Sustainability of Applied Aquaculture in the US

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Abstract

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With the current world demand for ocean resources, and the impact that our historic harvesting levels have had on natural systems populations, aquaculture has been introduced as an alternative methodology to traditional wild harvesting for production of food-fish to fulfill this market demand. Aquaculture systems have been developed to supplement needed resources and to aid in the restoration efforts of natural fisheries populations, by mass producing organism to be commercially sold or introduced into natural system. The application of aquaculture in wild fishery restoration and commercial production within the US has greatly intensified over the last couple of decades. Ecological and sustainability issues have arisen in this time as the impact of our actions has become apparent and quantifiable. While both commercial and restoration aquaculture systems serve a believed function in there place in society, their environmental impacts and sustainability must be addressed before expansion in the US continues at the current rate. Identifying the variables that jeopardize sustainability in aquaculture applications in the US is necessary to develop methodologies that maintain native ecological stability and prolonged resource availability.

Table of Contents

Introduction

The global reliance placed on the oceans fisheries for dietary needs and social well-being has created economic opportunities that fuel the exploitation of the resources far beyond the sustainable limits needed to maintain healthy fishery populations and the dependent economies. Just as progressions in other agricultural sciences to domesticate and harness the resources of the land, allowing managed creation of desired crops and animals for surplus and sale, developments in aquaculture have attempted to harness the productivity of the ocean systems by selectively rearing desired aqueous species in artificial environments.

With the current world demand for ocean resources, and the impact that our historic harvesting levels have had on natural systems populations, aquaculture has been introduced as an alternative methodology to traditional wild harvesting for production of food-fish to fulfill this market demand. Aquaculture systems have been developed to supplement needed resources, and to aid in the restoration efforts of natural fisheries populations, by mass producing organism to be commercially sold or introduced into natural system.

The modern global expansion and intensification of commercial aquaculture has lead to serious concerns regarding the existing ecological impacts of production systems and the long term sustainability of the industry. These environmental impacts are evident in the destruction of the ecology in areas used for intense aquaculture systems, the degradation of water quality used by the systems, and in the disturbances to populations of organisms inhabiting the natural system.

The application of aquaculture in wild fishery restoration and commercial production within the US has greatly intensified over the last couple of decades. Ecological and sustainability issues have arisen in this time as the impact of our actions has become apparent and quantifiable. While both commercial and restoration aquaculture systems serve a believed function their place in society, their environmental impacts and sustainability must be addressed before expansion in the US continues at the current rate. Identifying the variables that jeopardize sustainability in aquaculture applications in the US is necessary to develop methodologies that maintain native ecological stability and prolonged resource availability. A better understanding of the ecological and sustainability issues surrounding commercial aquaculture expansion in the US can be derived from the examination of the existing global system. Accounting for the existing systems and the problems that have already been identified should serve as an aid to US development in aquaculture sustainability.

Chapter One

Trends of Global Aquaculture

The various ecosystems created by the oceans, rivers, and lakes of our planet host the most biologically diverse and species rich communities known to exist in our world, acting as one of the most complex biological systems for us to attempt to interpret and understand, but one of the easiest resources for us to access and utilize. The fertility and productivity of our oceans and waterways have fed the people and societies of our world throughout time, and have shaped cultural beliefs, economic proliferation, and global colonization. Historic costal and island civilizations as well as inland populations have all benefited from the resources of the oceans from direct access or through trade. As the human race has progressed through time, and societies and cultures have evolved and grown in complexity and sophistication, so have our efforts in attempt to extract and utilize the resources of our Earths water systems. With our increased efforts, intensity, and effectiveness in harvesting and processing the resources of our oceans and rivers, our world cultures have become more dependent on the resource's availability and abundance.

The ocean fisheries targeted by commercial productions have in general decreased in population abundance, and have been unable to regenerate and maintain populations that would allow long term continued harvest at historic intensities. A society's location in regard to proximity to ocean resources is no longer an issue for resource availability. In modern day times with the expansive capabilities of global trade, and ocean product can be obtained virtually anywhere there is a free market and the appropriate funds are available for acquisition of desired resources.

When examining the use of aquaculture in the context of all global cultures, it becomes apparent that the incorporation of various aquaculture methodologies in societies' agricultural systems created valued food, needed by-products, as well as potential marketable goods. Aquaculture is a complex arena, with a multitude of possible applications and functions. Each system attempts to produce a desired organism or organisms, by providing appropriate conditions and inputs to manage the target species to a harvestable stage in there lifecycle. The goal of aquaculture is similar to the efforts of horticulture or livestock management with the exception that we are dealing with an aqueous environment.

With the wide assortment of desired organisms and their associated environmental needs, aquaculture systems take on many forms and serve numerous societal and environmental functions. Aquaculture systems also vary greatly in their system complexity, intensity, and levels of disturbance to local ecology.

The flexibility in application, and ability to meet economic and social needs, has made aquaculture a valued form of agriculture utilized and incorporated in the majority of the world's cultures (Pister, 2001).

Within the last couple of decades the science, technology, requirements of global fisheries, and consumer demand, has fueled the application of aquaculture to meet global demands. This has promoted the expansion of aquaculture to a level of competitive global commercial production. The global aquaculture market consists of a multitude of systems contributing to the industry, varying in scale, intensity, species focus, and location, all attempting to create a cash crop. The Center for Study of Marine Policy (2002) states that aquaculture accounts for roughly 25 percent of total seafood production, and that fish now account for 16 percent of the world's supply of animal protein (Browdy, 2002).

Aquaculture has developed into a major industry, and is no longer just a component of subsistence agricultural but a system designed to produce cash crops. With an increase in number of systems that exceed the subsistence levels of the population, allowing the operators and proprietors to create an economic good for trade, aquaculture has attempted to meet the global demand for products that traditional fishing and aquatic harvesting methods cannot fulfill, as well as meet the nutritional demands the growing population requires.

Increased interest in developing commercial production of aquaculture goods in the 1950's and 60's was enhanced by the "Green Revolution" and the increased funds invested in large scale agro-businesses in developing worlds, by the World Bank and private US agricultural interests. The main areas of interest for the potential application of aquaculture was to attempt to meet dietary needs of growing populations while creating economic stimuli, both in a manner that was efficient in function and expense.

With the lackluster results in production and potential profitability of early attempts, interest and willing investors dwindled. The growth of commercial aquaculture has been restricted to specific areas of the globe where there is historic cultural significance, local nutritional dependency or an economic climate that creates substantial economic potential from participating (Ryther, 1981).

The science and applicable technology of aquaculture is limited in its development in comparison to other agricultural counterparts and the available science is estimated at twenty years behind that of Horticulture (Tibbetts, 2001). This lack of scientific advancement in methodologies and system control has contributed to the failure to gain the large scale investing that horticulture has experienced, for the fear of inefficiency and profit loss to any investor. Regardless of the lack of US interest, aquaculture has not failed to develop into successful industries in many developing countries utilizing the fundamental methodologies that do exist.

While aquaculture has historically failed to develop into a large scale industry in the US, it has developed intensely, almost explosively, in the Asian, Asian-Pacific countries such as China, India, Japan, Korea, Indonesia, and Vietnam (Levin, 2001)   The US and EU contribute to the global aquaculture market, but the volume is not a considerable amount in comparison, roughly 7% of the production as of 2005 (USDA).   The developmental intensity experienced in these specific areas of Asia is due to numerous variables. The ecology of the area, tropical/subtropical climates, and the abundant available resources of water, river systems, and inter-costal areas all provide perfect conditions for aquaculture production (Nakamura, 1985). The economic status, available work force, and lack of environmental regulatory constraints all contribute for the rapid expansion of operations as well (Shaftel, 1990).

With the lack of overseas funding for current and expanding elements of aquaculture, practitioners are often forced to use available technology and resources in ways that can be more detrimental and have a greater impact on the surrounding ecology. Corporate operations and private large scale agricultural operations are often times preempted with the typical negative connotations, regarding exploitation of the local people, natural resources and economy. But Government funded operations often times have the resources to allow more environmentally responsible operation of the system, than that of subsistence farmers attempting to produce cash crops under the circumstances of a third world economy.

Countries such as India and China have expansive aquaculture programs and private operations and create over half of the global production of aquaculture products, and generating more national income via aquaculture than all other producers combined (Fridley, 1995). This effort to develop aquaculture programs has aided in providing necessary food fish for the population and economic possibilities for the people. But the developments in aquaculture application have also created great environmental concern regarding commercial aquaculture and the associated impacts on surrounding native ecosystems, fisheries, and resident non-target species. There is growing global concern amongst governments and environmental monitoring institutions that there is the need of the institution of regulation and monitoring of aquaculture production, for the insurance of sustainability of the system and market and to aid in necessary environmental protection.

Social, economic, environmental, and general feasibility issues, coupled with varied existing US regulations have suppressed prior growth rates of commercial aquaculture in the US (Mann , 2000) Recent trends in the commercial expansion and requests for agricultural subsidies indicate that aquaculture is the fastest growing sector of agriculture in the US currently (USDA census, 2005). This is not saying much considering the small production level aquaculture currently represents, and the expanse that horticulture contributes to our countries agricultural production, but it does create need for concern in addressing key issues surrounding aquaculture expansion within the US, and the proper steps needed to ensure sustainable practices and beneficial application.

The US has not engaged in the global commercial aquaculture market like India or China. The aquaculture programs in the US are designed and applied to produce for niche markets, with relatively low level production and high return, and also to aid in restoration/management utilization of existing commercial fisheries and species of ecological importance (Gillis, 1995). Federal regulations and restriction with regard to commercial activity in near shore waters and costal waters has reduced the use of these areas for aquaculture production, leaving the availability of expansion to shoreline activity, freshwater systems and land-based reservoirs/manmade retaining ponds.

The majority of the commercial aquaculture production in the US is finfish for food, particularly carp and salmonids-second in production is mollusks; clams, mussels, and oysters (deFur, 1995). The remaining commercial production consists of other food fish, shrimp, tank fish, and ornamentals (ibid). These species are raised in combinations of artificial containment systems and modified natural existing ecosystems. There are many variables of concern with considering the expansion of aquaculture systems in the US, and the current leading global producers, India, and China, are having their industries scrutinized for modeling purposes to developed appropriate management for US resources and industry.

While the commercial aquaculture production in the US is not expansive, the use of the methodologies and technologies of aquaculture for the use in hatcheries has become common place in marine restoration projects. The controlled propagation and rearing of species to introduce into wild populations is a restoration and management technique utilized to increase desired fish populations. The use of aquacultures methodologies to propagate fish species has created a new aid to conservation and restoration efforts but has also brought with it a whole new ration of environmental complications and detrimental impacts.

Chapter Two

The Environmental Concerns of Aquaculture

The environmental concerns surrounding the aquaculture industry are well documented and believed to have far reaching effects on native ecology, local water systems, and various indigenous species inhabiting the surrounding areas if aquaculture systems. Depending on the individual site in question, and the applied methodologies used, the extent of the detrimental environmental impact resulting from the practice of aquaculture will vary. The available technology, materials used, and production intensity often times dictate the effectiveness of the system and the eco-cleanliness of the process.

With the majority of commercial aquaculture existing in developing countries, the systems utilized are lacking clean technologies, and environmental restrictions to control the extent of ecological impact due to systems and their externalities. The economic situation of the people in developing countries, partaking in the operation of aquaculture systems, does not allow for the consideration of the negative impacts to local ecology. But rather the focus of the people resides primarily on the production rate and potential profit gained from the aquaculture system. This is not an intentional evil, or a flagrant disregard of their community's ecological wellbeing, but a consequence of the economic status of the people and their essential need for nourishment and a financial stability.

Exporting dangerous and detrimental processes, and industrial externalities, is a privilege of wealthy nations and often times not an option for developing countries. Developing nations are forced to internalize and deal with processes and byproducts that pose human and ecological threats, until, the developing nation posses the economic stability to export these processes to an even less developed nation or choose to invest in cleaner more efficient technologies.

The quality of life of the people and environmental health of a nation is unfortunately dictated by the economic standing of the nation, and the ability to afford to pay someone else to deal with dangerous products and processes that the country and people do not want to deal with. Those countries that cannot afford this privilege, of pawning off accountability, are then looked upon by the global community as developing nations and utilized as such. Because the majority of aquaculture occurs within these circumstances of economic and social need, and environmental degradation is consistently present, the opinion of aquaculture in developed countries contains the stigma that the process is destructive and detrimental to the environment.

While this negative perception held by the developed countries is supported by some global activity, it would be unfair not to identify the countries that are attempting to make ratifications to the existing and future aquaculture systems to attempt to address the environmental threats. Both India and China are developing extensive programs to promote aquaculture, and are intent on creating systems that can sustain the population with consistent supplies of protein, a marketable product, and ensure minimal environmental destruction (Nakamura, 1995). These countries by no means have completed their goals of rectifying their nation's aquaculture sector, but their efforts and attempts serve as case studies for the future of aquaculture and its potential application, representing the potential of ecologically sensitive aquaculture when proper technology and funding is made available.

The environmental concerns surrounding commercial aquaculture are similar in kind to any other industrial process. The nature and scale of the system, required inputs, created externalities, and the final product, all contribute to the creation of environmental conflict. Understanding the variables that create an aquaculture system and their potential hazards is essential to create change and allow proper management to encourage productivity while mitigating ecological compromises.

The first variable of aquaculture that leads to potential environmental impact is the system location. Aquaculture can take on many forms; land based in man-made tanks or retention ponds, in modified coastal regions and floodplain areas, or in near-shore waters. The location of an aquaculture system dictates the extent of interaction between the system and the surrounding environment, and the ease in which externalities and farmed organism can affect local ecosystems. But, regardless of whether an aquaculture system is in a fully artificial aqueous system on land, or in floating pens in coastal waters, interaction exists between the aquaculture system and local ecosystems just in different levels of directness and intensity. The land based system will interact with the surrounding environment and water system through its effluent waste and escaped organisms, where a costal based system will release externalities directly into water system that it resides in. All systems have impacts on surrounding ecology, but the physical location of the aquaculture system will determine the extent of disturbance to local ecology for the creation of the system and the pathways of externality interactions.

In addition to the physical location of the aquaculture system, the extent of localized ecological manipulation and necessary water utilization required for establishment and maintaining a system has serious impacts on the surrounding ecology. Land based operations can reduce ecological manipulation in that retention ponds are created in clearings and floodplains, and local native ecological systems are not highly disturbed (Meffe, 1992). But these artificial land-based aqueous systems require continual water inputs. This results in deferment of localized surface water systems, or intense ground water pumping for impoundment and utilization in the system. These actions result in reducing flow of the rivers/streams that water is being drawn from, lowering water tables surrounding wells, as well as increasing pollution levels in these water systems as effluent is released from the aquaculture system back into the respective water source (Kreeger, 2000). This reallocation of water to aquaculture systems can reduce available water to other agricultural and social needs, putting strain on the hydrological cycle within a community or watershed, and can drastically change the available quantities of water for both natural systems and human activities.

Costal aquaculture systems potentially create the greatest disturbances to natural ecological conditions. Many of these systems utilize the existing ecological conditions of naturally occurring habitats, but introduce modes to contain organisms within the system, usually levees or retaining walls. This methodology takes a portion of an intact ecosystem and isolates it from natural interaction, and then utilizes its natural function to attempt to support a farmed crop. These areas are productive for periods of time, but without the ability to interact with its surroundings and maintain ecological function, the area decreases in fertility, sustainability, and carrying capacity (Ryther, 1981), creating a weakened ecosystem and sometimes destroying the area by the time the aquaculture system is relocated to a new area. Often times in these natural costal enclosures, or near shore areas that are flooded, the salinity level is modified by either pumping in fresh water or salt water, this can have drastic effects of the local ecology depending on its ability to tolerate brackish, salt or fresh water, and can lead to salt brine accumulation and crystalline deposits that can render soils infertile, destroy native ecology and render the areas unusable for any form of agricultural production for long periods of time (Keir, 1912). This manipulation of costal areas not only debilitates and destroys the native ecology of the coastline but also has far reaching effects on the native species that rely on this area for habitat and nutrients, including birds, reptiles, and other invertebrates.

The next variable of aquaculture that leads to potential environmental impact is the organism of production. Depending on the target organism of the aquaculture system different life-cycle, nutritional, and habitat requirement must be met. Some organisms are less demanding than others with regard to nutritional inputs, and environmental conditions. But other organisms have strict biological requirements demanding continual manipulation of the system to create desired environmental conditions and nutritional needs. Meeting these ecological and nutritional goals can demand intensive inputs and energies spent on environmental control, and ensuring proper nutrients availability, especially in conditions where the target environment varies greatly from the existing ecosystem being used to house the aquaculture system. The target organism dictates the requirements the system, and therefore control the extent of the manipulation of the local ecology to create the necessary environments and the quantities of required inputs to maintain production within the system.

From the simplest monotypic to the complex polytrophic systems of aquaculture, all require nutritional inputs. As aquaculture is an artificial environment the nutrients must be provided for the system. The availability and abundance of nutrients dictates the carrying capacity for the population as well as the growth potential. With the various requirements for nutrients determined by the target organism, nutritional inputs can vary from synthetic chemicals or nitrogen rich animal and human waste to promote algae growth, protein pellets made from ground fish or continual flow of ocean water latent with micro organisms (Baker, 1998).

Most commercial aquaculture populations demand high quantities of protein to ensure growth and health within the systems. The majority of feed supplies for aquaculture systems come from processed wild harvested fish populations, often by-catch and unusable commercial waste and agricultural by products from processing operations as well (Fleming, 1994). Sometime but rarely, feeder fish are grown on vegetative blooms and cellulose material that are in turn fed to the omnivorous target species. The nutritional inputs required by aquaculture systems makes them dependent on the harvesting and processing of wild marine species for system function. This reliance on wild harvest does not help ease the pressure on wild fish populations, or make aquaculture anymore sustainable than traditional fishing operations. Without alternative nutritional sources that are sustainable, the aquaculture industry is dependent on wild fish harvest and does not counter the effects of traditional harvesting methods but rather is an enabler of the existing system in place.

The various components that create the externalities of an aquaculture system pose some of the greatest threats to ecological health in surrounding environment and to sustainability of the system. The effluence, water waste, of the system carries a multitude of contaminants, pathogens, organisms and pollutants that can have severe implications on native ecological health, function and productivity. Herbicides, extraneous nitrates, antibiotics, waterborne pathogens, and escaped organisms can all potentially be present in waste water from aquaculture systems (Kreeger, 2000). Each of the listed variables contribute to the total amount of externalities produced, within the system they play a role in maintaining system health and productivity, when released into native environments via waste water in concentration and in persistent frequency their damage and extent of interaction can not be controlled.

Chapter Three

Commercial Aquaculture in the US

Aquaculture exists in the global community as a major industrial enterprise and as a consistent element of subsistence agriculture in developing nations. Outside the US, large scale aquaculture operations and family farms provide opportunities for a large workforce within developed and developing nations. These systems provide employment, economic and social benefits, and access to nutritional needs, which in turn fuels an industry that contributes increasingly to the world market demand for food fish and inevitably large scale environmental degradation (Metcalfe, 2003). Within the United States we find that these social and economic patterns are not so evident, commercial aquaculture is a regionally restricted activity lacking serious national notoriety, and the use of aquaculture in restoration and resource management programs is similarly restricted with regional application and public awareness. But with the recent tracking of US aquaculture trends it is becoming apparent that it is one of the fastest growing sectors of US agriculture (USDA, 2005) and demands a closer examination of the industry and its counterparts.

The commercial production of food fish, mollusks, and other aquaculture products in the US is a relatively small portion of the overall US agricultural program, limited in national extent and production diversity (Thorpe, 1994). With the first census of aquaculture conducted by the USDA-NASS in 1998 and the second in 2005 (USDA-NOAA, 2005) the historically first comprehensive examination of the US aquaculture sector was established. The census conducted included all commercial and private aquaculture farms generating one thousand dollars or more in annual revenue. The goal of the inquiry was to establish a base line of the location distribution of aquaculture production, products and their respective values, methodologies of operation, surface water acres and sources, and aquaculture distributed for restoration, conservation or recreation.

While the focus of the census played heavily to economic analysis of production capabilities and product value, key environmental variables where identified as well that could help lead to developing methodologies of sustainable expansion. Understanding or at least having the ability to quantify the production methodologies, water usage, organism production rate, and location concentrations allows the incorporation of these variables into watershed and fishery management; creating the possibility for compensation and consideration of the impact of aquaculture on our current natural resource management plans and our proposed ideas for expansion in the future.

The information from the census show us that in the year 2005 there were roughly 4300 aquaculture farms in the US. These farms occupied four hundred thousand water acres of land, producing 1.09 billion dollars a year worth of food fish, sport fish, mollusks, and crustaceans. The highest concentrations of production sites exist in the Southern states of Mississippi, Louisiana, Alabama, Florida, and Texas, in the Northeast region of the Carolinas, Virginia, Maine, and the Pacific Northwest in

Washington and Idaho. The numbers for 2005 were up from the original figures obtained from the census in 1998, showing nearly a ten percent gain in the total number of farms and their production value, and a fifteen percent increase in the total water area of the farms under operation. Following the trend in growth of farm's number and area of occupation, the recorded water usage for operations increased in all areas of interest; surface water, ground water, imported water and salt-water. This industry dependence to water availability, leads to serious questions regarding industry expansion and water usage, and the environmental and social impacts of increasing water diversion to this growing industry.

The majority of aquaculture farms in the US are producing food fish, approximately 1800 farms, almost half of the total number of farms in production. The greatest frequency in farm number and the highest production rates recorded of food fish is occurring in the Southeast. This region constitutes roughly two-thirds of the total US production, with the aquaculture systems almost exclusively being conducted in fresh water closed tank systems, flow through raceways, designed for various carp species and introduced exotics such as tilapia. These closed aquaculture systems take advantage of the regional climate, existing warm water systems, and the native species, allowing for high rates of productivity and successful proliferation of organisms within the system. The inherit productivity capabilities of the warm water systems that can be maintained in the area, and the growing number of farms and intensity of production, has made the Southeast region of the US the dominate producers of aquaculture products. Aquaculture in this region is an integrated part of the social and economic community, creating serious income for residents and dependable, cheap, food for the communities of the area. The rearing of food fish in these areas with aquaculture has become a dependable and profitable alternative to harvesting from wild fisheries, and is widely accepted by the community as a viable alternative for supplying needed food and jobs.

Mollusks and crustacean-based aquaculture systems are second in farm number and intensity within the US, with 980 and 925 farms respectively. These~~s~~ aquaculture systems are predominantly established in the Pacific Northwest and in the Northeast, both areas of high native populations and naturally existing communities. Mollusks appear to be one of the few target organisms of aquaculture that is not grown in artificial environments, but rather the aquaculture systems utilize the natural costal waters and tidal flats of the production area. These systems are mostly cold water environments with the exception of the production that occurs in the Gulf of Mexico. Similarly to the warm water systems of the Southeast, the mollusk based systems utilize the existing ecological conditions and ecosystems that are based in the regions. The development of aquaculture systems in these areas is a byproduct of the traditional harvesting methods of wild populations.

The initial discoveries of the resource, mollusks, in these areas lead to unsustainable harvesting of naturally occurring communities of native species. As industrial harvesting of the resource intensified, it became apparent that management of native species and the creation of controlled areas of production were necessary to maintain productivity of the industry as well as allow ease in which to access the resource and control its location and availability. While the food fish production of the Southeast is primarily a locally utilized resource, the products of the mollusk industry are valued nationwide and are exported outside the US as well (Policansky, 1998) creating a much different economic and social scene. The production of these aquaculture products is an engrained practice that contributes to the cultural identity of the areas and is a necessary portion of the economy.

The bulk of the current aquaculture industry in the US is divided between food fish and mollusk production; these systems take advantage of two distinct environmental climates and water conditions. The mollusk industry utilizes the Cold water environments of the Northeast Atlantic and the Northwest Pacific, the food fish systems focus around the warm water systems of the Gulf of Mexico, Mississippi river basin, and the South Atlantic. With the difference in climactic and ecological conditions the systems utilize different operational parameters catering to the existing conditions, aiding the productivity and system function. Each system type creates its own ecological concerns that relate to water quality and native ecological health such as, effluence content, native species interaction, water allocation and misappropriation, native habitat reduction and regional ecological degradation. The wide range of ecological concerns that are identified when examining the inputs, system parameters and externalities of US aquaculture industry warrants proper planning for sustainable expansion that considers the environmental variables, economic contributions of the industry, and the social role in region. These environmental issues of concern surrounding future expansion of the aquaculture industry of the US will be addressed in a future chapter.

Chapter Four

Aquaculture in US Resource Management and Restoration

Commercial aquaculture has experienced rapid growth in both practice and production within the US in the past thirty years. Developing into a sizable industry, aquaculture production contributes to regional economies, world markets, and to the overall agricultural production of our nation. While commercial aquaculture in the US is a profitable and growing sector of agriculture, other forms of applied aquaculture outside the commercial arena, used in restoration and recreation in the US, are equally important to include in creating plans for future management of public resources and expansions of sustainable aquaculture.

The Federal Government has had a hundred year history of incorporating hatchery practices into public resource management and restoration efforts (USDA, 2005) The effects of early industrial exploits of commercial fisheries became more than apparent in the late eighteen hundreds, and salmon harvests of the Pacific Northwest and California began to suffer (Towle, 1981). The necessity for artificial supplementation to fishery populations and management of the resource was deemed more than necessary. The National Fish Hatchery System was established by the U.S. Congress in 1871 through the creation of a U.S. Commissioner for Fish and Fisheries, this lead to the development of the first federally run hatchery and Salmonid restoration program in the country almost 120 years ago (Black, 1994). The System is now administered by the U.S. Fish and Wildlife Service, and is currently comprised of 70 National Fish Hatcheries, 9 Fish Health Centers, and 7 Fish Technology Centers (USFW, 2005).

Along with the expansion of federally run hatchery infrastructure and technology, public policy and laws have been enacted to structure the commercial and restoration efforts in the US. The National Aquaculture development act, "put in place in 1980, directed the Secretary of Commerce, in consultation with Secretaries of Agriculture and Interior, to develop a National Aquaculture Development Plan… to identify those aquatic species that could be cultured on a commercial or other basis and to set forth for each species a program of necessary research and development, technical assistance, demonstration, education and training activities" (USNADA, 1980)

Later ratifications to the Act further required the "Secretaries to conduct studies of the capital requirements of the aquaculture industry, to provide advisory, educational and technical assistance to interested persons, encourage implementation of aquaculture technology and to provide informational services… ratifications went on to establish the Secretary of Agriculture as the permanent chairman of the Joint Committee on Aquaculture and directed the Chairman to establish the Office of Aquaculture Coordination and Development. It also established the National Aquaculture Board composed of 12 private sector representatives and authorized appropriations" (USNADA, 1980)

The responsibility of this board was to create a management plan for potential expansion of the aquaculture industry, identifying key production species, effects of restoration efforts, and potential exotic/invasive species and environmental complications. The early developments of aquaculture implementation and management by the federal government in 1871 established applied aquaculture in the US, but it was the laws allocating management authority to FWS and USDA, and the millions in funding, that sparked the interest in commercial expansion of aquaculture and the unrealized potential that the role of hatcheries could play in restoration efforts.

Federally run hatcheries and associated science centers are just a portion of the total number of hatchery systems contributing to restoration efforts in the US. While Federal hatcheries have extensive funding, a large range of organism in production, and state of the art facilities; various State, Tribal, and private run hatcheries also contribute considerably to the total volume of organism produced for recreational sport fishing and the restoration of natural fisheries, threatened/endangered species (Fleming,, 1994). Washington State alone houses over one hundred state run hatcheries that provide for and estimated seventy-five percent of the total salmon catch from the native fisheries (Levin, 2001). This cooperative of hatchery operations is arguably the driving force keeping salmon in Northwest waters.

In the US today the role of hatcheries constitutes one part of a three piece approach used in restoration efforts to counter the dwindling populations of threatened and endangered aquatic species. The current methodologies utilized by Federal and State agencies alike attempt to initiate restoration efforts and build populations back to sustainable levels by targeting improvement and modification to three main variables of the situation; target organisms and their community habitat, the supplementation to native populations via hatchery input, and reduction in commercial, Tribal, and recreational harvest from fisheries.

In a hypothetical situation, approaching a restoration project with the current methodologies, the three main variables of the approach seem to encompass the primary objectives that would be thought to be needed to address the situation and to ensure positive restoration effects. There is regard and importance placed on the need for habitat and the associated improvement or creation of caring capacity for the system, the incorporation of hatcheries allows for the introduction of organisms at controlled levels to contribute greatly to native populations, and the reduction of harvest allowing fished population to have time to recover to sustainable levels. But the problem that exists is that two of the three main variables are not able to fulfill their roles in the restoration process.

Though habitat restoration projects are abundant, well funded, and becoming more and more effective in reconstituting disturbed habitat, the existing proportion of viable habitat in comparison to disrupted or nonviable areas within a watershed cannot support historic populations or populations that would not be considered threatened for many of the species that restoration efforts revolve around (Waples, 1994). The extent of damage to our freshwater systems through urbanization, agricultural expansion, road systems, dams, and industrial pollution can not be mitigated with the small extent of intact and restored habitats created and expect true ecological recovery in such a short time period. These improvements to the habitat conditions within water systems is a valiant effort to aid the inhabitants of the natural system, but restoring sporadic reaches of a river system that provide ecosystem function cannot offset the levels of disruption and loss in function the water system as a whole has suffered (Fridley, 1995). Nor is it possible for the available habitat that has been restored to support a self regulating population that we harvest so intensely.

Reducing the commercial catch is also very tricky and is not easily negotiated or enforced. With numerous State fleets and international fleets all harvesting from associated fisheries, monitoring and maintaining set harvest levels is highly demanding. The only effective measure to regulate and decrease harvest seems to be the incremental reduction in available population within the fishery itself. With current US and Canadian protection regulations implemented on some salmonid species, reducing the commercial harvest to a lower level at this point would eliminate the profit of the industry (Tibbetts, 2001)

The inefficiency of two of the three variables used in fishery restoration leaves a tremendous burden on hatcheries to compensate for the situation, and attempt to keep the restoration functional or at least the species population from hitting extinction levels. For many restoration projects the hatcheries function serve as a life support system for the organism within the system, continually supplementing the native population in order to attempt to maintain a semi-functioning system of individuals. The intention of a restoration effort is to aid the endangered population in reaching a self perpetuating population, by providing adequate habitat for life cycles, decreasing the harvest levels, and introducing groups of compatible individual organisms to the wild population, with the optimistic chance that the species and system will eventually regain self regulating stability.

This vision of restoration has become distorted from its original intentions. We now find ourselves stuck in a cyclical process that demands huge inputs of individuals into a system that cannot support the population naturally, to attempt to maintain a population that can provide for the dependent industries and not succumb to extinction. The identified negative impacts on native populations and natural systems from hatchery practices stem from the form and function of hatchery systems, consistent with the general ecological concerns of commercial aquaculture. The issues that have abundant scientific interest surround sustainable inputs for the support artificial populations; hatchery practices impacts on native systems, proper handling of externalities and localized pollution, and the diversion of fresh water and proper watershed allocation (Mann, 2000). These key variables are all brought up when dealing with the ecological impacts and unsustainable future of the hatchery process and the needed elements of change.

With the full extent of the long term ecological implications that hatchery practices present still an unknown, the identified disturbances, sometimes even destruction, of natural systems and their respective species by the influence of hatchery operation is becoming well documented These apparent trends are supported with the accumulation of studies and ongoing monitoring of native species/ hatchery offspring interactions and population fluctuation since the introduction of hatchery operations (Pister, 2001). The grandiose attempt to restore disturbed natural systems, with the application of aquaculture to manipulate and control large scale ecological situations has resulted in an unforeseen result. With the current indicators that hatchery operations potentially are doing more harm than aid to the natural system, and the natural populations that are attempting to be aided are now primarily consisting of hatchery fish not native ones. The question for the future development of management strategies is; is it best we attempt to correct the failure of the current management practices to get back on track to original goals for the natural system? Or embrace the situation that has been created and attempt to utilize the technology and application of aquaculture to perpetuate the current situation with modifications to unsustainable practices.

Chapter Five

The Future and Sustainable Aquaculture

The practices and applied methodologies of aquaculture in commercial operations and restoration efforts in the US are not currently contributing to systems that are sustainable in *nature*. The required inputs for the hatchery systems, resulting externalities, and the organisms produced, contribute to degradation of local ecological conditions, stress on the source systems providing inputs, and the disruption and exclusion of native species within ecosystems containing released captive reared populations. The concerns of sustainability surrounding aquaculture, and its contribution to commercial production and fishery restoration, consist of more than ecological issues. Social and economic change is needed in the way we view resources and an increase in the understanding of the limitations and capacity of natural systems to be exploited must be addressed to allow for sustainable progression.

Modifications to both the existing commercial production systems and restoration hatchery operation methodologies must be made to ensure a positive contribution to natural systems and social needs, and to reduce the ecological impact and stress created on other natural resources. A reevaluation of the function and role of aquaculture in natural ecosystems and in our agricultural industry must be addressed prior to the pending large scale expansion within the US, as not to intensify the complications we are currently creating. Modifying the existing practices and methodologies used in aquaculture to enhance the overall system sustainability benefits all parties involved; the consumers, the producers, and the environment, as everyone benefits from the persistent availability of the resource and the reduction in ecological stress and degradation.

While both commercial and restoration/resource management applications must be addressed to ensure positive progression towards sustainability, the scale and context of ecological impact that restoration hatcheries have been shown to have on native species and systems demands priority attention. The system of hatcheries used in restoration and resource management in the US poses the greater threat of widespread impacts on our native freshwater systems and coastal ecosystems than the current commercial industry. Developing plans to aid realistic change within restoration hatchery operation that leads to more sustainable systems, via methodology and application modification is needed to ensure long term effectiveness of system and resource availability. It is necessary to correct the current counterproductive path of applied aquaculture to ensure stability to the natural system and the dependent social and economic variables. Some of the identified inputs of aquaculture systems that contribute to unsustainable practices are the required nutrients, use of antibiotics, herbicides, and the quantities of fresh water allocated to the industry. Examining the sources of the inputs for the system, their long term availability, effectiveness in maintaining the system, and the effect on natural systems once they have left the aquaculture system is critical in developing sustainable methodology.

Most commercially cultured populations exist in artificial conditions for the entire life cycle until harvest, while restoration populations live in captivity until release into native systems. For the full duration of the time spent in the hatchery system, all protein and nutrients must be supplied to the population from an outside source. This outside source can be an agricultural byproduct, waste or by-catch from the fish industry, or a commercially processed protein based feed (Ryther, 1981). The demands of the captive populations require the extraction of resources from other natural systems to supplement the inability of the aquaculture system to self perpetuate. The demands of the artificial system contribute to reduction in the stability and fertility of the natural systems that resources are being drawn from.

Traditional methodologies of aquaculture from China utilized polyculture, or populations consisting of multiple related species, to create stability and a simulated trophic structure within the system. With the incorporation of multiple species, various niches, function, utilization of varying elements, and opportunities are created within the system. The methodologies of mixed population systems have proved to be productive and sustainable, but not as productive as monotypic systems with direct inputs (Nakamura, 1985). This difference in productivity and potential profitability reduces the natural tendencies of commercial operations to utilize these methodologies. If functioning trophic assemblages were identified, the incorporation of polyculture in commercial systems could greatly contribute to the improvement in sustainability, potentially reducing the demand for nutritional inputs, and the associated degradation to current sources.

Antibiotics and other biological control agents such as herbicides and insecticides that serve as key management elements are utilized in aquaculture systems to control disruptive environmental conditions created and to maintain the health of the population (Fridley, 1995). High population densities and species homogeneity create numerous problems within systems, threatening its basic stability and demanding consistent modifications and inputs. Chemical agents are used to attempt to counter the biological side effects and changes that occur in the systems condition resulting from normal operation. Density and composition of the system population allow communicable pathogens to be spread at rampant rates, increasing mortality potential within the population if exposure occurs. Antibiotics and insecticides are applied to control pathogens and vectors of exposure, while highly effective at times, these agents are passed on through the waste water into natural systems affecting all native organisms that comply with the effective parameters of the agents used. Decreasing population density and increasing biological diversity within the system would reduce the tendencies of vulnerability that is exhibited in current systems, ideally decreasing the need for agent inputs.

The density and confinement of populations within hatcheries typically creates superfluous levels of waste in the system. Inefficient means, or incapacity to replace, circulate, or filter the water of the system properly will result in the build up of extraneous nutrients, primarily nitrates. This nutrient rich water can be released into surrounding ecosystems to cause spikes in biological activity, disrupting normal nutrient cycling, or it can remain within the system resulting in undesirable biological blooms within the water column. These biological blooms are detrimental to the aquaculture system and native systems, decreasing available oxygen levels and providing habitat for pathogens and vectors.

Herbicides are used to manage unwanted biological growth feeding on the available nutrients. Like antibiotics, these herbicides are passed on through the water system into native environments, continuing to effect biological systems outside the intended application. Unwanted algae blooms and other biological growth within hatchery systems are an effect of the system intensity and insufficient nutrient cycling within the system, and are managed primarily with chemical agents (Kreeger, 2001). While these algae blooms are not desirable in salmonid hatchery systems, they can serve as nutritional inputs in other aquaculture system types. Numerous carp based aquaculture systems utilize biological growth associated with extraneous nutrients, and are fully incorporated into the larger agricultural system as an externality utilizing function; essentially turning agricultural waste into a valued product, reducing pollution and contributing to the social and economic well being (Tibbetts, 2001).

Current US system designs fail to integrate aquaculture into larger agricultural systems, attempting to operate as an individual process. This lack of integration into a multifaceted agricultural system creates individualistic goals for the aquaculture operation. Developments in system application and agricultural integration of aquaculture to convert agricultural waste to valued product would be a great step in sustainability for application of aquaculture.

The ability to maintaining manageable concentration levels of waste and extraneous nutrients within hatchery systems depends on water availability and the systems processing capabilities. As aquaculture systems exist within water, the availability and abundance of water is essential to the systems ability to be productive. Freshwater availability and its allocation for use, is a mounting concern for the future as resources become limited and the demand increases (Meffe, 1992). Water availability, and the entitlement to access to the water, is a potential obstacle for aquacultures future. With regional droughts and dwindling aquifers, aquaculture will have a hard time arguing for water allocations that will be needed to maintain the horticultural, social and industrial aspects of our culture. Current water allocations and natural availability have limited the capacity for fresh water land based expansion of commercial operations, marine and estuary based commercial operations currently are limited to shore operations exemplified by the mollusk industry. While marine expansion into the economic zone in our oceans has been proposed, there has been not been any approval for these expansions into federally controlled waters.

Some sustainability issues surrounding aquaculture pertain primarily to restoration hatcheries methodologies. The genetic manipulation of hatchery populations and the interactions that occur between hatchery populations and native system has have proven to be counterproductive, and hindered the attempts to aid native population. The genetic manipulation of hatchery populations has impacted the wild genetic composition; roughly 80% of Salmonid species in Pacific Northwest fisheries are hatchery raised, reducing the genetic diversity of wild populations, and effecting the natural distribution of species within respective watersheds. This has caused a decrease in the ability for the population to cope with environmental changes; there is 90-95% mortality rate of salmonid raised hatchery fish once in open ocean conditions (Fleming, 1994). These mortality responses are linked to the loss of temperature and climate toleration associated with historic breeding grounds that has been lost via breeding methodologies of hatcheries. These genetic variations that have occurred within the natural populations have impeded the ability for the species to perform normal biological functions such as returning to breeding grounds and procreation.

The massive insurgence of hatchery populations that were intended to replenish and aid the wild populations has accomplished the total opposite. Wild fisheries of salmon, in the Pacific Northwest, consist of hatchery organisms with the fate of wild genetics in great jeopardy (Thorpe, 1994). The attempt to save wild salmon populations has failed. Existing populations do not reflect the historic genetic composition of the species, and hatcheries are perpetuating a fishery that is essentially foreign to the ecosystem. The natural system interaction that occurs between hatchery fish and wild populations result reductions in wild population's stability, via genetic manipulation and out breeding of native genotypes (Waples, 1994) hatchery fish have out competed and replaced the wild populations in natural systems, proving to be more aggressive and monopolizing available habitat and resources. The manipulation of genetic composition and mass release of hatchery populations is not a sustainable contribution to fishery recovery. While captive breeding might be able to aid populations, introducing a population of engineered organisms will not improve the status of wild populations or strengthen their place within the ecosystem. The current situation requires the operation of hatcheries to maintain the population of salmonid species, despite the fact that the practices are unsustainable and damaging, as long as there is industrial demand and the desire of the people perpetuating the system it will continue. Restoration of salmonids might be possible, the use of hatcheries must be reevaluated to determine how

Creating systems that demand less manipulation to maintain stability, and are more environmentally friendly, currently requires the sacrifice of production potential. Current system models are industrializing a natural process, without the consideration that natural processes demand multiple variables and conditions to be productive. This lack of consideration of function content of natural ecological processes has created a system that has a greater production capacity than its natural counterpart, but none of the sustainable or self-perpetuating properties. While aquaculture has the potential and the ability to serve as an aid in resource management and restoration, its current applications are not contributing to positive change or sustainable systems. Restoration efforts have been able to perpetuate species populations using current methodologies but there have been ecological consequences. The apparent short term gains in population regulation are overshadowed by the looming environmental and system complications that are arising from our efforts. Reassessment of the extent of positive change aquaculture can provide for the management of our resources must be made with the considerations of existing environmental stability and expectations of future progression of natural systems.

Chapter Six

Conclusions and Discussion

The development and expansion of applied aquaculture in the global community varies little from the historic progression of other agricultural endeavors. Production methodologies of aquaculture were identified in systems of subsistence agriculture, and then implemented as independent functions in commercial systems; production potential as opposed to sustainability became the primary objective. The progression of aquaculture as a commercial industry, has allowed an increase in the availability of nutritional needs to the global community, and has contributed to the economic prosperity of those people and nations involved in the industry. But this development in controlled resource production has come at a high cost, resulting in local environmental degradation or destruction and serious negative implications surrounding the impacts on the stability of natural aquatic systems. As commercial aquaculture has attempted to supplement the demand for ocean resources, and divert harvesting from dwindling wild fisheries, the inefficiencies and externalities of the systems have resulted in further unintentional complications and degradation of the oceans resources and natural ecosystems.

The environmental complications resulting from industrialized aquaculture are apparent in the regions of application, and the influences on natural system stability are quantifiably, but the industry continues expanding to fulfill the growing market demand. The identified industry impacts on the environment, and resource sustainability concerns, are beginning to be prioritized into system management approaches and the need for change has been recognized (Fridley, 1995). Developed countries such as India and China that support large, well-established aquaculture systems, are attempting to ratify environmental complications and implement sustainable practices (Shaftel, 1990). The infiltration and redirection of the industry with sustainable practices will inevitably take a long commitment to bringing about change, but is more than necessary to curb current destructive practices and to ensure future resource availability.

The extent of commercial aquaculture development experienced within the US has been regionally restricted, and fails to compare to existing systems in other developed nations. While the US does not suffer from the severity of environmental degradation associated with the global industry, applied aquaculture has left its mark on US fisheries and natural ecosystems. The incorporation of hatchery operations into restoration efforts has reshaped the approach to fishery management and securing resource availability, and has greatly effected the composition and stability of some of our commercial fisheries.

The introduction of hatcheries into salmonid restoration methodology in the Pacific Northwest exemplifies the capacity of applied aquaculture to manipulate large wild fishery populations. Hatcheries were used to compensate for commercial take and general decline of wild populations by supplementing the wild fishery with artificially raised populations. The intentions of the restoration efforts were to reestablish the wild fisheries, and aid in the natural recovery of the species populations. What resulted was a bombardment of the natural system with hatchery spawned salmon that were able to out-compete, and essentially replace the wild populations within the natural system (Gillis, 1995). The wild populations of salmonids that exist today can hardly be referred to a wild at all, with the genetic composition of all salmonids populations consisting of roughly 80% hatchery origin (Policansky, 1998) the system created has not allowed the restoration of the wild populations but replaced them with farmed organisms.

The decision to incorporate hatchery operations into restoration efforts, and attempt to manipulate multifaceted natural systems, now seems to have been a mistake. The effects on the salmonid populations are irreversible, and the system created must be perpetuated by human input to maintain the existing population (Pister, 2001) It is impossible to determine the fate of these species if we had not interjected them with hatchery introductions, but what qualifies our current situation to be viewed as successful or superior to potential natural extinction? The methodologies of aquaculture have proved to be powerful tools in population production and manipulation, and the misappropriation of this technology has become apparent in the ecological impacts that have resulted. The expansion of commercial aquaculture and the continuance of hatchery application in restoration efforts must be reevaluated and intelligently modified to perform desired functions while maintaining sustainable practices. Resource exploitation and natural system destruction is a thing of the past, our future and the future of people, require accountability and intelligent use of our renewable resources. Sustainability is not an option for operational management of industries and resource management but essential to creating systems that we can continually benefit from without repercussions.

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