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Preventing Escape from Aquaculture Operations

Jeffrey E. Hill[1] and Quenton M. Tuckett[1]

Concerns regarding the escape of aquaculture products and potential solutions

The escape of aquaculture products, both non-native and native, is a problem for the environment, aquaculture producers, and the aquaculture industry as a whole. Following introduction, some non-native species have spread into suitable habitat, become established, and caused environmental impacts. The United States and the Southeast in particular, have a large number of established aquatic non-native species. Some of these non-native species escaped from aquaculture. Native species also may escape culture into the surrounding environment. Escape of native species from culture is not without its risks, including potential genetic effects on local stocks. While relatively small in number, aquaculture escapees (whether native to a particular region or not) contribute to a mounting management concern. This management concern has led to new laws regulating aquaculture practices and the escape of non-native and native species. Ultimately, producers should be concerned about aquaculture escape because the potential for environmental harm and the possibility of additional regulations, including potential prohibitions by state and federal agencies.

This document on preventing the escape of aquacultured products focuses on application of a framework most commonly employed to reduce food safety hazards. Producers can reduce the probability of escape of aquaculture products by identifying critical release points, which are instances in the aquaculture production chain which, if failed, can lead to the escape of aquacultured species. One way producers can identify these critical release points is through application of the Hazard Analysis Critical Control Point (HACCP) framework (Fig. 1). Following its food safety origins, HACCP has now been used at federal fish hatcheries, and Midwest baitfish operations, amongst others. The HACCP has a formal process, but formal HACCP application may be unnecessary; instead, application of some parts of this framework can help operators to systematically evaluate aquaculture escape. An example of HACCP application can be seen in our research on the implementation of Best Management Practices (BMPs) and their ultimate outcome in affecting the escape of aquaculture products.

Hazard Analysis Critical Control Point (HACCP) Framework

The seven HACCP principles:

1. Conduct a hazard analysis
2. Identify the critical control points
3. Establish critical limits for critical control points
4. Establish critical control point monitoring
5. Establish corrective actions
6. Establish verification procedures
7. Establish record-keeping procedures

[1]Tropical Aquaculture Laboratory, University of Florida, Ruskin, FL

Hazard analysis	▪ How do organisms escape from aquaculture? ▪ How can it be controlled?
Critical control points	▪ Most important process or location(s) where escape from aquaculture can be effectively reduced
Controls for CCPs	▪ Point at which escape is considered controlled ▪ This is often informed by regulation
CCP monitoring	▪ Establish protocols for routine monitoring of CCPs identified in Step 2 ▪ Monitor CCPs
Corrective actions	▪ Establish procedures for correcting failed CCPs ▪ Fix CCPs in a reasonable time frame
Procedures for verification	▪ Establish procedures for identifying if the hazard plan and especially the CCPs are working
Record keeping	▪ Keep records indicating when CCPs have 1) been monitored, 2) failed, and 3) been corrected

Figure 1. The seven principles of the HACCP process as applied to the escape of organisms from aquaculture facilities. Producers need not implement all seven principles in a formal HACCP implementation; instead, steps, principles, or procedures should be utilized if they best fit the particular aquaculture facility.

Hazard Analysis Critical Control Point Principle 1: Conduct a Hazard Analysis

In this case, the hazard to be analyzed is the escape of non-native or native species from aquaculture. However, producers should be aware of additional hazards inherent in aquaculture production not covered here, including pathogens, release of aquaculture wastes, and health and safety concerns. *Hazards can be identified based on the likelihood of occurrence and the potential severity.* Conducting a hazard analysis involves completing a preliminary plan which identifies the hazard, escape of aquacultured organisms, and also identifies control points where measures can be taken to reduce or manage the hazard. Some of these control points will be further identified as critical control points (CCPs) in the next HACCP step. In practice, conducting a hazard analysis and producing a hazard plan requires that producers are familiar with how and when particular cultured species escape farm operations.

How do organisms escape?

Fish and other cultured species can escape across multiple life stages, from fertilized eggs to broodstock; however, it is the free-swimming stages, juvenile and adult, which are more likely to escape. Aquacultured organisms mostly escape when effluent is discharged offsite, ultimately reaching adjacent surface waters. The particular flow and configuration of aquaculture effluents and how they reach surface waters will differ within and among segments of the aquaculture industry. However, general patterns can be discerned as aquacultured organisms escape through drainpipes, spillways, nets, and control structures at the property boundary. Secondarily, leaping fish and crawling organisms can escape of their own accord. Escape may be more common during high-flow, but also occurs during normal base flow conditions. During high-flow and especially flood events, containment barriers can be compromised, screens can become blocked, control structures can be undercut, and pond and property berms can fail.

Additional escape vectors have received attention, including vandalism, fish transfer and transportation, and carry-off by birds or other animals. Vandalism is thought to be important for marine cage culture, transportation can be a vector for hitchhiking species in the live organism trade, and movement by animals, especially fish-eating birds, could be important in the movement of fingerlings or broodstock. Yet, for the most part, recent research suggests these pathways, at least for ornamental aquaculture in Florida and probably many other industry segments, are unimportant. Still, producers should examine their own practices and determine the pathways of escape that are most important.

Aquaculture facility layout

The layout of an aquaculture facility plays an important role in affecting how organisms escape. Aquaculture facilities in the Southeastern United States will vary widely, from large-scale catfish operations to zero-discharge production of marine ornamental fish (Fig. 2). However, facilities often exhibit a common set of practices and facilities, including a desire to minimize fish losses and a combination of buildings, greenhouses, and outdoor production ponds. *Yet, how water leaves the facility is one of the most important facility layout concerns and should be the focus when identifying hazards.* Many aquaculture facilities have a water retention system consisting of ditches, ponds, and wetlands. Others exhibit a simple ditch system without containment ponds or wetlands, which is more prone to allowing fish to escape. The location of the farm within the landscape can affect whether fish escape. For example, location of farms near streams and wetlands which may be prone to flooding, can compromise on-site containment structures. Whatever the layout, producers will benefit and escape will be reduced if producers are intimately aware of the farm layout and how water is discharged from the property.

Control measures

Aquaculture organisms can escape from facilities through a variety of pathways, but producers also have a variety of solutions to employ. This is the ultimate objective of the analysis: recognize hazards and identify actions and strategies to prevent escape. Because of the potential benefits and drawbacks of various control measures, producers should weigh their options, consulting with Extension agents and regulators when necessary, to select the most appropriate solutions. Physical controls can include screens, dead-end filters, covers, riser-board control structures, trickle-flow control structures, constructed wetlands, detention/retention ponds, recirculating systems, and security (Fig. 3). Controls need not be restricted to physical barriers; they can also include management actions and protocols, including the proper training of employees.

Screens

Screens can be utilized wherever they can be reasonably placed, from pipes to hoses. In fact, screens are one of the easiest and cheapest ways to prevent escape, especially when recycled seine nets and other materials are used. While screens are easy and cheap, producers need to consider several criteria in placing screens, including selecting appropriate mesh size to capture target life stages and

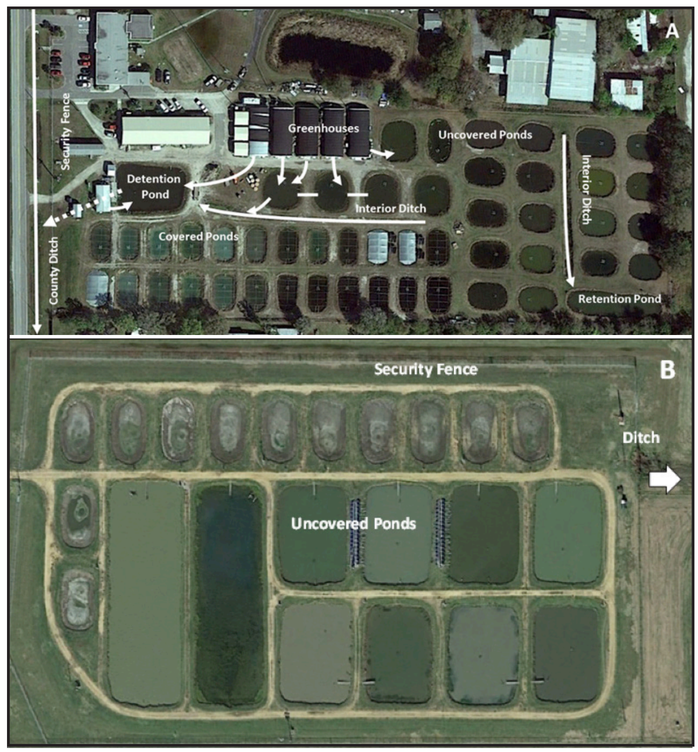

Figure 2. Farm layout figure for (A) ornamental fish production in Florida (University of Florida Tropical Aquaculture Laboratory) and (B) catfish production in Mississippi (Thad Cochran National Warmwater Aquaculture Center fish-health ponds). (A) There are at least 3 CCPs for the ornamental fish facility, including movement of water from greenhouse to interior ditch and ponds, from the interior ditch/pond complex to the detention pond, and from the detention pond to the county ditch. The most important CCP is the connection between detention pond and ditch. (B) The catfish fish-health research facility has only a single location for effluent; this would be a major CCP. Facilities vary in configuration of ponds, ditches, and buildings and in the movement of effluent offsite. While both industries rely on outdoor production ponds, their hazards and ultimately CCPs differ.

specific to the discharge being received (larger for effluent laden with waste), and redundant in that they are placed at multiple points along the discharge route.

- *Appropriate mesh size:* because mesh size is highly variable, from a small fraction of an inch to greater than an inch, select a mesh size which is most appropriate to the life stage of the species in production. Mesh size should be specific to the type of discharge received. Screens are expected to receive discharge from a variety of sources and need to consider tradeoffs between maximizing the capture of the smallest life stage of species in the pond, vat, or aquaria, avoiding fouling by algae and aquaculture wastes, and resisting abrasion and UV damage when appropriate.

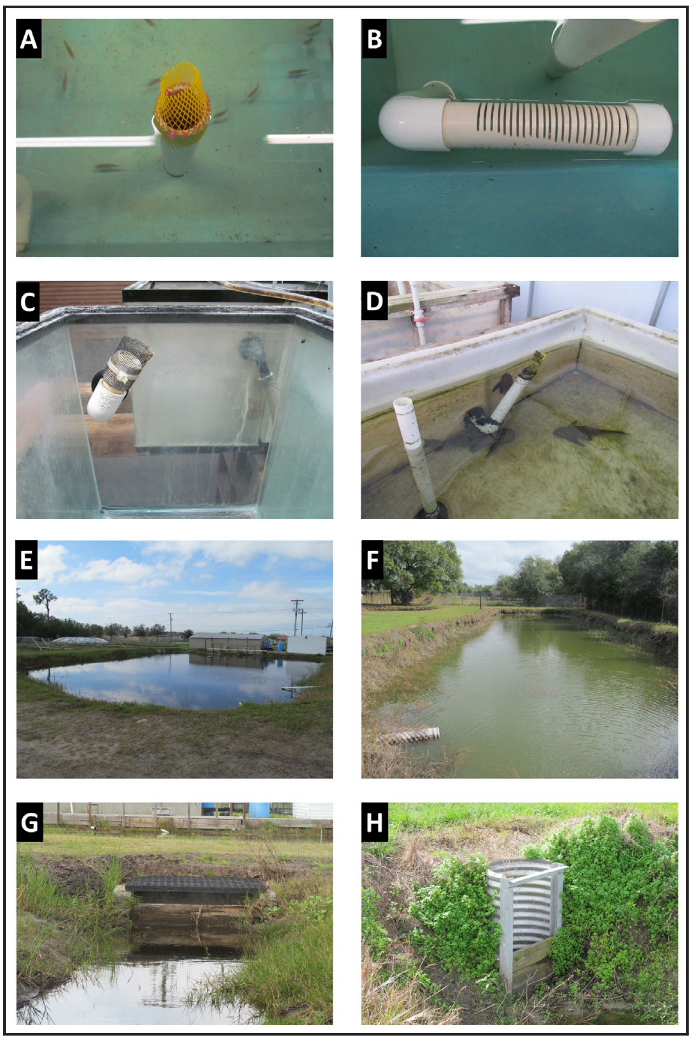

Figure 3. Examples of physical barriers used at a tropical fish farm. Similar physical barriers may be used at other types of aquaculture facilities, scaled to appropriate sizes. Barriers include screens on tanks vats (A, B, C, and D), detention pond (E; water is eventually discharged), retention pond (F; water is not discharged), and riser board control structures (G and H).

- *Redundancy is important:* redundant screened barriers are important to increase the effectiveness of screens and reduce escape. Because no single screen will be completely effective at preventing the escape of aquacultured organisms, redundant screens will be important across the aquaculture facility.

Dead-end filters

Any filter which is composed of fine mesh and is sock-shaped could be considered a dead-end filter. Dead-end filters are used to effectively capture sediments, particulates, and most life stages of aquacultured organisms, from egg to adult. These filters can be placed on pipes and hoses and are most often used to prevent the escape of organisms that pose a high risk of invasion. While highly effective, dead-end filters such as geotextile bags can be difficult to maintain when wastes need to be removed and are also prone to rupture if the mesh becomes clogged or if pressure is too high.

Covers

Like screens, covers create a physical barrier used to prevent the escape of aquaculture organisms. There are two purposes of covers: 1) prevent the loss of fish and other aquacultured organisms to predatory birds and mammals and 2) prevent losses and escape due to leaping by fishes or crawling by invertebrates and amphibians. Covers are cost-prohibitive and impractical (e.g., feeding, multiple-harvest, and sampling) on large ponds like catfish or crawfish ponds. Like dead-end filters, covers may be important for species with a high risk of escape and impacts in the environment.

Riser-board control structure

Also called a flash-board riser, the riser-board control structure is a common feature of aquaculture facilities throughout the southeast. Riser-board control structures are typically placed in ditches and can be constructed of galvanized steel pipe or the more expensive concrete structure. Both the galvanized pipe and concrete structure will have guides where slats can be placed, typically wood, but other materials are also used; placement of additional slats can then raise or lower the water level in the ditch, which can alter residence time and prevent the release of sediments and wastes. However, despite the fact that this structure is a common feature of aquaculture facilities, it is not known how effective they are in preventing aquaculture escape. This could be due to variation in species behavior, which, our research suggests, leads to variable movement over the riser board. Screens placed behind or above the riser boards can greatly increase effectiveness. Thus, additional and redundant escape barriers may be needed at different points along the effluent path.

Trickle-flow control structure

These structures serve the same purpose as riser-board control structures in that they are designed to increase the residence time of water, allowing for the settlement of particulates and aquaculture wastes. Further, they also have similar drawbacks in that trickle-flow control structures may not impede the escape of a range of species unless screens are used. Screens are often incorporated around or over the pipe to prevent cultured species from getting caught in the outflow and damaged against or in the pipe. These screens also prevent the escape of organisms if correctly sized. A larger mesh may be used on the pond side to capture large materials to prevent clogging and escape by larger organisms along with an interior, smaller mesh that can prevent escape by smaller cultured organisms. Trickle-flow control structures are typically used in ponds to control the water level and freeboard, which is the difference between the water height and pond bank. These structures include a standpipe which acts as a spillway and ultimately prevents pond flooding. Trickle-flow control structures are often used on detention and retention ponds.

Constructed wetland

A constructed wetland is a shallow heavily vegetated basin typically used in row crop agriculture. However, it can also be used to process wastes from catfish, shrimp, and tilapia production or other types of aquaculture. A constructed wetland's main benefit is that of a mechanical filter, which captures sediments and particulate wastes, and a biological filter which processes nitrogenous wastes. Constructed wetlands typically contain an outflow which maintains an appropriate water level for wetland plants. However, if temporary in nature, constructed wetlands can be effective at preventing the escape of aquacultured organisms. The constructed wetland can also be paired with the trickle-flow control structure to increase its effectiveness. The constructed wetland has the benefit of being low cost, once created, but can be expensive to construct and lead to lost acreage devoted to production.

Detention and retention pond

Our research suggests one of the most effective ways to prevent the escape of aquacultured products is through the appropriate design and construction of detention and retention ponds. These ponds are relatively large and typically permanent with the objective of greatly increasing the residence time of aquaculture effluents prior to leaving the facility. These ponds differ in that retention ponds retain water and never or rarely discharge effluent whereas detention ponds increase residence time for waste processing, allowing predation by native species, and eventually discharge effluent offsite. If aquaculture products are susceptible to predation and suitable native predators are stocked into detention ponds, these structures can be one of the most effective ways to reduce escape. In fact, of the facilities assessed during a 2013-2014 survey of aquaculture producers in Florida, facilities with detention ponds had substantially reduced rates of non-native species escape. In addition to being effective at reducing escape, detention and retention ponds are among the most effective ways of reducing the off-site discharge of aquaculture wastes. While retention ponds seem like the ideal solution, these ponds sometimes cannot handle the discharge loads of typical aquaculture producers in the southeast, take up room on the farm, and may be expensive to install.

Perimeter berms

Flooding of ponds or buildings by nearby surface waters can lead to high levels of escape by aquacultured organisms. Berm height should be designed to prevent flooding, often at least 1 foot above the hundred-year flood level. Perimeter berms may not be needed if the land has adequate drainage and is located at an appropriate elevation to prevent flooding.

Indoor recirculating system

For some industries, the use of mechanical and biological filtration to recirculate water is of paramount concern. Few organisms can readily escape from these types of culture systems. This is particularly common for indoor marine aquaculture and the culture of valuable and risky species.

Fencing

Finally, in terms of physical barriers, fencing, lighting, and other features which aim to decrease the incident of theft and vandalism, can possibly be used to prevent escape. However, to date, there is little evidence to support theft or vandalism as an important means of species escape from most aquaculture facilities.

Effluent treatment

Effluent can be treated with chemicals to remove cultured species from effluent streams before they leave the aquaculture facility. Chemical treatment of aquaculture waste is rare because of the large effluent volume common to many aquaculture facilities, high cost of treatment, and problem with removing chemical residues from the effluent prior to discharge. Chemicals which can be used to treat waste streams include Antimycin-A (fish toxicant), Bayluscide® (molluscicide), chlorine bleach (sterilant; fish toxicant; molluscicide), and rotenone (fish toxicant). The control of species through chemical treatment is more appropriate for the treatment of static batches of water in ponds, vats, and tubs, not in flowing water effluent streams. Ultimately, consult relevant regulations and guidance before selecting and applying a chemical treatment.

Facility and equipment maintenance

At ornamental aquaculture facilities in Florida, the failure of water-control structures was one of the most common BMP non-compliance issues observed. This can be problematic because these structures may also form a barrier to the escape of aquacultured organisms and are a common feature of most aquaculture facilities which exhibit off-site discharge. In addition to control structures, ditches, and berms around ponds and near the property boundary, the maintenance of these structures could be considered both a CCP and a possible control.

Discharge management

Because our research suggests aquaculture effluents are the dominant pathway by which aquacultured species escape, managing aquaculture discharge is one of the most important things producers can do to manage escape hazards. Reducing the volume and frequency of discharge limits the opportunity for escape, lessens the time and effort involved in monitoring effluent, and may render the ditch or other receiving waters less suitable for survival, persistence, and dispersal of escapees.

Of course, for most aquaculture industries, zero-discharge will be unrealistic. Yet, simple solutions can still be implemented. For example, producers can eliminate water flow to empty vats or aquaria, consolidate stock in fewer vats and other holding systems, and utilize recirculating systems where this is reasonable. Allowing outflow ditches to dry down instead of maintaining permanent water may eliminate escaped organisms near farms. Discharge volume can also be managed during winter by using periodic rather than continuous release in order to reduce warm water refuges for cold sensitive species in effluents.

Draining of outdoor aquaculture ponds contributes disproportionately to annual discharge at many facilities. Discharge can be reduced by pumping water to adjacent ponds and internal ditches, rather than discharging effluent off-site. Practices that increase discharge should be reduced to prevent escape, while also reducing nutrient release. A comprehensive approach can be used to manage effluent discharge, one that eliminates unnecessary release, reuses water when possible, and reduces pumping and draining (also saves time and money).

Water-level management

Management of water level is related to the water budget, with inflows due to pumping ground water and precipitation and outflows due to seepage, evaporation, discharge, and spillover during flood conditions. The ultimate goal of water-level management should be to reduce the effluent volume while maintaining excess capacity in the event of high precipitation. Thus, from an escape standpoint, seepage from earthen ponds is fine, as is evaporation; however, spillover, which is affected by water storage capacity, should be avoided by leaving freeboard in ponds during wet periods.

Water level can also be managed to promote periodic drying and also to prevent scour-hole formation. Ditches can be gently sloped to reduce erosion and to allow more complete draining. When filling ditches, as during pond pumping, be aware of the pumping rate so that ditch capacity is not reached (and that of the control pond). This will be especially important for those ponds and ditches near the property boundary.

Employee management

Employees are authorized agents of the aquaculture producer; thus, it becomes the employer's responsibility to prevent environmental issues caused by their employees. This follows from common law doctrine where negligent actions by employees that lead to environmental problems become a problem for employer. Proper training of employees in the requirements and guidelines can lead to greater outcomes in preventing the escape of non-native species. Training can be facilitated by one-on-one or group discussion, printed materials and signage, and on-farm demonstration. On-going training with regular updates is more effective than a one-time event. Consult with Extension agents for further assistance.

HACCP Principle 2: Identify the Critical Control Points

A Critical Control Point (CCP) is an important pathway for escape of aquacultured organisms, a location or activity which disproportionately affects escape, or a feature of an aquaculture facility where, if corrective actions are employed, the hazard can be effectively prevented or the hazard reduced. While emphasis is typically placed on the escape of non-native species, the escape of native species is also of environmental concern. If a comprehensive approach is taken, one that utilizes a full HACCP analysis and begins with Principle 1, CCPs are typically identified from the potentially numerous control points recognized during this first HACCP step.

It is important to consider the farm layout when analyzing CCPs. For a typical aquaculture facility, the most important CCP for escape is often located where the effluent flows through a series of redundant barriers and leads off site. Specifically, for the image in Fig. 2 (A), CCPs can be seen at the following locations: 1) between greenhouses, packing houses, and ditches, 2) between ditches and detention/retention ponds, and 3) ponds and the point where effluent leaves the property boundary. By comparison, for the image in Fig. 2 (B), water is discharged first to a ditch and then off-site. For most facilities, more than one effluent discharge point is associated with a facility. Producers should be aware of all off-site effluent discharges, however minor or intermittent.

Many control points can be conceived; producers should place focus on those that are actual CCPs, those points where significant hazards can be significantly reduced. Producers should also be aware of potential differences among aquaculture products if more than one product is under production. For example, CCPs for crawfish often differ from those identified for catfish.

HACCP Principle 3: Establish Critical Limits for CCPs

The critical limit of a particular control feature or critical control point is the maximum (or minimum) point at which a control is considered to be still functioning. What are the critical limits for the escape of aquacultured organisms? Here, the limits might differ. For example, a critical limit might not be reached until an aquacultured organism is observed off-site. Thus, the establishment of critical limits involves a certain level of risk management, where critical limits may be more stringent for riskier species or particular CCPs.

Regulations and Best Management Practices (BMPs)

In practice, the establishment of critical limits will be informed by state and federal regulations. Multiple state and federal agencies are involved in regulating aquaculture practices and the escape of aquacultured species. Aquaculture BMPs are implemented by a number of states, but implementation can vary throughout the Southern region. For example, regulation of Florida aquaculture falls under the Florida Department of Agriculture and Consumer Services (FDACS), Division of Aquaculture, which implements mandatory yearly inspections. Florida Aquaculture BMPs mandate that no aquacultured organisms are to be found off-site. A discussion of state regulations is too expansive to be covered here, but best practices suggest producers should be aware of current regulation in their state and how they relate to the establishment of critical limits.

HACCP Principle 4: Establish CCP Monitoring

After the hazard analysis has been completed, CCPs have been identified and control measures put in place, ongoing monitoring of CCPs should continue periodically to ensure proper hazard control. Monitoring ensures that CCP controls are working to prevent fish escape and that conditions have not changed. Because of the relationship between environmental fluctuations, heavy rainfall, for example, and aquaculture practices, which can lead to the escape of organisms, monitoring frequency can be adjusted to follow these potential hazards. Thus, monitoring frequency and intensity will vary during normal operations and periodic events, including during elevated production schedules. For some states which mandate yearly inspections, these regulatory inspections do not take the place of CCP monitoring. Aquaculture producers can conduct their own routine inspections. Ultimately, routine inspections are recommended because they identify escape issues before they become major problems.

What should be monitored in relation to CCPs:

- *Screens:* materials degrade over time, especially outdoors; screens should be periodically monitored if they are part of controls at a CCP and to create redundancy.
- *Filters:* if used, waste material should be periodically removed from dead-end filters to prevent rupturing and a decline in capacity.
- *Covers:* similar to screens, covers can degrade over time.
- *Control structures:* examine control structure slats to ensure proper fit and rigidity. Also, be sure to examine under the bottom slat and around the control structure itself for signs of scour.
- *Control ponds (detention ponds, retention ponds, wetlands):* excessive pumping can fill ponds and wetlands with sediment which can reduce resi-

dence time and the effectiveness of these structures. Vegetation can also grow around pond banks, proving refuge. Finally, native predators can disappear in ponds over time; these predators including native largemouth bass should be stocked if the density becomes too low. Thus, control ponds should be periodically dug out, weeds sprayed, and native predators stocked.

- *Boundary and property berms:* compromised berms (on ponds near the property boundary, or elsewhere) can lead to the rapid discharge of aquacultured organisms. Maintain water levels in ponds near the property boundary to avoid sloughing. Inspect berms periodically for integrity.
- *Security features:* monitor security features (lighting, fencing, etc.) and the surrounding areas for potential issues.
- *Employees:* to ensure the HACCP plan is being correctly followed, employees should be properly trained and procedures to prevent escape should be properly reinforced.
- *Ditches:* these effluent conduits should be monitored to ensure sediments are not accumulating, scour holes are not being formed, vegetation is not excessive, and ditch banks are not compromised, which can lead to escape.
- *Discharge:* because effluents are the dominant pathway for the escape of aquacultured organisms, effluent monitoring should be added to a routine monitoring program. This can be done with a simple inspection program where effluents are visually evaluated and/or sampled with nets or other fish collection gear for the presence of aquacultured organisms.
- *Water levels:* examine water levels in ditches and ponds to ensure sufficient freeboard to prevent flooding. Freeboard can be actively managed if extreme rainfall events are forecasted.

HACCP Principle 5: Establish Corrective Actions

If CCPs become compromised corrective actions are recommended to be taken as soon as possible, depending upon the severity of the compromised CCP (e.g., the response will be different if redundant barriers are in place below the CCP). For a hypothetical situation where aquacultured fish are observed beyond a critical limit or CCP during a routine inspection, corrective actions could include:

- Minimizing effluent discharge by pausing the pumping of ponds, reducing water flow to vats and tanks, and other measures which provide time to correct the issue without being an undue burden on facility operations.
- Placing a temporary barrier below the CCP to prevent further spread of the species while the controls are assessed.
- Chemically treating the pond, vat, or effluent to remove potential escaping aquaculture organisms.
- Recapture of escaped organisms if possible.

Ultimately, corrective actions are often immediately focused on compromised CCPs; however, corrective actions can also include an examination of whether the HACCP plan or CCPs need modification.

HACCP Principle 6: Establish Verification Procedures

Verification is used to ensure the HACCP plan is working. This can include the verification that the HACCP plan has been implemented and the hazards are being effectively controlled, implementation of CCP controls follow the plan, and whether hazards, CCPs, and ultimately control measures need to be added, eliminated, or modified. As stated above, of particular importance is verification of the CCPs. Because CCPs are the most important aspect of the HACCP framework, ongoing verification and reevaluation of these sites or procedures is important.

HACCP Principle 7: Establish Record-Keeping Procedures

The final principle of this framework is the principle that aquaculture producers should keep adequate HACCP records. These records can be useful because they help identify where problems occur, allow for the identification of patterns related to fish escape and particular CCPs, and facilitates communication between management and employees on how to best limit escape.

Records should be appropriate for the operation and the potential hazard. For example, more detailed records might be kept for the containment of high-risk species. Records should also contain sufficient detail for employees to understand the when, where, what, and why so that procedures can be consistently applied and adequately described to employers and agency staff as needed. Whether the HACCP framework has been adopted in full or reduced form, producers should at least keep records of when CCPs and associated control measures were monitored or examined. Ultimately, routine record-keeping of maintenance and inspection logs related to CCPs, control methods, monitoring, and corrective actions can help producers gain insight into what escape prevention procedures work for a particular facility.

Concluding remarks

Aquaculture producers can use the HACCP as appropriate for the scale and potential hazards of their operation. While the framework may appear prescriptive and rigid, producers can use all or part of a HACCP framework. Contact university extension programs in your state and even state regulators for additional guidance on how to implement and maintain a successful plan to prevent escape.

Structures and management practices beyond those listed in Principle 1 can be utilized and the ideal strategy for various aquaculture industries, species in production, and individual operation will vary; use what works best for your facility. This statement suggests flexibility to controlling aquaculture escape should be maintained, where producers are continuously open to new and better strategies: better ways to manage employees, more efficient maintenance of structures, and even new and better physical barriers.

Suggested readings

Gunderson, J., and R. Kinnunen. 2004. Aquatic nuisance species: hazard analysis and critical control point training curriculum, 2nd ed. Available at http://www.seagrant.umn.edu/downloads/ais-haccp_manual.pdf

Hill, J.E. 2008. Non-native Species in Aquaculture: Terminology, Potential Impacts, and the Invasion Process. SRAC Publication No. 4303. Southern Regional Aquaculture Center, Stoneville, Mississippi.

Hill, J.E. 2009. Risk Analysis for Non-native Species in Aquaculture. SRAC Publication No. 4304. Southern Regional Aquaculture Center, Stoneville, Mississippi.

Hill, J.E. 2011. Emerging Issues Regarding Non-native Species for Aquaculture. SRAC Publication No. 4305. Southern Regional Aquaculture Center, Stoneville, Mississippi.

Hill, J.E., Q.M. Tuckett, C.V. Martinez, J.L. Ritch, and K.M. Lawson. 2016. Preventing escape of non-native species from aquaculture facilities in Florida, part 2: facility evaluation strategies. University of Florida/IFAS Extension Publication FA 196. Available at http://edis.ifas.ufl.edu

Tuckett, Q.M., C.V. Martinez, J.L. Ritch, K.M. Lawson, and J.E. Hill. 2016. Preventing escape of non-native species from aquaculture facilities in Florida, part 1: general considerations and regulations. University of Florida/IFAS Extension Publication FA 195. Available at http://edis.ifas.ufl.edu

Tuckett, Q.M., C.V. Martinez, J.L. Ritch, K.M. Lawson, and J.E. Hill. 2016. Preventing escape of non-native species from aquaculture facilities in Florida, part 3: structural strategies. University of Florida/IFAS Extension Publication FA 197. Available at http://edis.ifas.ufl.edu

Tuckett, Q.M., C.V. Martinez, J.L. Ritch, K.M. Lawson, and J.E. Hill. 2016. Preventing escape of non-native species from aquaculture facilities in Florida, part 4: operational strategies. University of Florida/IFAS Extension Publication FA 198. Available at http://edis.ifas.ufl.edu

Tuckett, Q.M., J.L. Ritch, K.M. Lawson, and J.E. Hill. 2016. Implementation and enforcement of Best Management Practices for Florida ornamental aquaculture with an emphasis on nonnative species. North American Journal of Aquaculture 78:113–124.

USFWS (U.S. Fish and Wildlife Service). 2015. Hazard analysis and critical control point (HACCP). Available at http://www.fws.gov/fisheries/ans/ans-haccp.html

Zajicek, P.W., J.E. Hill, N. Stone, H. Thomforde, C. Ohs, D. Cooper, G. Flimlin, B. McLane, and W.D. Anderson. 2009. Preventing Hitchhiking Nonindigenous Species in Live Shipments. SRAC Publication No. 3902. Southern Regional Aquaculture Center, Stone-ville, Mississippi.

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