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Emerging Issues Regarding Non-Native Species for Aquaculture

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Aquaculture in the United States faces many environmental issues. Despite oversight by U.S. federal and state regulatory agencies and despite sustainability efforts within the aquaculture industry, advocacy groups and the public are concerned about the effects of aquaculture on the environment. Specific concerns include the effects of effluents and nutrient-loading; water, land and energy use; feed composition; drugs and chemicals; and food safety. These issues challenge the growth and sustainability of aquaculture.

One of the greatest concerns has to do with the potential for non-native species, genes and pathogens to escape from culture systems and enter the environment. Four of the main emerging topics related to non-native species in aquaculture are:

- the culture of new species,
- introduced pathogens and parasites,
- genetic alterations of native stocks, and
- genetically modified organisms (GMOs).

These topics are not all negative. For example, new species and GMOs may someday increase food supplies and improve the economics of U.S. aquaculture. Unless they are properly managed, however, these issues could cause economic losses to disease or lead to more restrictive regulations. It is important for the U.S. aquaculture industry and those who support and regulate aquaculture to understand these issues, address the environmental concerns, and participate in the process of defining and managing risks.

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Non-native species

Non-native species may be raised for their favorable culture characteristics, to diversify products, to meet market demands, or to improve profitability. However, non-native species may escape from aquaculture facilities or during transport, or may be released by purchasers if a live product is sold. Some non-native species may establish permanent populations and become invasive, causing harm to the environment, economic activities (including aquaculture), or human health. More information on the risks associated with non-native species can be found in SRAC Publications 4303 and 4304.

Producers who plan to culture new non-native species should investigate pertinent regulations before spending time and money. The possession and culture of non-native aquaculture species is primarily regulated at the state level. Federal regulations mainly pertain to interstate and international commerce. Because state regulations differ, producers should contact their state agriculture, fish and wildlife, or natural resources department for specific regulations. The "injurious wildlife" listing by the U.S. Fish and Wildlife Service (USFWS) under the Lacey Act is the main federal regulation. This information is available online at *http://www.fws.gov/fisheries/ans/ANSInjurious.cfm*. Injurious wildlife may not be imported into the U.S. or transported across state lines except by permit from the USFWS; possession of injurious wildlife within states is regulated by state agencies.

Producers should understand that proposing a new non-native species for culture may cause concern among scientists, regulators, or environmental groups. Even if the new non-native species is approved, stronger risk management requirements may be imposed, which will increase production costs. Proposals to culture large, predatory fish or species with a history of invasiveness may cause the greatest concern, but many other aquaculture species could be problematic as well.

Expanding the uses of non-native species already being cultured, especially those cultured in small industries, may also trigger increased scrutiny and potential regulation. For example, adding fee fishing to an existing barramundi (*Lates calcarifer*) operation caused the Florida Fish and Wildlife Conservation Commission to conduct a risk analysis of barramundi culture, re-evaluate existing regulations, and subsequently increase restrictions on the possession and culture of all *Lates* species in Florida (Fig. 1).

Figure 1. The addition of fee fishing at a barramundi culture facility prompted a full-scale risk analysis that resulted in increased culture restrictions. These regulatory changes and the unfavorable attention this species received eliminated the small industry growing barramundi as a food fish. (Photo by D.B. Pouder and J.E. Hill).

Regulators may mandate the use of biosecure facilities or sterile stocks such as triploids for non-native species; such requirements might make production economically or technically infeasible. Species that are unlikely to survive outside an aquaculture facility (such as tropical species in temperate zones) may face fewer regulatory hurdles, but this is not consistent across all states or all species. Some states have specific regulations and culture requirements to prevent the escape of tilapia and some tropical aquarium fish even though these species would not survive winters except in warm sewer or power plant effluent or geothermal springs.

Producers who ship aquaculture species in interstate commerce must be familiar with federal regulations and those of the receiving state. This is especially important when shipping a non-native species to a state for the first time. Illegal shipments across state lines are violations of the Lacey Act and subject to federal prosecution. ***Ignorance of regulations is not a valid excuse or legal defense.*** The USFWS has an online document that explains the injurious wildlife provisions of the Lacey Act and penalties for violations. It is available at *http://www.fws.gov/fisheries/ans/pdf_files/InjuriousWildlifeFactSheet2010.pdf.*

Both current regulations and the potential for regulatory change must be considered when planning any aquaculture venture. This makes the commercial development of new non-native species a potentially risky business enterprise. Producers who are already culturing non-native species should be aware that state and federal regulations may change over time and affect their business. Examples at the federal level include listing snakeheads and some Asian carp as injurious wildlife and recent initiatives to institute national lists of approved non-native species (e.g., HR 669; *http://www.govtrack.us/congress/bill.xpd?bill=h111-669*).

Pathogens and parasites

The importation and spread of non-native pathogens and parasites are major concerns for the U.S. Department of Agriculture/Animal and Plant Health Inspection Service (USDA/APHIS), state agriculture agencies, and federal and state natural resource agencies. Non-native pathogens and the diseases they cause are often called emerging or foreign animal diseases. Some of the recent, high-profile diseases of fish are Infectious Salmon Anemia (ISA), Spring Viremia of Carp (SVC), and Viral Hemorrhagic Septicemia (VHS) (Fig. 2). In mollusks there have been problems with *Perkinsus marinus* (perkinsosis or Dermo), Multinucleated Sphere X (MSX), and Quahog Parasite Unknown (QPX) diseases. Other aquacultured species have similar examples.

Pathogens may be imported along with fish or other aquaculture species, moved from facility to facility, or moved between cultured and wild stocks. Producers should follow recommended biosecurity practices, such as quarantining new stock, to prevent pathogens from entering culture facilities (see SRAC Publication 4703). It is sometimes advisable to screen for specific pathogens before bringing new stock into culture facilities. Failure to plan for biosecurity can result in reduced production, unhappy customers, agency intervention, and economic losses.

Many pathogens are widespread and already endemic in the U.S., and many are not. When emerging diseases are detected, the government may respond with dramatic action. For example, entire fish farms have been depopu-

Figure 2. Gizzard shad with hemorrhages caused by viral hemorrhagic septicemia (VHSV IVb). This virus has caused mortalities in a variety of wild fish species in the Great Lakes Basin but to date it has not been found in culture facilities. Agencies have attempted to control the spread of this disease by banning the movement of live fish that have not undergone fish health inspections. (Photo courtesy of Dr. Paul Bowser, Cornell University).

lated to control SVC and the movement of live fish from areas with VHS has been prohibited to prevent its spread (Fig. 2). Actions such as these can severely disrupt operations and could halt sales for extended periods of time, in some cases years.

There are varying opinions on the danger introduced pathogens pose to cultured and wild stocks. Certainly, some pathogens have caused major losses. Viruses have caused the most concern in recent years as methods of detecting them improve and as more examples of viruses infecting cultured or wild fish accumulate. It is particularly difficult to assess the risk from viruses because uncertainty is high and the losses from some viruses have been considerable. Opinions are influenced by the history of human and livestock epidemics, the often dire warnings in the media of human influenza pandemics, the difficulty of treating viral infections, and a general "unknown factor" associated with viruses. The "unknown factor" includes the fear that there are many highly pathogenic viruses in fishes and other aquaculture species that have yet to be identified. Even with biosecurity programs such as health certification and screening for specific pathogens, the fear that all aquatic species carry dangerous viruses can lead to many restrictions on the importation, culture, or interstate shipment of aquatic species.

More information about emerging diseases and aquatic animal health programs may be found at *http://www.aphis.usda.gov/animal_health/animal_dis_spec/aquaculture/* and *http://www.fws.gov/aah/aah-ep.html.* Various state agencies and land-grant universities also have programs on emerging pathogens and aquatic animal health.

Genetic alterations

Aquaculture producers are frequently advised to raise native species to avoid the potential problems associated with culturing non-native species. However, the genetics of captive populations of a species will be different to some degree than the genetics of wild populations of the same species. Then, if captive individuals escape and interbreed with wild stocks, there may be genetic change in the wild populations. Interbreeding may be especially problematic for small, wild populations of imperiled species.

One kind of genetic change is the introduction of genes not found in the wild population, such as occurs if cultured hybrids breed with wild fish. More often, though, there are changes in the frequencies of variants or alternate forms of genes called alleles. Some genetics experts consider these changes, which they call genetic contamination by native aquacultured species, to be worse than the effects of non-native species. Although this opinion is debatable, the issue of genetic contamination is increasingly important for aquaculture.

Genetic contamination is most likely to occur where large numbers of captive individuals may escape, as with net pens, floodplain ponds, or shellfish leases, or where captive individuals are stocked into public or private waters. An example would be the escape of native species such as cobia (*Rachycentron canadum*) or snappers from net pens located in coastal or offshore marine waters. Concerns about genetic contamination have led to restrictions on the commercial culture of native species even where it is unlikely that captive individuals would escape. An example is the prohibition on the commercial culture of native sturgeons in Florida to prevent the escape of individuals into breeding populations in the northern portion of the state. Even though the probability of escape under sturgeon culture Best Management Practices (BMPs) is low, only non-native sturgeon may be cultured in Florida.

So when is a native species not a native species? When it is raised in aquaculture. That is the essence of the genetics contamination issue as it pertains to the interbreeding of captive and wild stocks. The genetic composition of cultured populations will differ from that of wild populations even if broodstock originate in the local, wild population and care is taken to use a reasonable number of broodstock. These procedures do not prevent changes in allele frequencies if enough captive individuals interbreed with wild individuals. Broodstock may have only a subset of the genetic variability present in a wild population (a small sample may miss some alleles) and likely will differ in overall allele frequencies due to sampling error. It should be noted that genetic interchange between hatchery and wild stocks has been occurring in many species for a long time, in some cases more than 100 years, especially because of stocking programs for popular sport fish. Allele frequencies also change naturally in wild populations, so the baseline genetic composition of these stocks varies across time. Still, most agencies attempt to minimize genetic changes caused by stocking.

Alleles are variants of a gene and produce slightly different versions of the protein that is the gene product (see SRAC Publication 5001 for a discussion of genetics in aquaculture). Alleles arise naturally in populations over time because of gene mutations. The importance of different alleles and allele frequencies is less well known. Some argue that alleles are adapted to the local environment and that having native alleles gives individuals an advantage. Therefore, if cultured individuals interbreed with wild individuals, the resulting offspring will be less fit and fewer of them will survive to reproductive age, causing the wild population to decline. Loss of fitness may occur because affected individuals grow more slowly, are less tolerant of environmental extremes, are less attractive to mates, have lower quality eggs or sperm, or have other disadvantages. Others argue that most genetic variation is neutral and does not affect fitness. Still others are less concerned about genetic exchange if there are no noticeable negative effects, as with many sport fish stocking programs. This debate is important because it greatly affects how the escape of cultured native species is viewed.

Several factors determine the frequencies of alleles within a population, including selection, random drift, immigration from other populations, and genetic bottlenecks. Selection occurs when alleles are favored by some process. These may be natural processes within the environment, as when an allele gives increased survival or preferential mating. Selection may also occur in captivity because of differential survival in the captive environment, captive mating reducing or eliminating mating preferences, or human selection for desirable traits (e.g., faster growth or color). Allele frequencies also change randomly over time if selection forces are not strong. Random changes occur more frequently if the effective population size—the number of individuals that actually produce offspring—is small. Individuals from other populations that immigrate into and interbreed within a population can affect gene frequencies, especially if there are enough immigrants. Lastly, drastic declines in abundance or effective population size can create genetic bottlenecks where there is loss of genetic variability, especially the loss of rarer alleles.

The same principles hold true when hybrids or intergrades (crosses between subspecies; Box 1) escape and interbreed with wild stocks of one or both parental species. Channel catfish x blue catfish (*Ictalurus punctatus* x *I. furcatus*) hybrids are becoming more common in aquaculture and are frequently cultured within the native range of both species. Hybrid sunfish (*Lepomis* spp.) can backcross with wild stocks. If one of the species making up the hybrid is not native to the region, concerns about genetics and non-native species may be greater. For example, green sunfish (*Lepomis cyanellus*) is a prohibited,

Box 1. The largemouth bass (*Micropterus salmoides*), one of the most important sport fish in the U.S., is cultured by agencies and commercial aquaculture producers for stocking in public and private waters. Traditionally, taxonomists classified this species into two subspecies—the northern largemouth bass (*M. s. salmoides*), which is native to much of the eastern half of the U.S. except peninsular Florida, and the Florida largemouth bass (*M. s. floridanus*), native to peninsular Florida. Recently, some taxonomists have used genetic data to elevate both subspecies to species rank—largemouth bass (*M. salmoides*) and Florida bass (*M. floridanus*). Regardless of the taxonomy, the two forms freely interbreed and produce fertile offspring, including a natural region of intergradation where the genes of both forms occur naturally in the southeast U.S. Florida largemouth bass and the Florida x northern cross have been stocked into the range of northern largemouth bass for decades to produce bigger, faster growing bass for angling. Northern largemouth bass have been stocked into Florida less frequently. Florida largemouth bass are less able to survive cold temperatures and some data suggest that the crosses have reduced fitness or other undesirable performance characteristics. The stocking of largemouth bass or Florida x northern crosses outside their native range has been discontinued by some agencies, and some states are enacting or considering regulations on the possession, culture, and stocking of bass genetic stocks. Producers and live haulers should be aware of these actions in their states or the states of their customers, be in compliance with current regulations, and be prepared to adapt to new regulations.

Florida largemouth bass or Florida bass. (Photo by J.E. Hill) non-native species in Florida, and hybrid sunfish containing green sunfish genes are prohibited.

Producers should be aware of the potential for genetic interchange between captive and wild stocks when planning new aquaculture operations. Carefully follow any genetics policy required by regulatory agencies. Compliance requirements may include reducing or preventing escape, using broodstock from the region, rotating broodstock often, and using breeding schemes that explicitly address genetic diversity and artificial selection.

Genetically modified organisms (GMOs)

Genetically modified organisms (GMOs) result from the insertion or deletion of genes using genetic engineering methods. Transgenic organisms are most common; these are produced by incorporating genes from another species into the genome. GMO crops such as corn and soybeans are typically engineered to resist disease or herbicides. A variety of transgenic fish have been developed for research and potential commercialization. The only transgenic animal commercially available to the public in the U.S. is the GloFish™ (Yorktown Technologies, L.P.), the zebra danio (*Danio rerio*) produced in a variety of fluorescent colors and marketed as an aquarium fish (Fig. 3). Growth-enhanced Atlantic salmon (*Salmo salar*) is in the approval process for food fish aquaculture. There are also growth-enhanced strains of channel catfish (*Ictalurus punctatus*) and tilapia (*Oreochromis* spp.) used in research. Other traits being researched include increased cold tolerance and the production of proteins for pharmaceuticals in transgenic fishes and improved disease tolerance in oysters.

Although GMOs may have desirable characteristics for aquaculture, many factors must be considered: GMOs have unique risk attributes, U.S. regulations make it difficult to obtain approval for commercialization, state regulations vary, consumers may resist genetic modifications, and advocacy groups vigorously denounce GMOs. Producers and trade organizations of non-GMO aquaculture species also may oppose GMOs because of consumer perceptions or other negative effects on markets. All these factors will influence any aquaculture business plan based on GMOs.

The risks GMOs may pose to the environment and to human health will depend on the species, the traits or characteristics altered, the culture system, the geographic region, and the intended market. If a GMO is also non-native, it will have risks comparable with any similar, non-native aquaculture species plus any specific risks associated with the genetic engineering technology and the altered trait. If the GMO is a native species or one

Figure 3. A. The red GloFish™, a red fluorescent protein zebra danio, was the first transgenic organism legally available to the public. GloFish™ are aquarium fish. (Photo courtesy of Alan Blake, Yorktown Technologies, L.P.). **B.** Other fluorescent color varieties of GloFish™ now are commercially produced. (Photo courtesy of *www.glofish.com*).

capable of interbreeding with native species, there will be risks associated with genetic interchange and the potential for a Trojan gene to occur that could drive local wild stocks to extinction (Box 2). Transgenic ornamental species may be released into the environment by the public, and food species may escape. Food species also must be deemed safe for human consumption.

Some GMO species, if they escape, are unlikely to establish in the environment or become problematic, especially if the genetic alteration decreases survival. Organisms can be engineered to have low survival or reproductive dysfunction. More traditional methods of sterilization, such as triploidy, may be used with some species. Transgenic fluorescent zebra danio is a good example of a low-risk species because it could not survive the cold winters in much of the U.S. and is highly vulnerable to predators. Other species, such as catfish, salmon or tilapia, have more history of invasiveness and may survive and establish in some areas. Increased cold toler-

Box 2. The Trojan gene hypothesis describes a phenomenon in which a transgene, even though rare in a population, may eventually drive the population to extinction if it produces both a mating advantage and lower viability at one or more life stages such as juvenile survival. Muir and Howard coined the term and described the phenomenon in a paper published in the Proceedings of the National Academy of Sciences in 1999 (PNAS 96:13853-13856). This phenomenon is a concern for transgenic species that may escape and interbreed with wild relatives. Not all transgenic organisms would have a mating advantage over wild individuals, and most transgenic organisms have disadvantages that reduce the survival of their offspring relative to wild types. Therefore, most escaped transgenics would be rapidly eliminated from a wild population. Nevertheless, the potential for Trojan genes must be considered.

This concept is named for the unusual tactic employed by the ancient Greeks to successfully end their 10-year war with Troy. The Greeks built a large wooden horse as an offering to the sea god Poseidon and sailed away, acting as if they were giving up on their quest to capture Troy and retrieve Helen. The Trojans were overjoyed by their departure and decided to bring the horse into their city to gain the favor of the gods themselves. What the Trojans did not know was that Odysseus and other Greek warriors were hidden inside the horse. Once the horse was brought into Troy and the Trojans were drunk from celebrating, the Greek warriors came out of the horse and opened the city gates to the Greek army, which had returned during the night. Troy was destroyed because of this trick.

Muir and Howard chose the name "Trojan gene" because the mating advantage provides a way for the transgene to enter and spread, and the reduced viability of offspring leads to eventual extinction.

ance could allow tropical species to establish in temperate climates (e.g., increased cold tolerance in tilapia). Some traits may have mixed effects relative to establishment potential. For example, growth enhancement may give GMO individuals a mating or survival advantage or may increase their vulnerability to predation because they feed more actively.

GMOs are regulated as New Animal Drugs by the U.S. Food and Drug Administration (FDA). As for any new aquaculture drug, the approval process is lengthy and requires considerable data collection and expense. No GMO fish has been approved by the FDA. Growth-enhanced salmon have been in the approval process for more than 10 years. Glofish™ are sold legally because the FDA evaluated them in a separate process, determined that there was no overriding public or environmental risk, and used regulatory discretion to allow their sale. This is somewhat similar to the legal use of unapproved aquaculture drugs such as low regulatory priority drugs like salt. It is unlikely that regulatory discretion will be used to allow the legal sale of other unapproved GMO species, especially for food fish.

States also regulate GMOs, but most have little experience with this issue. Producers should expect each species, trait, and development technique to require separate, case-by-case approvals. Proposals to culture GMOs will undoubtedly require that a regulatory or policy framework be developed, which is a lengthy process with an uncertain outcome for the applicant. California bans all GMOs and, based on history with the GloFish™, is unlikely to grant exemptions. Florida, the state where GloFish™ are cultured, has a comprehensive set of procedures and regulations for culturing GMOs through its lead aquaculture regulatory agency, the Florida Department of Agriculture and Consumer Services (FDACS). FDACS handles applications on a case-by-case basis and uses a scientific advisory panel made up of state agency and university experts in GMOs, genetics, aquaculture, fisheries, invasion ecology, and ecological risk analysis to identify risks and provide specific recommendations on risk management.

Another consideration is the potential for patent infringement. Most GMOs are patented, which may prevent the effective development and marketing of a competing GMO. An attorney knowledgeable in patent law and biotechnology may be a valuable resource to potential aquaculture producers.

A variety of factors such as concerns over food safety, lack of information to make informed decisions, ethical or moral opinions about genetic engineering, the influence of advocacy groups, and a fear of the unknown have caused mixed reactions to GMOs among the public. Several advocacy groups oppose the development and use of GMOs, especially in food products, and they influence public and political sentiment. Aquaculturists considering the culture of GMOs should understand that advocacy groups may lobby politicians, contact regulatory agencies, and pursue legal avenues to prevent the approval, culture and sale of GMOs or products derived from GMOs. For example, several advocacy groups sued the FDA over legalizing the sale of GloFish™. Labeling food products as GMOs allows the public to make personal decisions about consuming them but also suggests to some consumers that the products are qualitatively different than and perhaps less nutritious, wholesome or safe than comparable, non-GMO products. If GMO aquaculture products are to be successful in the marketplace following future approval, educational and marketing campaigns may be needed to ensure product acceptance.

Conclusion and recommendations

Aquaculturists face several emerging issues that may change the way they do business. These include the development of non-native species and new marketing methods for existing species, pathogens and associated diseases, genetic interchange between cultured and wild stocks, and the commercialization of GMOs. The science is still developing, there is scientific and economic uncertainty, and regulations are changing and frequently increasing in each of these areas. Some concerns caused by these issues are well-founded; others are more questionable. Extension faculty and researchers should work together to generate, compile and disseminate the best possible information. Producers and aquaculture industry groups should discuss these issues with their Extension faculty and learn all they can to more effectively interact with regulatory agencies and politicians to ensure that regulations are reasonable and science-based. Attention to emerging issues is important when developing new aquaculture business plans and when changing existing practices; but even well-established operations must adapt to changing regulatory requirements.

Additional resources

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USDA

United States Department of Agriculture

National Institute of Food and Agriculture

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