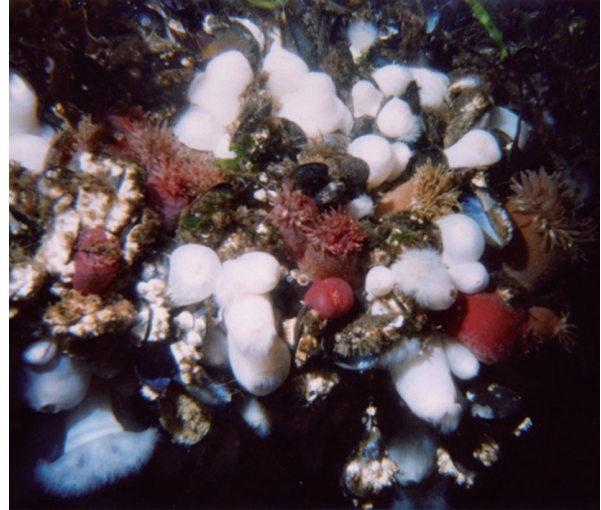


Fig. 9. Collection of white anemones (*Metridium senile*) and other diverse invertebrates on a walkway float of a net pen in Puget Sound, Washington. (Photo credit: Jack Rensel, Rensel Associates Aquatic Sciences, Arlington, WA)

leases were similar to seagrass habitat. Overall the biogenic habitat created by the aquaculture gear was more diverse than without the gear (**Fig.8**). In addition, Rensel and Forster (2007) surveyed fish net pens in Puget Sound, Washington to quantify the types and volumes of biofouling organisms and found that the typical net pen system there was populated by a diverse group of over 100 species of seaweeds and invertebrates, many of which are important components of the food web (**Fig.9**). Some were also commercially important (e.g., mussels and kelp).

Economic Sustainability

The collapse of some fisheries, plus other economic and environmental factors (e.g., fleet consolidation, hurricanes) have resulted in a loss of jobs for some fishers and support industries in coastal areas involved in the seafood business. Aquaculture has the potential to stimulate the economy in some locations by directly providing jobs in aquaculture, and indirectly by servicing boats, seafood processing, marketing, transportation, and other positions that help keep and maintain working waterfronts (Rubino, 2008). For example, results of one modeling study predict that the number of jobs created across all sectors per thousand metric tons of production per

year would be 102 jobs for mussels, 261 for salmon, 475 for cod, and 683 for scallops (Posadas, 2004). When the development is properly scaled for the location and region, it can create entrepreneurial opportunities that have a ripple effect in local economies (Soto *et al.*, 2008b).

Monitoring and adaptive management

Adaptive management (Fig.10) is “a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood” (Williams *et al.*, 2009). It is a process that allows for flexible decision making that takes some degree of uncertainty into consideration and adjusts actions and decisions to resolve the issue or problem. The process improves understanding of a resource system and tests key assumptions through monitoring. Monitoring and adaptive management are key to developing ecologically resilient and sustainable aquaculture projects. Adaptive management is a tool which should be used not only to change a system, but also to learn about the system. Because adaptive management is based on a learning process, it improves long-term management outcomes. In this way, decision making simultaneously meets one or more resource management objectives and, either passively or actively, accrues information needed to improve future management (Holling, 1978).

Conclusion

NOAA’s National Marine Fisheries Service has long recognized the importance of implementing ecosystem-based fisheries management in order to explicitly account for environmental changes and make trade-off decisions for actions that affect multiple species; however, this approach has not been applied specifically to aquaculture. If marine aquaculture is to grow in accordance with societal values, there need to be guidelines and a framework for this effort, just as there are for capture fisheries. Based on a similar definition for an Ecosystem Approach to Fisheries, we define an Ecosystem Approach to Aquaculture as follows: An ecosystem

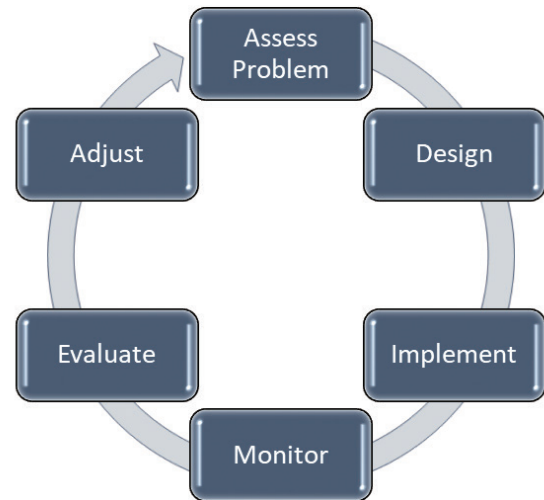


Fig. 10. Conceptual diagram of the six-step adaptive management cycle (adapted from Fig. 1.1 in Williams *et al.* (2009)).

approach to aquaculture is a systematic method of managing aquaculture that: 1) is in a geographically specified area, 2) contributes to the resilience and sustainability of the ecosystem, 3) recognizes the physical, biological, economic, and social interactions among the affected aquaculture-related components of the ecosystem, including humans; 4) seeks to optimize benefits among a diverse set of societal goals and 5) is adaptive over time. The stage is set for an ecosystem approach to aquaculture to flourish in the US. The current small US marine aquaculture industry is an example of where EEA is already guiding responsible and sustainable development. EEA principles are being used in the US, but not as a management paradigm and the use of EEA tools is not widely recognized.

Many factors affecting the success of marine aquaculture in the US are unknown; however, Knapp (2008) cites several examples of offshore aquaculture ventures that indicate a bright future for aquaculture expansion in the U.S. There is increasing interest in, and need for, a more robust marine aquaculture industry in the U.S., including finfish, seaweed, and bivalve farms. The impetus for aquaculture expansion in the U.S., from both an economic and food sustainability perspective, has never been greater.

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Annotated bibliography

- (1) Soto D., Aguilar-Manjarrez J., and Hishamunda, N. (eds), 2008: Building an ecosystem approach to aquaculture, FAO/Universitat de les Illes Balears Expert Workshop (7-11 May 2007, Palma de Mallorca, Spain), FAO Fisheries and Aquaculture Proceedings. No. 14, FAO, Rome, 221pp.

This FAO report summarizes findings from a workshop co-organized with the Universitat de les Illes Balears that took place from 7-11 May 2007 in Palma de Mallorca, Spain on "Building and ecosystem approach to aquaculture" (EAA). Participants defined the phrase "ecosystem approach to aquaculture" and several main principles that should guide the sustainable development of aquaculture. These included the development of aquaculture consistent with resilience of ecosystem functions; improving

human wellbeing; and consideration of other relevant sectors (social, technical, economic, and political). They state that EAA should address the many needs and desires of societies without compromising ecological integrity. The workshop participants also agreed on various ecosystem approaches for different scales (e.g., small or “farm”, regional or zone, and global) and that regulations should focus more on the recipient body of water (e.g., stream, estuary, large marine ecosystems) rather than the scale and intensity of production.

(2) Aguilar-Manjarrez J., Soto D., and Brummett R., 2017: Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture: Full document, Report ACS113536, FAO, Rome, and World Bank Group, Washington, DC., 395pp.

The Food and Agricultural Organization of the United Nations and the World Bank Group convened an expert workshop on Site Selection and Carrying Capacities for Inland and Coastal Aquaculture in December 2010 in Northern Ireland. Spatial planning is becoming increasingly important in the growth of aquaculture and the issues involved require an ecosystem approach to management that addresses larger spatial units than just the individual farm or site. The main purpose of the workshop was development of a guide or handbook for aquaculture site selection and carrying capacity estimation within an ecosystem approach to aquaculture that can be used by a broad range of stakeholders. The publication provides useful and practical information and guidance for managers, policy-makers, technical staff, and aquaculturists about zoning, siting, and management based on experiences and examples from ten case studies in countries around the world. They identify relevant processes and activities for various users on different spatial scales in a systematic fashion.

(3) National Oceanic and Atmospheric Administration, 2016: Ecosystem-based fisheries management policy of the National Marine Fisheries Service, National Marine Fisheries Service Policy Directive 01-120. May 23, 8pp.

Several national laws or mandates require the

National Oceanic and Atmospheric Administration (NOAA) to manage the nation’s living marine resources, including fisheries in a sustainable manner. In order to enable better decision-making among various groups and concerns, (e.g., commercial, recreational, and subsistence fisheries), aquaculture, protected species, biodiversity, and habitats, NOAA is implementing Ecosystem-Based Fisheries Management (EBFM). The policy directive issued in May 2016 is a framework for an ecosystem approach to fisheries, which defines EBFM; describes the benefits of EBFM; discusses how EBFM relates to existing legal authorities and requirements; and establishes a framework of guiding principles for implementing EBFM within NOAA Fisheries. It builds on the NOAA’s past progress and commitment to integrating its management programs for living marine resources and considering interactions among fisheries, protected species, aquaculture, habitats, and other ecosystem components, including human communities in decision-making. The policy defines EBFM as “*a systematic approach to fisheries management in a geographically specified area that contributes to the resilience and sustainability of the ecosystem; recognizes the physical, biological, economic, and social interactions among the affected fishery-related components of the ecosystem, including humans; and seeks to optimize benefits among a diverse set of societal goals.*”

The EBFM policy document specifically mentions aquaculture as an ecosystem component, and NOAA includes aquaculture in the term “fisheries”. Therefore, this document although mostly intended for commercial fisheries, forms the basis for the development of a separate Ecosystem Approach to Aquaculture (EAA) which recognizes the similarities, but also the distinct differences, between “capture” or “wild” fisheries and aquaculture. Although the EBFM directive focuses on “capture” or “wild” fisheries, the language and concepts in it are also directly applicable to aquaculture and, in most instances, the phrase “ecosystem approach to aquaculture”, or EAA could easily be substituted for “ecosystem-based fishery management” (EBFM), and the word “aquaculture” substituted for “fisheries”.

Since there are distinct and important differences between capture fisheries and aquaculture, the

NOAA Office of Aquaculture is developing a separate Ecosystem Approach to Aquaculture (EAA). An EAA is the first step or level along a continuum toward a more complex and detailed plan for implementing ecosystem-based management of aquaculture.

(4) National Oceanic and Atmospheric Administration, 2011: Marine Aquaculture Policy, NOAA Office of Aquaculture, Issued June 2011.

The NOAA Office of Aquaculture developed a Marine Aquaculture Policy in 2011 to enable the development of sustainable marine aquaculture within the context of NOAA's multiple stewardship missions and legal mandates. The document defines aquaculture as "*the propagation and rearing of aquatic organisms for any commercial, recreational, or public purpose*". It includes production for food, wild stock replenishment or restoration (for finfish as well as shellfish and other marine organisms), and rebuilding populations of threatened or endangered species. It contains specific goals with regard to aquaculture

development and management, and provides the basis for the policy and some background information. The policy also describes the benefits and challenges of sustainable aquaculture in the U.S. and sets forth NOAA aquaculture priorities and actions for implementing the policy in terms of regulations, interactions with various agencies and groups in the U.S., and cooperation with other nations. One of the stated goals in the policy is ecosystem compatibility; that is to say, aquaculture development in federal waters should be compatible with the functioning of healthy, productive, and resilient marine ecosystem. In keeping with this goal, aquaculture operators should be held accountable for protecting the species and environment in which they are working. Other goals include compatibility of aquaculture facilities with other authorized uses of marine waters and basing management decisions on the best available science and information.