

Emerging Aquaculture Species for Recirculating Systems in the Northeast U.S.

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ABSTRACT

Emerging species are organisms for which we have enough information, regarding biology, nutrition, morbidity, etc., to allow individuals to attempt to culture them with some difficulty. With emerging species, there will be information a culturist would like to know that is still lacking; for example, market and economic information. Only highly knowledgeable fish culturists will be successful in culturing these species. Which aquatic organisms can be considered as emerging species for recirculating aquaculture will vary with the individual's knowledge and interest. This paper is an attempt to disseminate information on several freshwater, brackish and saltwater species that appear to meet the 'emerging' definition. Their inclusion as emerging species does not imply they are profitable to produce and market. Freshwater species include: barramundi, walleye, carp, white sucker, and grass carp. Brackish or saltwater species include: bay scallops, blue crab, mummichog, ornamental fish and invertebrates for the pet industry, rainbow smelt, cobia, European oysters, American oysters, bloodworms and sand worms, green sea urchins, black sea bass, and several species of aquatic plants.

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INTRODUCTION

Terrestrial agriculture has been practiced for over 10,000 years. Culture of aquatic organisms has been documented for over 2,500 years (Milne 1972). Harvest of fish from the wild has been practiced probably as long as hunting. Terrestrial agriculture has narrowed down the number of species, especially in animal agriculture, that are most profitable and useful to farm. Aquaculturists are still working to determine which aquatic species are the best and/or most profitable to culture. There are many species that are commercially cultured, some in natural waters and some in culture systems of various types. Relatively few species have been cultured in recirculating systems.

More than 38 species of fish were stocked in the natural waters of the northeastern region of the U.S. in 2005, mostly by state agencies and the U.S. Fish and Wildlife Service. These fish amounted to over 2.3 million kg in weight, and over 355 million individual fish. There are more than 110 species commercially cultured in the Northeast (NRAC Situation and Outlook Reports 2008). Thus, the technologies necessary to at least grow all of these species exists, although it may not allow culture throughout the entire life cycle. Culture techniques for some of these species are well-known (e.g. trout), while for other species, culture is currently limited to some modification of wild harvesting methods (e.g. grow out of oysters).

There are several other aquatic species for which production technologies are not well known, or for which other limitations preclude significant culture. These species may be divided into two categories: 1) emerging species, and 2) experimental species. Emerging species are defined here as species for which there is currently limited commercial culture occurring based on results of research on the species. The knowledge base is still limited, especially commercial culture information, and commercial culture may or may not be profitable. Experimental species are species for which there is insufficient information on biology, production techniques, markets, diseases, etc., to allow commercial culture to be successful. Basic information on culture of these species is still being developed in research laboratories, and in a research mode in industry.

In the Northeast U.S. there are three different natural environments in which fish, shellfish, plants, and other aquatic organisms are cultured. The first of these is the freshwater environment, which is the primary production environment in states including West Virginia, Maryland, Pennsylvania, New York, Vermont, and others. Common commercial species in these areas include several species of trout, tilapia, goldfish, koi, and several aquatic plant species. The second environment is brackish water, including the Chesapeake Bay and most of the coastal bays in the Northeast. Water in these areas ranges in salinity from essentially 0 ppt to approaching sea water strength (35 ppt). Estuarine animals such as oysters, clams, and striped bass, and a variety of halotolerant plants inhabit this environment. The third environment includes the ocean and bays close to the ocean having salinities of approximately 35 ppt. Commercial species in these areas include some clams, some macro species of algae such as Spanish moss, and many species of saltwater fish. In addition, there are temperature variations that tend to divide the Northeast U.S. into coldwater species, typical in New England, in mountain areas, and in deep waters, and coolwater species that tend to be found in the Mid-Atlantic region. Culture methods vary widely from simply providing screens to exclude predators in the natural environment to complete recirculating systems.

Thus, the Northeast U.S. has great variability in habitats, species cultured, culture methods, and environments available for culture. In addition, 21 percent of the U.S. population lives in the northeast region (U.S. Census Bureau 2008). This leads to user conflicts for water resources, coastal sites, legal limitations, “NIMBY” conflicts [not in my back yard (or in front of my beach house)], conflicts with wild fisheries and shipping, and many other limitations on culture of aquatic organisms. However, the region’s population also represents a tremendous market for fish, shellfish and aquatic plants. Recirculating systems are a method that resolves many of these potential conflicts, minimizes water and other resource use, and provides excellent product quality on a continuous basis. This latter attribute is of great interest to buyers at premier markets, and is one that may provide a marketing edge for recirculating systems.

The natural environments described do not limit recirculating systems in the Northeast, except in terms of economics. For example, if it costs more to provide the required temperature for a tropical species when grown in

the cooler Northeast, this could be a limitation. Salinity, temperature, and most other variables can be adjusted to the desired levels in recirculating systems. However, people tend to buy products they are familiar with and are confident about how to prepare and serve. Therefore, while raising unfamiliar species in recirculating systems may be possible, the market must be available in order for the endeavor to be feasible from a business standpoint. An aquaculturist only makes money when the crop is sold at a price above what it cost to raise. Marketability is often a constraint that has little to do with recirculating systems (or any other type of production system) but may determine the potential for development of a species or product.

Having set the stage for the natural environment in the Northeast U.S., let us turn to emerging species that provide potential for aquaculture in recirculating systems in the region. Brief discussion will be given on each species, and some controversial viewpoints will be included to spark further thought. This discussion will not necessarily include all emerging species.

FRESHWATER SPECIES

Barramundi (*Lates calcarifer*)

Barramundi are native to the tropical and semi-tropical Indo-Pacific region, including the entire north coast of Australia (Native Fish of Australia 2008). They are known by many local names including barra, silver barramundi, giant perch, palmer perch (Native Fish of Australia 2008). They are catadromous (i.e. growing to maturity in fresh water and moving downstream to spawn) and start life as males, becoming female later in life. Their white, flaky flesh and their fighting ability make them a sought-after sport fish. In natural settings, barramundi eat crustaceans, mollusks and smaller fish, while juveniles feed on zooplankton.

Barramundi are currently raised in recirculating systems by at least one company in Massachusetts. Fingerlings are imported from Australia at approximately 0.5 g. They are raised in freshwater with an alkalinity and hardness of at least 100 mg/L. In recirculating systems, they take approximately one year to attain a market size of 0.7 kg (Buttner *et al.* 2008a).

The literature provides considerable information on the environmental tolerances of barramundi, including their temperature and oxygen needs (Glencross and Felsing 2006, Katersky and Carter 2007); ammonia tolerance (Okelsrud and Pearson 2007); and growth rate, feed conversion ratios, and feed consumption (Williams *et al.* 2006, Katersky and Carter 2007). Information is also available on diseases (Parameswaran *et al.* 2008). To some extent, culture techniques are established, and they are currently farmed in recirculating systems. One big difficulty in production is the shortage of a dependable fingerling supply (Buttner *et al.* 2008a).

Walleye (*Sander vitreus*)

Walleye have been cultured for at least 35 years, mostly for stocking by natural resources departments (Bartley *et al.* 2007). Walleye is a well-known sport fish in the midwest and northeast regions of the U.S., and is grown by a few producers in the northeast region using cage culture and ponds (Buttner *et al.* 2008a). Culture methods are thus available including for recirculating systems (Aneshansley *et al.* 2001, Summerfelt 1990). Canada markets 7,585 metric tons of walleye to the U.S. from wild catch. Market studies have also shown that there is widespread acceptance of walleye as a food fish in the U.S. (Intensive Culture of Walleye in the United States 2006, Delwiche *et al.* 2006). However, commercial culture of walleye is not widespread, mostly because of this species' specialized requirements to produce a market-sized fingerling (Intensive Culture of Walleye in the United States 2006). Buttner *et al.* (2008a) classified walleye as a research species for the Northeast. This species has been produced in recirculating systems, a considerable volume of research is available on its environmental needs, feeding, stressors, and other factors, and a market appears to exist, so it would appear to be an emerging species in the Northeast U.S. It is not clear, however, why this species is not more widely grown. Economics may be a significant factor.

Carp (*Cyprinus carpio*)

Common carp are widely grown and cultured in Asia and other locations around the world. The culture techniques are well known and the production technology exists. They are hearty fish that will withstand environmental conditions that would kill or seriously stress many other fish species. However in the U.S., lack of consumer acceptance limits production. The price is low and the market volume limited. The catfish

industry faced a similar problem in the 1970s in the Northeast. It was nearly impossible to sell catfish in the Northeast because consumers identified catfish as a fish to be eaten only when they could not afford saltwater fish such as cod and haddock. Extensive advertising and consumer education by the catfish industry has reversed this perception of catfish and there is a good probability that a similar reversal could be accomplished for carp through similar methods.

In addition, the use of carp in value-added products such as fish sausage (Buttner *et al.* 2008a) may provide another method to make carp culture in recirculating systems economically feasible. This will also require considerable marketing, consumer education, and product development to penetrate the consumer market.

White Sucker (*Castostomus commersonii*)

White sucker (also called mullet, bay fish, brook sucker, common sucker) is most often raised as a bait fish. Adults will grow to 30 to 50 cm in length and typically reach 0.9 to 1.8 kg in weight. Although the flesh is firm and good tasting, it is rarely found on restaurant menus, probably because the name does not lend itself to marketing. Also, there are significant economic constraints in raising white sucker to the larger sizes required by restaurants. However, white suckers are used for processed products such as fish sticks, soups or chowders (Fish of the Great Lakes 2008). Young white suckers are commonly used for bait by sport fishermen when fishing for bass and pike. For this reason, bait is likely to be the primary market for any culture operation growing these fish at the present time.

Currently there are a few live bait producers in the Northeast that capture live suckers during the spring spawning run. Their eggs are stripped, fertilized, incubated, and hatched, and the resulting fry are reared in ponds. Suckers grow faster than golden shiners and usually achieve a size desirable for fish bait in one season (Buttner *et al.* 2008a). The ability to reach saleable size in one season in natural ponds suggests that they would grow even more rapidly in recirculating systems, thereby permitting a greater turnover in a facility. However, for production in recirculating systems there are questions about the most desirable feeds: in ponds they eat a variety of naturally-available foods, and in natural systems, juvenile white suckers eat plankton. When they reach 16 to

18 mm in length their mouth shifts to the underside and they become bottom feeders (White Sucker 2008). Because the price of white sucker as a smaller bait fish is higher than the fillet price, the time to market is shorter, and there is less risk to the producer in raising smaller fish. White sucker producers will find the bait market more desirable than other markets.

White suckers are also widely used as a test subject for pollution detection and in laboratories to determine toxicity of various chemicals (Dorval *et al.* 2005). Whether or not this represents another potential commercial market for this species is currently an unanswered question.

Grass Carp /White Amur (*Ctenopharyngodon idella*)

Grass carp are native to rivers in China and the Soviet Union and have been introduced into over 50 countries, primarily as an aquatic weed control agent (New York Department of Environmental Conservation 2008, Buttner 2008a). They are well known as effective biological control agents for a wide range of nuisance aquatic plants (Sutton and Vandiver 2006). In the U.S. there are several states that treat them as nuisance species, and importation into many states is illegal. Import limitations are generally related to grass carp's potential for escape into natural waters of the state, and their tendency to radically disrupt the natural aquatic ecosystem. Thus, anyone considering producing them must confer with their state department of natural resources (or similar agency) to determine the status of grass carp in their state. Some states only allow stocking of triploid grass carp (e.g. New York and West Virginia). Thus, grass carp triploids provide greater market potential as they are acceptable in more states. Culture techniques are known but market and economics may limit their production.

SALTWATER / BRACKISH SPECIES

Bay Scallop (*Argopecten irradians*)

Bay scallops are relatively fast-growing bivalves, but in New England they will not reach market size in one summer. Overwintering is problematic in the harsh winter climate and often results in very high mortalities. Relatively little attention has been directed to their culture. Bay scallops are mobile, and must be contained when grown in the natural

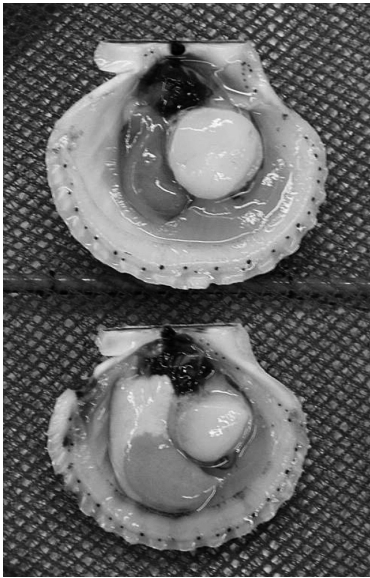


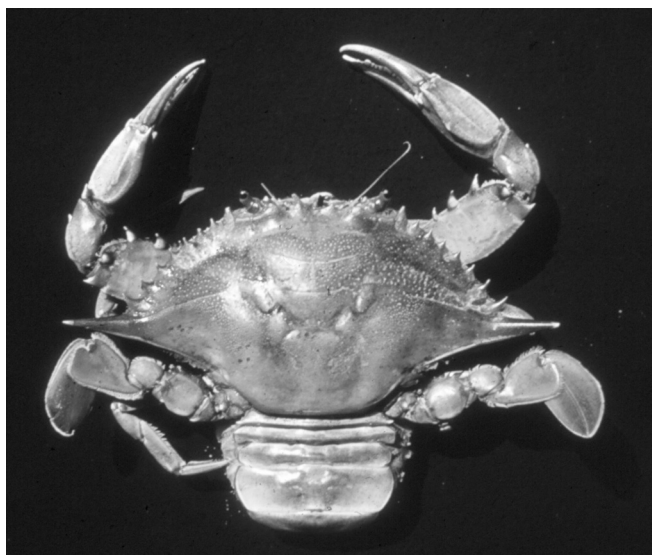
Figure 1. Triploid bay scallop (top) and diploid bay scallop (bottom) raised under the same conditions. Note the larger size and larger-sized adductor muscle of the triploid (by permission from Leavitt *et al.*, 2006).

environment. Some culture has been done using lantern nets, but labor requirements are high and costs can become prohibitive (Buttner *et al.* 2008b). Recent work has shown that triploid scallops will grow faster than diploids and often reach market size in one summer, thereby eliminating the problem of mortalities during over-wintering (Figure 1, Leavitt *et al.* 2006). Recirculating systems can eliminate the overwintering mortalities and should allow bay scallops to reach market size in 6 to 8 months or less. However, the economics of production in the natural environment has not been worked out, and has also not been assessed in recirculating systems. For this reason, bay scallops might be classified at the research stage by some people. Markets appear to be available for quality product, but additional market work will need to be carried out on this species.

Blue Crab (*Callinectes sapidus*)

Blue crab (Figure 2) harvesting is a major industry in the Chesapeake Bay and along much of the U.S. East Coast. However, the industry is based on wild-caught crabs, a resource that has been declining in recent years. There is a proven market for hard and softshell blue crabs from the wild harvest (Buttner *et al.* 2008b). The hard shell industry is strictly a wild harvest system. However, watermen harvesting blue crabs using long lines or pots often set aside crabs that show signs of nearing a molting stage. These are then held in either flow-through or recirculating systems until they shed their shell, at which point they are removed from the culture system, packed as soft shell crabs, and shipped to market. Soft shell crabs bring a much higher price than hard shell crabs. Recirculating systems control environmental parameters such as temperature, ammonia

Figure 2. Blue Crab
(Source: Wheaton)



concentration and salinity, and the crabs need no feed, as they will not eat during the shedding

process. However, as soon as a crab molts it must be removed from the culture system to prevent cannibalism and keep the crab from growing a new shell.

In the mid 1970s, blue crab aquaculture was investigated by researchers from the National Marine Fisheries Service (College Park, MD, USA). This group developed feeds for larval stages and were able to grow the crabs to market size based on culture techniques they developed. Unfortunately, funding for the project was eliminated before the work was finished. Culture of blue crabs was restarted about 2002 by a research group at the Center of Marine Biotechnology (University of Maryland, Baltimore, MD, USA). This group developed methods to spawn and raise the larvae through the various stages up to young adults. This research was supported as a method of replenishing the blue crab population in the Chesapeake Bay. The group successfully developed mass culture methods for blue crabs and released about 25,000 young crabs (6-30 mm carapace width) into the rivers and bays off the Chesapeake Bay, then followed the released crabs to determine survival rates (Zmora *et al.* 2005, Davis *et al.* 2005).

Thus, culture system requirements are known for spawning and growing blue crabs from egg to adult. However large-scale culture has only been attempted for juveniles intended for stocking wild fishery populations. Culture in recirculating systems has not been done from egg to marketable adult. The economics of such production has not been

explored and the feeding of the adults as they mature has not been done on a large scale in recirculating systems. Thus, the blue crab may be an emerging species, but the economics and growout of blue crabs in recirculating systems both need to be demonstrated. Cannibalism is also a major problem when attempting to grow blue crabs, and until this problem is solved, production will be limited.

Mummichog (*Fundulus heteroclitus*)

Mummichog is an extremely hardy species that is harvested from the wild and sold as live bait and for use in research, including as a pollution biomonitor (Buttner *et al.* 2008b; Fortin *et al.* 2008, Roling *et al.* 2007). Pesek *et al.* (2004) surveyed bait dealers to determine if locally-produced mummichog bait would have a market. They found 25 bait dealers in coastal New England, 41 in New Jersey, Delaware and Long Island, and 45 in the Chesapeake Bay that sold mummichog. This indicates that there is a sizable market for mummichog, but it is market that is currently supplied primarily through the wild fisheries, making it a difficult market to break into from a culture standpoint.

Mummichog has received considerable attention as a potentially viable species for aquaculture. However, there remain several issues that need to be resolved for culture to be viable, including: the determination of optimum stocking densities for growout; the effects of water quality parameters on mummichog (George *et al.* 2008); the effects of various feeds and their efficiency of utilization by mummichog; and economics of culture in relation to competing with wild-caught mummichog. A few producers are currently farming mummichog in ponds, but their long-term success has not been established. Relatively little information is available on production of mummichog in recirculating systems.

PET INDUSTRY FISH / INVERTEBRATES

There are a variety of fish and invertebrates being cultured by small individual growers for the pet industry. The importation of live freshwater and marine fish for the pet industry is valued at over \$660 million per year in the U.S. The largest sector of this market is found in the Northeast. Of the 1475 species of fish traded in the ornamental pet fish industry, only about 30 have been successfully reared in a commercial

setting (Pomeroy 2006). Culture methods for some species are known, for others, methods are being worked out. For a significant number of these species, little is known about growing them in captivity. For example, culture methods for freshwater angelfish (*Pterophyllum scalare*) are known and they are widely cultivated by individuals and a few companies in aquariums as pets and for sale. Clownfish (*Amphiprion ocellaris*) and pygmy angelfish (*Centropyge argi*) are the subjects of a research project led by Dr. Harold Pomeroy from Roger Williams University and involving investigators from the University of Maryland and Black Duck Farm, Ltd, a private marine ornamental fish producer. They are developing feeds and culture techniques for commercial production of these species in recirculating systems with funding from the Northeastern Regional Aquaculture Center. This work has led to the startup of at least one commercial culture facility for clownfish and/or pygmy angelfish. Obviously, not enough is known about many of the other species traded in the pet industry to permit farmers to culture them.

Many of the species sold as pets should be viewed as potential culture species, as the price consumers are willing to pay for many of them is probably sufficient to make culture feasible. Goldfish (*Carassius auratus*) and koi (*Cyprinus carpio*) are ornamental fish that have been cultured commercially for nearly 100 years in the northeast U.S., however, considerable research is needed on other species before they will be viable candidates for commercial production.

Rainbow Smelt (*Osmerus mordax*)

Rainbow smelt are salt/brackish water fish that spawn in freshwater. They are a favorite food for Atlantic salmon and other carnivorous fish, and hence are widely used as bait by fisherman. Some authors have stated that as a baitfish they will bring from \$73 to \$100 per kg (Kricheis and Elliot 1989). Given this price, there is considerable interest in culture of rainbow smelt. Based on culture methods developed by Ayer *et al.* (2005), a few farmers have commercially cultured rainbow smelt as a baitfish. The high price is a big incentive to farm rainbow smelt, however, the bait market's response to increased supplies of rainbow smelt is currently unknown. Information on the economics of production also are not readily available to interested culturists.

European Oysters (*Ostrea edulis*)

The European oyster is a potential emerging species in the Northeast (Buttner *et al.* 2008b), although there does not currently appear to be any commercial production. Concerns about the ecological effects of importing a new species of oyster into the area constrain its introduction in the Northeast U.S. Although *Ostrea edulis* have been cultured in New England in the past (Burke *et al.* 2008), permits to culture these oysters may not be secure. There appears to be considerable information needed to refine hatchery, nursery and growout techniques for this species (Buttner *et al.* 2008b). Burke *et al.* (2008) has shown there are reproducing populations of *Ostrea edulis* in the waters of Eastern Canada.

Sea Worms (*Various species*)

Sand worms (*Nereis virens*, also called ragworm) and bloodworms (*Glycera* sp.) both show promise as developing species for culture. Currently there is limited culture of these species, but the scale of production is very small and is not a major commercial enterprise for most producers. Worms are widely used for bait, mostly by sport fishermen. They can be sold for good prices by bait dealers, which makes their culture attractive in some locations. Traditional recirculating systems would probably have to be modified to support culture of these species.

American Oysters (*Crassostrea virginica*)

The University of Delaware pioneered production of American oysters (Figure 3) in recirculating systems in the early 1970s. They were successful in producing American oysters for about \$40 per bushel at that time. However, commercial wild caught oysters were selling for about \$10 per bushel at that time, and competition with the wild-caught oyster was not economically feasible. There is a much greater shortage of American oysters today due to the drastic production declines in the Chesapeake Bay and Delaware Bay,



Figure 3. American Oyster (Source: Wheaton)

which are the result of to disease, over harvesting, pollution, and other factors. Thus, it may be a good time to again explore the feasibility of culturing American oysters in recirculating systems.

Oyster production currently requires phytoplankton as feed for the oysters. In the last 30 years much has been learned about algae and phytoplankton production. In addition, much has been learned about manufacturing feeds in particle sizes that are <100 microns in diameter, which is what oysters require. Combining advances in phytoplankton production and microparticle manufacture may greatly reduce the cost of feeding oysters, the primary cost found in the University of Delaware studies on oyster production. The ability to control disease in recirculation systems may also make oyster culture much more possible from an economic standpoint today.

Green Sea Urchin (*Strongylocentrotus droebachiensis*)

There is a limited wild harvest of green sea urchin (Figure 4) in New England. There has been considerable research conducted on culturing green sea urchin as it brings excellent prices in the Japanese market. The sea urchin is little used in the U.S., but there is commercial interest in developing cultured sea urchins to meet overseas demand. There are several research groups in the U.S. that have worked on the culture of sea urchins. Feeds have been developed for the sea urchin, spawning and nursery methods have been developed, and growout methods are currently under development in the natural environment and in recirculating systems (Walker 2006). Although knowledge of green sea urchin



production economics and of markets is very limited, the green sea urchin is a potential commercial species in the Northeast.

Figure 4. Green sea urchin (by permission from Walker, 2006)

Figure 5.
Water lily
(Source:
Wheaton)



Aquatic Plants

Aquatic plants are being raised to supply the ornamental plant market, the aquarium trade, to restore wetlands, and more recently, as a method of removing various pollutants from runoff water, hatchery outflows, and other waste sources (Lazur 2007). Many aquatic plants are very beautiful and are sold to consumers for their backyard ponds and other uses (Figure 5). Plants that can rapidly take up heavy metals, nutrients such as nitrogen or phosphorus, or other pollutants are also becoming important. The use of aquatic plants to restore wetlands also represents a potential market. Considerable research needs to be carried out to determine the “best” plant species for specific applications. However, the commercial industry is currently supplying plants for all of the uses discussed.

Black Sea Bass (*Centropristis striata*)

Black sea bass are a highly desirable sport and commercial fish caught from Maine to Florida. There is a growing demand for the fish for food and to make sushi. Production of black sea bass has been demonstrated in recirculating systems (Skidaway Institute of Oceanography 2008, Northeast Fisheries Science Center 2008). Feeds are available for black sea bass, and the culture techniques have been defined. There is limited data on the economics of commercial culture in recirculating systems.

Cobia (*Rachycentron canadum*)

Cobia is a saltwater tropical and subtropical fish native to the waters of Australia and much of Southeast Asia (Benetti *et al.* 2008). Thus, it requires a relatively high temperature for maximum growth rates (about 25 to over 30 degrees C). In the Northeast, this relatively high temperature requires considerable energy for temperature control. Cobia is considered an excellent species for aquaculture because the fish has a high fecundity, is relatively easy to spawn using induced or natural spawning, is adaptable to confinement in tanks and cages (Benetti *et al.* 2008), has a high growth rate (Faulk *et al.* 2007), is adaptable to commercially available extruded diets, and has high-quality fillets (Holt *et al.* 2007).

Cobia is currently raised by at least one producer in the Northeast U.S. and a second in the Southeast U.S. They are commercially produced in Taiwan, Australia, Marshall Islands, Puerto Rico, Bahamas, Belize, Mexico and Brazil as well as several other countries. Thus, much information is available on spawning, egg incubation, larvae culture, temperature tolerance, growth rates (Sun and Chen 2009), feed requirements, and other environmental parameters. Cobia's rapid growth and good feed conversion make it a potential species for production in recirculating systems in the Northeast. The economics of production and marketing of cobia from recirculating systems is not well understood and is an area needing additional research.

Summer flounder (*Paralichthys dentatus*)

Summer flounder are found in the wild from Maine to Florida where they support a commercial and sport fishery (Colburn *et al.* 2009). They are a high-value, much sought after fish which makes them of interest to culturists. The literature contains considerable information necessary for culture. Because females grow much faster than males, methods of producing only females for culture are ongoing (Burke *et al.* 1999). Research on the best stocking densities (King *et al.* 2000), temperature tolerance (Schwarz *et al.* 2003), culture methods (Burke *et al.* 1999), diseases (Hughes and Smith 2003) as well as other studies on environmental parameters for culture have been done. Thus, considerable information is available for individuals interested in raising summer flounder, although there is still much to be learned about the species. It appears that the market for this species is good.

Summer flounder have been raised in recirculating systems and in net pens in the Northeast U.S. There is at least one major producer of summer flounder in New England and summer flounder have been raised in recirculating systems in West Virginia. Thus, the technology for raising summer flounder in recirculating systems exists but the economics have not been established enough for a major industry to develop. As research continues and industry begins to produce summer flounder, the potential for this emerging species in the Northeast looks good.

CONCLUSION

There are many possible aquatic species that could be classified as emerging species. What is 'emerging' and what is still a species classified as 'needing research' is open to many interpretations and often depends on the individual making the designation. To be an emerging species there needs to be considerable information available on culture of the species. This should include information on feeds, environmental needs, water quality needs, diseases, biology and other information. Generally, there is enough information on the species listed above for knowledgeable people to grow these species. There usually is additional information that remains to be discovered, and there is often considerable information missing regarding marketing and economics of production and distribution, particularly at the commercial scale. Thus, culturing emerging species is a risky operation and should only be attempted with knowledge of the potential for loss.

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