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New Opportunities for Economic Benefits for the American Southeast in the International Pearl Industry

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Economic participation of the United States in the global pearl industry has been minimal in terms of economic benefits received, although critical in terms of support to the industry. The United States is the primary provider of freshwater mussel shell nucleus and a major consumer of pearls, but economic benefits accrue mainly to foreign companies whereas environmental and economic externalities affect the economy and environment of the southeastern states. The economic role of the U.S. mussel shell industry and aquaculture sector can be enhanced if the mussel shell fishery is stabilized and if options to extract higher returns for the stakeholders are explored. Establishment of a freshwater pearl culture industry can aid in strengthening the U.S. role in the global industry through a variety of means: 1) by providing an economic incentive to conserve freshwater mussel stocks; 2) by establishing a local market for shell nucleus of the smaller size categories; 3) by supplying U.S. demand for pearls; and 4) by providing experimental animals for research and development to create marketable technologies for export to the pearl industry.

The purpose of this review is threefold: 1) to assess options for the United States to derive economic benefits from activities related to pearl culture; 2) to identify current trends in the global pearl industry that potentially affect the freshwater mussel fishery and aquaculture sector of the southeastern United States; and 3) to review development of pearl aquaculture in other nations to extract lessons that may aid in guiding development of a sustainable pearl industry in the United States.

HISTORIC AND CURRENT RELATION OF THE U.S. ECONOMY TO THE GLOBAL PEARL INDUSTRY

The five principal means by which economic benefit can be derived from global pearl culture activities are 1) freshwater mussel shell fishery, 2) manufacture and marketing of freshwater mussel shell nucleus, 3) pearl production, 4) commercialization of pearls, and 5) provision of services and materials to the global industry.

The United States has long played a largely unrecognized, yet key role in the international pearl industry as the principal source of freshwater mussel shell from which shell nucleus is manufactured. Large species of freshwater mussels are fished from the watersheds of the southeastern United States, and the shell is used to manufacture polished beads (nuclei) that form the core of nearly all cultured pearls. Only the American-sourced freshwater mussel shell is universally accepted by farmers, jewelers, and consumers as an acceptable nucleus material. Additionally, the United States has become a major consumer of freshwater and marine pearls, importing $18.6 million worth of black pearls in 1998, $25 million worth of Akoya in 1997, and approximately $8 million worth of South Pacific Pearls in 1998 (Canedy, 1998; GIE-Perles de Tahiti, 1999; Western Australia Fisheries, 1999). The multiplicative value of this import product is unknown, but pearls are the most popular colored gem product in the United States.

The United States has benefited relatively little from the other activities associated with pearl culture. Despite its rich resources, the United States is one of the few nations not to have taken concerted steps to protect its pearl-producing molluscan species and fully exploit the numerous historic and current opportunities. At least seven potential marine pearl-producing species are found in North American waters or in the U.S.–Affiliated Pacific Islands. Many of the 300 freshwater mussel species found in North America produce high quality natural pearls and may be potential culture species.

The reasons for the failure of a North American pearl culture industry are not clear. Pearl producing species are present, basic methods of pearl culture have been known in the United States since Japanese methods were thoroughly documented by the U.S. Department of the Interior in 1949 (Cahn, 1949), and the U.S. aquaculture sector has aggressively pioneered other forms of aquaculture. Although the basic elements of development have been present,

viable pearl production has never developed. Aside from the loss of revenues, lack of a local pearl culture industry has led to the failure to capture other benefits from pearl-related activities. Development of a domestic pearl culture industry might have provided the critical linkage needed to derive greater benefits from the five pearl-related activities described above. Had the shell industry possessed a local market for domestically produced nuclei, if pearl culture technologies had been the focus of research and development, or if the United States were able to supply part of its domestic demand for pearls, the United States might now occupy a niche similar to that of the Japanese in the global pearl industry.

Most pearl culture industries began as pearl fisheries. The United States once had productive, although short-lived, freshwater pearl fisheries throughout much of the continent. Freshwater pearls were one of the first valuable commodities discovered in the New World. Eastern watersheds, from Florida to as far north as New York, produced significant quantities of freshwater pearls until the early 20th century. At times, local freshwater pearl fisheries yielded such valuable pearls that local economies were disrupted because agricultural workers were tempted away to fish for pearls (Kunz and Stephenson, 1908). Unlike the Pacific Rim nations such Japan, China, and India, the U.S. freshwater pearl fishery never evolved into a pearl culture industry and has since dwindled to the occasional lucky finding of pearls by shell fishers.

The United States also has several marine species offering pearl producing potential. Pearl Harbor on Oahu was the source of pearls for the Native Hawaiians and early western colonists (Walther, 1997). The Hawaiian Islands, including the Pearl and Hermes Reef, once possessed abundant stocks of *Pinctada margaritifera galstoffi* and *Pinctada radiata*. The Hawaiian Islands also had a short-lived mother-of-pearl fishery in the early 20th century (Galtsoff, 1933) that ended as stocks were depleted. The U.S.–Affiliated Pacific Islands once had thriving mother-of-pearl fisheries prior to World War II (Clarke et al., 1996). The pearl producing potential of these species is once again being explored but is now limited by low stock abundance in the wake of overfishing and impeded by the lack of recognition of the latent potential. *Pinctada radiata* and *Pinctada colymbus* in the Caribbean, and *Pinctada mazatlantica* and *Pteria sterna* were the basis of longer lived fisheries that ended in the early 20th century (Kunz and Stephenson, 1908; Baqueiro and Castagna, 1988; Cariño and Monteforte, 1995; Monteforte, 1996). The queen conch (*Strombus gigas*) and various species of abalone (*Haliotis* spp.) are abundant in North American waters and produce unique and highly valued natural pearls. Culture methods are known for the latter (Fankboner, 1995), but neither species has served as the basis for a pearl culture industry.

These once abundant pearl producing species represent one of the most potentially valuable natural resources in the New World, yet despite the economic hegemony the United States exerted over much of North and South America, these resources appeared to have largely escaped the attention those seeking opportunities for economic development. Perhaps because early intensive exploitation of pearl-producing species led to their scarcity by the early 20th century, once Japanese researchers had developed reliable pearl production techniques, existence of the potential for pearl culture and public awareness of that potential had largely vanished from the North American scene. Only a few attempts at pearl culture in North America can be considered successful. A freshwater pearl farm in Tennessee operated by John Latendresse is widely cited as a successful demonstration of the biological feasibility of freshwater pearl culture. One of the first commercial pearl farms (for mother of pearl) in the world was established in Bahia de La Paz, Mexico, and currently three pilot efforts to cultivate *P. mazatlantica* and *Pteria sterna* in the Gulf of California exist. These efforts, although small, demonstrate that pearl culture can be feasible in North America either freshwater and marine species (Ward, 1995; Monteforte, 1996).

Contrary to the U.S. and North American experiences, once pearl fisheries depleted pearl oyster stocks, they were replaced by thriving pearl culture industries in a few areas of the Pacific, with Japan, Australia, China, and French Polynesia becoming the major pearl culture nations. Pearl culture is also conducted on a minor scale in the Red Sea and in India. Pearl culture, particularly in the Pacific Island Nations, represents one of the great opportunities for economic development; often the only option in very remote, under-developed locations. As other, less technologically able, nations developed pearl industries, the United States remained on the periphery.

As global pearl culture boomed, the United States benefited primarily as a supplier of freshwater mussel shell. Mussel shell is exported whole or in rough-cut form to be made into

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nucleus in other nations. The United States also became a major consumer of the high-value end product, cultured pearls. This is one of the few instances where the United States has essentially assumed a role similar to that commonly held by the developing nations. For much of the 20th century, a valuable natural resource was harvested and exported in a relatively uncontrolled manner at low prices in a scenario rife with economic externalities with subsequent reimportation of a "processed," high-value end product. This could be viewed as a means of redistributing wealth with the pearl producing nations as beneficiaries and the United States as contributor. Export of low-value raw shell has also served as a form of economic subsidy to Japan. A cheap and abundant supply of mussel shell for Japanese companies was a major factor permitting Japan to control the global pearl industry during the 20th century. Control of pearl marketing by Japanese firms has further reduced economic benefits to the U.S. economy.

The relationship of the United States to the international pearl industry can be characterized as paradoxical because the economic benefits received are strikingly low in comparison with the important role of the United States as the source of freshwater mussel shell and a major pearl consumer. Typically, the primary supplier and ultimate consumer of a product would benefit much more extensively if these key points of control were acted upon strategically and if it had greater participation in the intermediate stages of pearl production. Instead, the U.S. fishery and aquaculture sectors have allowed opportunities to go unnoticed; thus, foreign pearl production and marketing companies reap most of the benefits that result from a U.S. resource and its consumption.

After a period of explosive growth from 1970 to the mid-1990s, the global pearl industry is now undergoing a period of rapid changes due to a combination of factors that will affect all major players. These changes have shaken the existing status quo of the pearl industry and present new opportunities for the American private sector to enhance current modes of participation in the industry and develop new opportunities. New opportunities can be realized only if the true value of the natural resources is recognized and protected and by transferring applications from the formidable U.S. biotechnology sector to pearl aquaculture.

Current Trends Affecting the U.S. Mussel Fishery and Pearl Culture Industry

Four major trends promise to be determining factors in the fate of the U.S. shell and nucleus industry and will define the boundaries of potential for the nascent U.S. freshwater and marine pearl culture industry: 1) declining Japanese control of production and technology, 2) increasing Chinese dominance in pearl production, 3) rapid expansion of pearl culture into new areas and species, and 4) increasing and diversifying consumer demand.

Declining Japanese production and loss of technological control.—The key to understanding the international pearl industry is the realization of the long-standing and nearly complete control that Japanese pearl companies, supported by the Japanese government, have exerted over nearly all aspects of the industry. Japan has led world pearl production and exerted a wide range of methods to control and used economic benefits from overseas production and consumption for most of the 20th century. The highly successful strategy to which this global control is owed is the vertical integration of all elements of the industry.

The strategy of linking nucleus supply, grafting technology, and pearl marketing gave Japanese pearl companies nearly complete control over the pearl industry. Further reinforcing their control was the sheer volume of Japanese Akoya production, which for many years overshadowed production by other nations. A supply of inexpensive U.S. mussel shell enabled Japanese companies to produce nuclei for domestic use and for export. By controlling the purchase price of shell, and by manufacturing nuclei in other Asian countries where labor costs are low, Japan was able to control the costs of producing a pearl domestically (often of relatively low quality) in what would otherwise be a high-cost production environment.

Exclusive control over grafting technology allowed distribution of nuclei to be tied to the provision of grafting services. Two types of technology are required to produce pearls: 1) basic culture; and 2) grafting technology. The basic culture methods are fairly simple and do not differ substantially from other forms of bivalve culture. It is the grafting technology that is unique to pearl culture. Grafting is a surgical procedure by which the shell nucleus is inserted into the tissues of a mollusk along with a small piece of mantle tissue, which grows around the nucleus and deposits layers of nacre, thus producing a cultured pearl. By maintaining a covenant of strict secrecy, Japan was the sole source of trained grafting technicians for many years, and Japanese-trained technicians still offer the most reliable, highest quality service available today (Haws, 1998). The

lock on grafting technology is still the most important factor in enabling the Japanese pearl companies to exert wide-ranging control.

Japan was able to maintain itself as the sole supplier of nucleus for many years because of coercive mechanisms imposed on both the supply and demand side of the activity. A condition imposed on overseas farmers was that only Japanese technicians would supply nuclei. This arrangement allowed Japan to stifle competition from other nucleus suppliers particularly independant American suppliers, who often linked with either the shell fishery or shell export. Japanese technicians and associated pearl buyers also received a share of pearl harvest and, through various arrangements, often acted as the sole purchasers of pearl harvests. The pearl farmer often had little alternative to this integrated arrangement between Japanese pearl companies, grafting technicians, and Japanese pearl buyers. Refusal to purchase Japanese produced nucleus via the technicians or to sell pearls to Japanese buyers was punished with denial of grafting services. Because non-Japanese attempting to market nuclei can rarely provide grafting services, they are essentially barred from entering the market. Japanese control over the three key elements remains strong today, although domestic and foreign players are making inroads into this dominance.

The first infringements on Japanese technological dominance were made by the Australians and French Polynesians, although this was accomplished, in part, because of Japanese participation in ownership of farms in these nations. However, nationals from these countries are slowly working toward increased autonomy as grafting technology spreads and inroads are made into direct marketing to buyers. Other non-Japanese nations are discovering that the basic methods of pearl culture are not highly complex and are easily practiced even in remote locations by stakeholders with only minimal training. However, conquering grafting technology remains a key obstacle.

Plummeting Japanese pearl production over the last 2 yr after a long decline in the 1980s is a key perturbing factor. Production of poor-quality pearls with very thin nacre (<0.5 mm) has long stigmatized Akoya pearls with knowledgeable jewelers and buyers and has led to interest in the better quality Tahitian black pearls and South Seas pearls (SSP). Poor nacre quality is due to greed and environmental problems. Early harvesting of pearls with the slightest nacre coating became a standard practice. Severe disease problems that make long culture periods risky reinforced this tendency to harvest prematurely. Production of the larger size classes of Akoya pearls (>7 mm) has long been problematic.

In the last 2 yr, approximately half of the standing stock of Japanese pearl oysters have died. The cause of the mass mortalities is not completely understood but is widely believed to be linked to poor environmental quality (Canedy, 1998). Given the level of industrialization and urbanization of Japan's coastal areas, coupled with limited success in environmental management, this trend appears unlikely to reverse itself. The case of the Japanese pearl industry is widely regarded as a self-inflicted collapse (Ward, 1995). Recovery is doubtful without resolution of environmental degradation, improvement of culture practices, and several years to bring populations back.

A scarcity of Akoya pearls, which dominate the market for smaller size classes of the white and pink pearls traditionally preferred by American consumers, now exists. Prices have risen 15–20% in the last 2 yr, and much of what is currently being sold is from stockpiles (Canedy, 1998). The Japanese have traditionally stockpiled pearls of all types, which further enabled Japanese companies to manipulate the international market (Rowntree, 1993). How long stockpiles can continue to supply international demand is unknown.

As the Japanese companies continue to suffer financial loss, and as previously secret technology spreads, control over the global scenario will continue to loosen. New areas are being sought for pearl culture by Japanese companies, and their bargaining position may be considerably less strong than it has been previously. More Japanese technicians are expected to begin to work overseas as the domestic need decreases. Previously, demand for Japanese technicians exceeded supply, and if this is reversed, these technicians may also be in a weaker position to act as agents of Japanese pearl companies in enforcing the vertically integrated control structure. The decline of Japanese pearl production and loss of technological dominance have both positive and negative implications for the U.S. aquaculture sector, as well as providing lessons in industry management. These lessons are discussed below and should be heeded if the United States is to avoid similar mistakes while learning from the successful Japanese strategies.

Expanding Chinese dominance.—Another perturbing factor in the pearl industry is the dramatic increases in the volume, quality, and va-

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riety of Chinese freshwater pearls seen in the last few years. Historically, Chinese pearl production was of predominantly small, irregularly shaped, low-value freshwater pearls. Chinese freshwater pearls have only recently begun to compete with Akoya pearls, as the latter diminish in quality and increase in price, whereas Chinese freshwater pearls exhibit the opposite trend. Chinese freshwater pearls also come in a variety of attractive natural colors that can be imitated only by Akoya pearls, which have been dyed.

Much of the Chinese production is nonnucleated and is being marketed as a high-quality (all-nacre), inexpensive pearl for the working woman. Ten thousand small farms are believed to exist in China (Ward, 1995). Total production was 600–800 tons in 1998. The size range of round freshwater pearls has increased to 6–10 mm. The production volume of the larger sizes will probably increase. Larger, higher quality freshwater pearls present a potential competitive threat to Australian, Japanese, and future American producers. Although only a small percentage of the total production is round (~5%), this represents a significant quantity of pearls entering the market on a global basis (Ward, pers. comm; Xiuhen, pers. comm.). As methods improve, the percentage of round pearls will also increase (Ward, 1995; Ward, pers. comm.).

The market niche for smaller white, pink, and generally lighter colored pearls is most likely to be filled by Chinese freshwater pearls as Japanese production declines. However, there may be opportunities for this production to be supplemented by American freshwater pearls if a sufficient supply of light-colored, round pearls measuring 2–9 mm can be produced. Increased Chinese production is a clear threat to the Japanese pearl industry and may overshadow American prospects to enter into freshwater production. However, an expanding Chinese industry, whether freshwater or marine, may offer other forms of opportunities to the American aquaculture sector as a potential market for new and improved technologies (see below) (Pearl World, April/May 1999; June/July 1999).

Increasing production in new areas and with new species.—Pearl farming is rapidly expanding in new areas. Indonesia, the Philippines, Myanmar, and Vietnam are increasing production primarily with *Pinctada maxima* but also have stocks of *P. margaritifera* and *Pteria penguin*. Australian production levels, long controlled by a strict management regime that has kept prices for SSP high, will expand because of hatchery quotas (20,000 per existing farm). *Pinctada margaritifera* is increasingly being targeted for cultivation in Australia by aboriginal and other groups who have been previously excluded from pearl production by the quota system. Many Pacific Island Nations have recognized the potential for pearl culture and are making efforts to develop their industry, including the U.S.–Affiliated Pacific Islands and Hawaii. India continues to expand freshwater production and has potential to produce several types of marine pearls. The East African Nations and the islands of the Indian Ocean may also enter the arena. Additionally, Mexico is in the position to become a strong player with *P. mazatlantica* and *P. sterna*, and other Latin American countries where pilots are being conducted or considered (Belize, Venezuela, Brazil, and Ecuador) may soon follow. Abalone pearl technology is slowly advancing (Fassler, 1999), and conch (*S. gigas*) pearls would not be improbable.

The predicted global expansion represents competition to newly established American pearl farms but will also offer opportunities to provide technology and enter into joint ventures. Newer farms could be targeted as consumers of American equipment and supplies because they will be less subject to Japanese control. Further implications are discussed below.

Demand for pearls by U.S. consumers will play a significant role in shaping the direction of pearl industry.—Pearl consumption in the United States has historically been positively correlated with the condition of the economy because pearls are a luxury item (Rowntree, 1993). The status of the United States as the major consumer of pearls will most likely continue as the economy grows, with demand for pearls remaining steady or increasing. Traditionally, white or pink Akoya pearls are preferred by American consumers, but this preference is slowly changing as other types of pearls penetrate the U.S. market and in light of the recent price increases coupled with quality declines for Akoya pearls. For example, the United States became the second largest importer, after Japan, of Tahitian black pearls in 1998.

Although absolute demand will most likely hold steady or increase, the type of pearl consumers prefer should be expected to change dynamically and unpredictably over the next few years. Americans and Europeans are increasingly aware of the diverse types of pearls available aside from the traditional white or

pink Akoya pearl and are becoming more aware of the criteria for evaluating the quality of a pearl. Consumer willingness to purchase other types of pearls and the prices they are willing to pay will probably undergo major changes in the next few years and will be subject to influence by availability, price, and marketing campaigns, factors that prospective U.S. pearl producers must consider.

Opportunities for the U.S. Aquaculture and Fisheries Sector in the Pearl Industry

As public awareness of the existence and significance of the international pearl industry increases, and as the technology becomes available, increased opportunities for the U.S. aquaculture and shell fishery sectors become available. The major opportunities fall into three categories: 1) optimization of the freshwater mussel shell fishery and nucleus industry, 2) development of pearl culture, and 3) creation and marketing of new technologies for pearl culture. Capturing a larger share of the wholesale and retail pearl markets would also be beneficial, but is outside the range of this discussion.

The ability of the southeastern states to continue as the major suppliers of shell and shell nucleus to the pearl industry is widely regarded as questionable and may be facing a crisis. However, the causes and future significance of the purported crisis is difficult to analyze because of a paucity of information and a number of emerging factors. The status of the shell and nucleus industry was reviewed by Fassler (1996a, 1996b). Fassler predicted the demise of the fishery and shell export trade in the face of the increasing demand for nucleus by the booming pearl industry and weak fisheries management. However, the situation has changed in recent years and new trends are emerging that will affect the shell trade.

The shell fishery and fledgling nucleus production industry offer tremendous potential for expanded economic benefits, but realizing this potential depends upon 1) assuring stable and abundant populations to support a shell fishery, 2) eliminating externalities that drive unsustainable resource use and limit benefits to the U.S. economy, and 3) providing technical and financial assistance to support development of a sustainable fishery and nucleus industry.

Conservation of Freshwater Mussel Stocks

Conservation of freshwater mussel stocks is paramount to continued or expanded economic benefits. The most urgent issue under consideration is the preservation of freshwater mussel populations because maintaining the abundance and diversity of the stocks is a necessary precondition to continuing the current fishery and shell trade, and largely determines the fate of the world pearl industry. Should supplies of freshwater mussel shell dwindle, whether from conservation measures such as a reduction or ban on fisheries, or because of the impacts on mussel stocks from other threats such as habitat destruction, the global pearl industry would rapidly experience a crash; no immediate replacements for mussel shell as the raw material for nucleus manufacture are available. Only the Chinese-dominated freshwater pearl production would survive because most freshwater Chinese pearls are nonnucleated (Ward, pers. comm.). Additionally, of the 300 species of mussels, which species may produce the most valuable pearls is unknown, so preservation of biodiversity takes on new economic ramifications if freshwater pearl culture becomes a reality in the United States.

Conservation approaches and strategies for good management of the freshwater mussel fishery are complex topics and beyond the scope of this review. Nearly 300 mussel species with unique life histories and special management considerations are spread over hundreds of watersheds throughout the southeastern United States (Williams et al., 1993). Suffice it to say that unless stocks are protected, and a reliable and plentiful source of mussel shell remains available, the consequence to the United States and the world pearl industry could be dire. The United States has a large stake in protecting the resource, particularly in light of emerging economic opportunities, which are predicated on a continued supply of mussel shell.

Limitations on Economic Benefits and Threats to Mussel Populations

The current shell and nucleus industry is characterized by externalities that limit economic benefits and potentially threaten mussel populations. Before entering into discussion of this topic, the fact that the mussel shell fishery and nuclei industry are poorly studied and documented must be acknowledged. Insufficient data exist to fully characterize the many issues of interest associated with this economic activity. The lack of data for a major industry based on species with critical status is in itself an issue of concern. The discussion below is intended to qualitatively identify a limited

range of issues and to propose a model scenario as a premise for further discussion and study.

The mussel fishery is an extractive industry based on a dwindling natural resource, and whether the stocks will support the industry in the near future is questionable. Confronted by habitat destruction, elimination of animal species functioning as host for the glochidia larvae, a poorly managed fishery that may be overfished in both the biological and economic sense, and the threat from zebra mussels, populations of freshwater mussels are clearly at a critical juncture. Resolution of environmental threats to mussel populations must be found, and this will entail careful consideration of the economic and social factors underlying the way in which this resource is utilized and how economic benefits are distributed. The future of the mussel fishery and nucleus industry and the potential to establish freshwater pearl farms in the United States depend on finding means to eliminate the inequitable distribution of economic benefits that may drive unsustainable use and to capture increased benefits for the U.S. economy.

The economic benefits of exploiting freshwater mussel resources have been limited compared with the potential value because of a variety of constraints, many of which can be categorized as economic and environmental externalities. First, the participants in the U.S. shell industry are essentially barred from direct manufacture and marketing of nucleus because of coercive Japanese monopolies in the international arena, in addition to internal economic and technical constraints. Second, the extractive, competitive nature of the fishery coupled with the low price of raw or cut shell as compared with manufactured nuclei or, even more so, cultured pearls creates a classic scenario of the "tragedy of the commons" and may have contributed to overfishing in past years. Third, economic benefits accrue mainly to Japanese nucleus companies and overseas pearl farmers whereas economic disadvantages and environmental damage are manifested in the United States.

The economic benefits of the freshwater mussel fishery were once significant. During the peak of the export market, annual exports were valued at $50 million and employment in the sector was estimated at 10,000 (Cohen, 1994 as cited by Fassler, 1996a). During the period of highest demand, shell export companies competed to harvest the remainders of a common resource, motivated by a classic tragedy of the commons scenario. Law enforcement was inadequate to the task of protecting mussel populations, and poaching was reputed to be common (Fassler, 1996a, 1996b). However, improved law enforcement led to a major fine being imposed on the largest shell company in 1997.

Shell exports decreased to 6,500 tons by 1995 (Fassler, 1996b), and export now appears to have been essentially halted (Pillars, pers. comm.). Freshwater mussel shell is largely exported as whole or cut shell. The few attempts by U.S. companies to manufacture and market nuclei have been limited because of the difficulty of competing with Japanese-supplied nucleus. Because U.S. shell fishers and shell exporters are essentially barred from successful export of their product by the Japanese monopoly on the linked elements of grafting services, nucleus supply, and pearl marketing, the only option is to continue to harvest and sell low-priced raw material for manufacture elsewhere. Extractive fisheries with low-priced products conducted in relatively uncontrolled situations typically end only when stock abundances drop below the level of economic feasibility for the fisher. This appears to have been the case previously during the period of increased demand for shell as the pearl industry boomed in during the 1980s. Although the current status of the fishery in relation to international demand is presently unclear, resource managers would do well to heed lessons learned from the past and take advantage of the current low demand to improve regulation of the fishery in preparation for future increases in demand.

Demand for shell has recently declined because of the dramatic decline in the population of cultured Japanese pearl oysters; mortalities may have been as high as 70% in 1997–98 (Canedy, 1998). The Akoya sector consumes the bulk of the nucleus production and uses the smaller size classes of nuclei. With this demand diminished, the remaining consumers, the black and South Pacific pearl sectors, require much smaller amounts of larger nuclei. These larger nuclei are obtainable only from the rarer, larger shells. Thus, the dynamics of the fishery are changing because of fluxes in demand but remain largely uncharacterized and with little coordinated management between the states, despite the regional nature of the fishery.

American fishers and shell export companies are also vulnerable to market dynamics that are largely controlled by the Japanese companies. For example, shell export has slowed drastically because of the drop in Jap-

anese demand and because the Japanese nucleus manufacturing companies are now utilizing stockpiles of shell purchased from previous years, while American shell exporters have accumulated stockpiles of their own based on Japanese orders but which remained unpurchased (Pillars, pers. comm.). Lacking the option of direct sales to nucleus manufacturers or production of nucleus in the United States, these exporters are suffering economically.

Should demand for nucleus rise in the future as the international industry grows, the same scenario may repeat itself. If the means were found to secure direct control over nucleus manufacture and marketing, American fishers and shell exporters would have less incentive to overfish and would be less vulnerable to market dynamics because profit margins would most likely be higher and the resource users would have more direct control over commercialization of the vulnerable resource. Additionally, enabling U.S. nationals to compete fairly in the market place as nucleus producers and marketers will give new pearl farmers in the United States one of the means to avoid control by the Japanese industry. If pearl farming is established in the United States, it might also provide a local market for nuclei of the smaller size classes, the same size classes that are currently suffering from a decreased demand due to the Japanese collapse.

Even at peak levels, the economic benefit derived from shell export was miniscule in comparison with the value of the finished nucleus or of cultured pearls. Compare the annual export value of mussel shell ($50 million) at its peak (Cohen, 1994 as cited by Fassler, 1996a) with the value of world pearl production of $130 billion in 1998. Little data are available for comparison of the value of raw shell versus a finished nucleus. However, a single finished grade A nucleus in a larger size category (+13 mm) is valued at greater than $50; prices for large nuclei are high because large mussels that have sufficiently thick shells are increasingly rare. A nucleus of this size weighs ~2.0 g, rendering an estimated price of ~$25,000/kilo for large finished nuclei. Cut freshwater mussel shell has a selling price of $10–15 per kilo. Smaller size categories (6.0–7.0 mm) or lesser grades (B, B+) of nucleus typically have prices of hundreds of dollars per kilo.

The price differentials between raw or cut shell, nuclei, and a cultured pearl are even greater. A gem quality grade AA Tahitian black pearl measuring 14 mm may have a farm price of $1,000 or a retail price of up to 10 times that value. A pearl of this would have been started with a nucleus in the range of 10–12 mm, which has a value of $5–$50. Thus, the relatively thin nacre coating of a cultured black pearl, which typically comprises less than 10% of the total weight and is at best 2–3 mm thick, has a value hundreds of times greater than the shell nucleus, depending on the point in the marketing chain at which values are calculated.

The economic disadvantages of exporting raw or cut shell as compared with nucleus manufacture or pearl culture are clear. However whether shell exporters in the United States have had a choice in this is not clear. Although the technology to manufacture nuclei is not complex, introduction and adoption of this technology by the private sector in the United States is slight, giving shell exporters little choice except to sell their shell to Japanese firms at a price fixed by the Japanese. Because shell exporters do not cooperate in marketing, individual shell exporters have little leverage.

Economic Leverage of Shell Fishers and Exporters

Shell fishers and exporters may have greater economic leverage than commonly accepted. Feasible alternatives to freshwater mussel nuclei do not currently exist. A number of freshwater and marine bivalve and gastropod shells have been tested, and all have been found to be inferior to freshwater mussel shell or are not sufficiently abundant (Roberts and Rose, 1989). Efforts have been made to develop nucleus alternatives from synthetic material or from reconstituted waste shell, but cost, properties, and consumer acceptance are problematic.

The Chinese, lacking a cheap and abundant source of nuclei, have developed four alternatives: use of local species, use of poor quality freshwater pearls that are polished until round, use of giant clam shell (*Tridacna* sp.), and new techniques that enable production of large (>9 mm) nonnucleated freshwater pearls. The use of *Tridacna* species is troubling, both from an ecological perspective, because all *Tridacna* species are currently listed under CITES, and because of the tendency for these nuclei to shatter when drilled. No mechanism is in place to detect or bar imports of pearls produced in this manner. Nor are there barriers to importation of "all-nacre" pearls, which have processed freshwater pearls as nuclei, although this may constitute fraud.

These alternatives are inadequate to supply the international market for nuclei and will not be adopted by the other pearl-producing

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nations. International demand for freshwater mussel shell nuclei will continue and possibly increase from the currently low levels as pearl farming expands in new areas. The principal threat to the U.S. position as the sole supplier of freshwater mussel shell in the near future would be declines in populations of target mussel species. If improved management can maintain populations at stable levels, or if these species can be cultured, it is unlikely that economic incentives will exist to develop or adopt use of replacement materials.

Even greater benefits could be obtained from utilization of the mussel resource if enabling mechanisms were put in place to allow fishers and shell exporters to enter into the manufacture and sale of nuclei. A few strategies to consider would be examination of the coercive practices of Japanese companies to determine if these constitute unfair trade practices, financial support and technical assistance to prospective manufacturers, and assistance in international marketing. Shell exporters and domestic nuclei producers may also consider forming a marketing association as a vehicle for resolving common issues. If technical, legal, and marketing assistance were provided to the U.S. private sector to support a strategy of industry development, then a scenario could develop in which the U.S. stakeholders could usurp the position of Japan, which previously controlled all critical points in the global industry.

Opportunities for Pearl Production in the United States

Freshwater pearl production has been demonstrated to be biologically feasible in the United States by John Latendresse, who has produced freshwater pearls for over 20 yr (Ward, 1995). Interest in establishing other freshwater pearl farms is growing in the southeastern United States, but a number of constraints will be faced. Successful efforts have been made in Hawaii and the U.S.-Affiliated Pacific Islands to develop a pearl culture industry with the black lip pearl oyster (*P. margaritifera*) over the last decade, although development has been slowed somewhat by a number of factors, most of which have little to do with the biological feasibility of the endeavors. The same constraints and challenges have also hampered industry development in other nations. It is useful, therefore, to examine some of the constraining factors from other regions in order to develop better strategies for development of the pearl industry in the southeastern United States.

Lack of technology development.—Pearl culture technology, particularly grafting technology, has been a closely held secret until recently. As a result of this secrecy, most methods used today, whether basic culture methods or grafting methods, are essentially the same as those developed nearly a century ago. Pearl farming, although lucrative, is also highly inefficient. Current grafting methods typically result in 30% losses during the first month after the procedure, and of the remaining grafts, only about 10–15% will produce high-quality round pearls. These odds are daunting for new producers and for small-scale farms. Improving culture and grafting technology will enhance chances for establishing successful U.S. farms and lead to development of new products and procedures that may be marketable (Haws, 1998).

Lack of technical assistance.—Although the basic technologies are no longer secret, dissemination of information and the lack of trained personnel to provide technical assistance have hampered industry development. To the best of our knowledge, less than half a dozen qualified pearl oyster biologists are in the United States, and only one of these is employed in an extension capacity. Even fewer American grafting technicians who could work in the region are available. Finding and retaining a qualified foreign technician is difficult for new or small farmers because technicians, who commonly work for a share of the harvest, hesitate to work with farmers whose returns may be low (Haws, 1998).

Lack of technical assistance will be even more critical for the establishment of a freshwater pearl industry. The only model industry is China, and exchange of scientific information is limited. A further complication is that the potential American pearl-producing species differ from the Chinese species, and relatively little is known about the biology, culture, and ecology of these species compared with other aquaculture species.

The resolution of this obstacle would be increased funding for research and training, creation of opportunities for scientific exchange with China or other freshwater pearl producing nation, and allocation of extension resources. Transfer of technology from marine species is also possible and would provide a starting point for species-specific research. Basic culture methods for freshwater species

(Ram and Tripathi, 1992; Ram, 1997) and culture and grafting technology for marine pearl oysters are now thoroughly documented (Cahn, 1949; Gervis and Sims, 1992; Haws et al., 1997, in press; Haws, 1999).

Lack of industry and economic data.—Lack of industry and economic data is a key obstacle to improved benefits and new endeavors. Few comprehensive studies of the economic aspects of the international pearl industry are available to the public. This makes it difficult to engage in industry planning and development, marketing, extension, or promotion of data-based resource management. Among the few available publications are the following: a study focusing on black pearl economics (Rowntree, 1993), a description of the socioeconomic impact of pearl farming in the Tuamotus (Rapaport, 1991), and references to farm economics in Manihiki, Cook Islands (Anderson, 1997). A study of hedonic prices and consumer preferences is currently underway (Haws and Fong, unpubl.).

Given the current situation of rapidly changing productive sectors and markets, lack of even basic economic data increases the risks associated with attempts to increase economic benefits from current activities or establishment of pearl culture. Basic economic studies must be undertaken before freshwater pearl farming or domestic nucleus production is promoted.

Financing the pearl industry.—Pearl industry development outside of Japan was financed through a variety of means. Japanese capital provided a start for farms in Australia, China, Indonesia, and the Philippines. Many pearl farms in these areas are still owned or controlled by Japanese interests. The strength of Japanese capital to control local pearl industries led to bans or strict controls by several nations on foreign investment in pearl farming, although these measures are rarely effective given the lack of local capital and the Japanese control over technology. At the same time, these regulations, which are meant to protect domestic industries and producers, penalize the undercapitalized producer and well-intentioned foreign investors from other nations. As long as technology remains difficult to access and developing nations lack resources to support local development, legal foreign ownership or participation will remain problematic for both the investor and the local producer.

However, opportunities do exist for American investors to create joint ventures with foreign partners in many areas. Members of the aquaculture sector and shell fishery should consider under what circumstances joint ventures represent a viable alternative. If American partners can provide technology and nuclei, facilitate communications, market, and cooperate in good faith as equal partners, American investors or joint partners are likely to be welcomed.

The flip side of the coin is the role of the foreign investor in American pearl-related businesses. Anecdotal evidence suggests that foreign investment may be influencing activities related to pearl production in the United States and Latin American. As freshwater pearl culture or a nucleus industry develops, the American public sector and research institutions must play a role in countering the potential negative impacts that have occurred in other nations where foreign investment coupled with corrupt business practices have swayed the course of development of the pearl industry. These dynamics commonly lead to economic and environmental externalities at the cost of local industry. These problems can be countered by maintaining transparency, assuring equitability in allocation of public resources such as land and water, and stipulating that public research monies serve the public good. Examination of the experiences of other nations that have allowed heavy foreign investment in natural resource utilization such as pearl farming reveals that these conditions, fundamental to a free market economy in a democratic country, may be placed in jeopardy when powerful foreign investors manipulate public institutions that lack the experience or will to adequately oversee these issues.

A better alternative would be to catalyze and support industry development with local ownership through the usual channels used to promote economic development, such as grants, small business development loans, and provision of technical assistance. Priority target audiences should be shell fishers, shell exporters, or other rural groups in need of alternative economic options. Encouraging local ownership will also help with management issues because stakeholder participation is key when regulation and law enforcement are not equal to the task. However, risk levels must be reduced and good planning methods employed if pearl farming and associated activities are to be considered as viable candidates for this type of funding.

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Environmental Crises and Management of the Pearl Industry

The historic trend observed throughout the world's pearl fisheries is that of boom-and-bust. Pearl fisheries have existed for thousands of years but peaked in most regions in the late 1800s and again in the early 20th century, spurred on first by increased transportation to remote tropical areas and industrialization that made possible the mass production of mother-of-pearl objects. The introduction of diving technology proved to be the final nail in the coffin for most pearl fisheries and rapidly reduced populations in many areas to below levels of economically feasible fishing. Remnants of regional pearl fisheries persisted after the Second World War, but prices were depressed once plastics were introduced.

Despite the reduction in fishing pressure in most areas, stocks have been generally slow to recover even after long periods of no fishing. An example is that of the island of Suwarrow, Cook Islands, which supported a pearling industry during the first 20 yr of this century. Pearling ceased in the 1930s, but the population has not returned to its original abundance even after 60 yr of protection. Similar failures of populations to rebound have also been noted in the atolls of the Federated States of Micronesia and the Marshall Islands (Clarke et al., 1996). Although the southeastern United States will establish an industry with a different class of bivalve, low stock abundances will impose similar constraints as those resulting from overfishing in the Pacific.

When pearl culture arrives on the scene, populations may rebound and exceed sustainable levels. This may have occurred in some islands of the Tuamotus and Manihiki in the Cook Islands (Rapaport, 1991; Anderson, 1997), where rapid stock increases are most likely due to cessation of fishing, artificial spat collection, and aggregation of breeding populations of pearl oysters on farms. Once stock levels rebound, environmental problems may result from proliferating, densely stocked farms. Similar phenomena of stock enhancement may occur if freshwater mussels are aggregated on farms and if a live pearl-bearing mollusk has a higher economic value than its shell.

Although some research has been conducted on carrying capacities and environmental impacts of pearl culture (Intes, 1982a, 1982b; Haws, 1995; Vacelet et al., 1996; Anderson, 1997), insufficient data exist to reliably establish appropriate farm densities or total allowable limits for specific farming areas. This type of environmental research is a requirement for establishing a sustainable industry and should be undertaken well in advance of the expected growth of pearl farming in the southeastern United States. Appropriate farm and environmental guidelines can then be developed.

The consequence of failure to manage the industry has been illustrated repeatedly. Overfishing and unidentifiable diseases, attributed to environmental changes, wiped out the first culture efforts in the Gulf of California in the 20th century (Monteforte, 1996). Takapoto, the first site of intensive pearl culture in French Polynesia, experienced severe disease problems and mortalities in 1985–86 as the number of pearl farms skyrocketed (Rapaport, 1991; Vacelet et al., 1996). The famed Japanese freshwater pearls from Lake Biwa, which once supplied most of the world's freshwater pearls, disappeared as a result of pollution after 1984. Most tragically, after the example of Lake Biwa and after more than a decade of warning signs, the Japanese Akoya industry is being devastated by what are possibly environmentally linked diseases (Ward, 1995; Canedy, 1998).

Management of the pearl industry needs to assume two forms. In the early days of an industry, steps must be taken to protect the usually low levels of stock from exploitation. Early-stage pearl farming may be in competition with a mother-of-pearl fishery. Protective measures may assume the form of limited entry, individual quotas, total industry quotas, control of marine concessions, limits on the use of SCUBA gear for collection, and bans on foreign investment. As stock levels rebound or as hatchery and spat collection methods increase the number of farmed animals, management becomes more concerned with not exceeding the carrying capacity of farming areas by limiting the total number of farms or limiting the number of pearl oysters per farm. Restrictions on the transportation of stock may be imposed to maintain genetic variation and prevent transfer of disease. French Polynesia requires permits for spat collection and grafting and licenses concessions, whereas Australia has a sophisticated comanagement scheme limiting the total numbers of farmed pearl oysters. However, even the best management regimes are weakened by the lack of enforcement capacity or corruption.

Federal and state agencies in the United States will face similar challenges in establishing coherent management plans and a supporting regulatory system before the establishment of pearl farming. Currently, little inter-

institutional coordination of regulatory agencies exists in the various states, despite the regional nature of the mussel shell fishery. Federal agencies currently lack the resources and directive to promote integrated management of the mussel resources and their habitats. With the potential for pearl farming appearing, the need for integrated regional management efforts becomes critical. The first step in assuring that the shell fishery and future pearl industry are sustainable is recognition by the various institutions and stakeholders of the need for closer communication and cooperation. Policy-relevant research and sharing of information will also lend itself to this effort.

Opportunities for the U.S. Industry to Become a Leader in Research and Development and Provide Marketable Technologies

The United States, with its advanced aquaculture, biotechnology, and industrial sectors, is in a good position to usurp the role of the Japanese as the global technology provider to the industry. The United States also has the advantage of possessing both freshwater mussel and marine species that produce pearls, thus providing ready opportunities for research and development. However, the United States would do well to learn from the Japanese experience and adopt the attitude that positive cooperation and equitable distribution of economic benefits is the strategy that is most likely to lead to long-term success in this role.

The current technology employed by most of the pearl industry is sufficiently inadequate that many opportunities exist for improvement. Only 5–10% of harvested pearls sell for enough to earn a profit because of the inability to control pearl quality and losses during the culture period. Enormous room for improvement exists, particularly related to grafting (Haws, 1998).

The role of technology provider to the global industry has been targeted by researchers and extension agents at the University of Hawaii Sea Grant Extension Program, who, in collaboration with the University of Hawaii Hilo, have established the International Pearl Research and Training Program as a priority focus area. Initially, work will center on applied research to improve culture and grafting methods and development of marketable technologies. Training programs will enable residents of Hawaii and the U.S.–Affiliated Pacific Islands to take jobs in the industry, including pearl grafting. Armed with improved methods and skills and backed by a cooperative research and extension program, these trained personnel are expected to be highly competitive.

This strategy is partially based on the model provided by the role played by southeastern universities and the aquaculture sector, which became world leaders in providing technology to the international shrimp industry, as well as establishing shrimp farming in the southern United States. The lesson to be learned from this model is that even if production of a particular species never becomes widely established in the United States, an even greater economic value may lie in providing trained personnel, technology, and equipment. The Southeastern Sea Grant Partners and Universities are well positioned to build upon this platform to become leaders in the international freshwater pearl culture industry. Additionally, the southeastern states can offer technical assistance and commercial relationships with pearl farms that may appear in Latin America and the Caribbean, as well as exploring the possibilities of pearl culture species such as conch.

Conclusion

The international pearl industry is in flux, and the dynamic situation offers opportunities to new players in the field. The situation in the southeastern states is also changing rapidly as the mussel shell fishery undergoes significant changes and freshwater pearl farming emerges as a major opportunity for economic development.

American stakeholders in the public and private sector are presented with two possible outcomes for U.S. participation in the global pearl industry. In one scenario, the American mussel fishers, shell exporters, researchers, and resource managers fail to adequately assess the opportunities presented and fail to learn from the experiences of other pearl-producing nations. Public and private stakeholders prove themselves to be lacking the capacity to rapidly and flexibly adapt to playing a new role in the global economy while protecting valuable endemic natural resources. In this scenario, the freshwater mussel fishery is ended as mussel populations decline, the pearl industry loses its primary source of nucleus, and the fledgling attempts to establish an American pearl production sector grind to a halt. Without a source of experimental animals and with no industry to support research, the U.S. aquaculture sector also lacks the means to create marketable technologies for export, such as

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improved grafting methods. In this scenario, the United States remains marginalized with respect to the global industry.

In the opposing scenario, means are found to sustainably manage the shell fishery. Stablizing mussel populations establishes base conditions necessary to optimize the economic benefits through development of a local nucleus industry or to establish better marketing mechanisms for the sale of shell. In this more positive scenario, stabilization of the shell industry can be enhanced through establishment of domestic pearl farms, thus providing a domestic market for nuclei and creating an economic incentive to preserve mussel stocks. Once these cornerstones have been laid, the even more potentially lucrative role of technology development and delivery can be assumed by the southeastern private sector and research institutions.

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