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MANAGEMENT BRIEF

Risk Screening of Arapaima, a New Species Proposed for Aquaculture in Florida

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Abstract
Agencies have a growing range of options for risk assessment of nonnative species varying from comprehensive assessments to rapid risk screens. Risk screens identify high-risk and low-risk species and those where more evaluation is warranted. Despite development and testing of risk-screening methods, there is little information in the literature regarding their implementation in management decisions. We used a screening tool, the Fish Invasiveness Screening Kit (FISK), coupled with a detailed literature review to evaluate the risks of the genus *Arapaima* across Florida, where there is growing interest in its culture as a food fish. We found a medium risk of invasiveness overall, the greatest risk being to subtropical south Florida due to the low cold tolerance of Arapaima that it would experience further north. Ultimately the agency determined that a combination of literature review and the risk screen was sufficient to inform their decision making and that current conditional species regulations provided adequate risk mitigation to allow culture. The agency saved time and money by developing background information and a preliminary estimate of risk prior to engaging in comprehensive assessment. Flexibility allows agencies to tailor their risk assessment and management processes to different risk environments and to better inform decision making.

Nonnative fishes are socio-economically important in fisheries, aquaculture, and interstate trade in the USA (Chapman et al. 1997; Fuller et al. 1999; Trushenski et al. 2010). Many of these species are familiar to fisheries managers, have known benefits, and are of low or otherwise acceptable invasiveness risk, as reflected in the regulations governing their culture, possession, transport, and stocking. Nonnative species not yet cultured or traded within a state represent unknown risks. Changes in use of species or increases in trade volume also may change the risk environment (Hill 2011). Agency staff may wish to evaluate risks, cost–benefit ratios, mitigation strategies, and their current regulatory framework prior to development of large-scale commercial aquaculture or live trade in novel species. Agencies can thus proactively decide to allow use of the nonnative species under current regulations, place conditions on its use, or prohibit the species before a substantial industry develops, livelihoods are at stake, or the species is released into the environment.

Decision making regarding nonnative species management is increasingly supported by risk analysis as is recommended by the National Invasive Species Council (NISC 2008; see also NRC 1983, 2002; USEPA 1998). Risk analysis is the combination of two distinct but related processes, risk assessment and risk management (Orr 2003; Hill and Zajicek 2007). Risk assessment is a rigorous, transparent, replicable process used to define the nature, probability, and severity of risks (NRC 1983, 2002). Agencies have a growing range of options for risk assessment that vary from complex and thorough comprehensive assessments (e.g., Nico et al. 2005; Hardin and Hill 2012) to more simplistic, rapid risk screens (Pheloung et al. 1999; Branquart 2007; Lawson et al. 2013). Comprehensive assessments have the largest resource inputs of time, funding, and data but provide the most information for decision-making. Risk screening methods have been developed to provide managers with more rapid, cost-effective information tools (i.e., risk or hazard identification tools; Copp et al. 2005) to identify high-risk and low risk-species, as well as those where a more thorough investigation is warranted (Copp et al. 2005; Koop et al. 2011). Screening tools capture important elements of risk but lack the detail of comprehensive risk

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assessments. As such, screening tools typically are not decision-making tools per se but are used to elucidate data gaps and to determine when further risk assessment is needed. In some cases they are sufficient to inform risk management. Additionally, risk screens can serve as a first step or as a part of a more complex assessment (e.g, Copp et al., in press; present study).

Recent interest in culturing Arapaima (collective name for members of the genus *Arapaima*) in Florida as a food fish prompted an assessment of risks of this species. The large, predatory Arapaima was already on Florida's conditional species list, suggesting the potential for ecological or economic harm if such a species were to establish. Therefore, current regulation requires culture under specific, risk-mitigating conditions (FDACS 2007). Nevertheless, the creation and potential expansion of an industry culturing and promoting this species for food may increase risks or otherwise change the nature of risk for Florida's environment and economy. Interest in assessing the risks of culture of Arapaima was expressed by fish farmers and by aquaculture extension faculty prior to expending resources on commercial production or on research and extension programs. A proactive evaluation was desirable to prevent negative impacts to the environment and economy if Arapaima proved unacceptably risky or to allay concerns over its culture if risk was acceptable.

Florida agencies have undertaken a variety of risk assessments of nonnative aquatic species to aid in rule-making and other introduced species management (e.g., Zajicek et al. 2009a, 2009b). Most have been full risk analyses with comprehensive assessments, such as the substantial process for assessing risks of the Barramundi Perch *Lates calcarifer* (Hardin and Hill 2012). In contrast with the Barramundi Perch, which is ecologically similar to an important native species, the Common Snook *Centropomus undecimalis*, the situation for Arapaima was less complex, allowing more flexibility in choosing a risk-based response. Before resorting to a full risk analysis, the Florida Fish and Wildlife Conservation Commission (FWC), the agency with the lead authority to regulate nonnative fishes in the state, determined that a combination of a comprehensive literature review in the form of a species synopsis and a risk screen would provide the agency with information on risks of Arapaima, data gaps, research needs, and potential management actions. A more comprehensive risk assessment or a full risk analysis would be done only if subsequently needed. Herein we report on the risk evaluation of Arapaima, discuss risk management recommendations, and describe the resulting management actions. Although risk screen development (Lawson et al. 2013) and species assessments (Hill et al. 2014) have been reported in the literature, there is little information on the use and implementation of risk screens in management decisions (Verbrugge et al. 2012). This case study describes a risk-based process of lesser complexity and cost than a full-scale risk analysis and thus provides managers with information that can help guide their own assessment and management process when faced with potential changes in the risk environment of nonnative fishes.

METHODS

Study species.—The genus *Arapaima* (Osteoglossidae) contains some of the largest freshwater fishes in the world with observed sizes of up to 290 cm TL and 173 kg (Arantes et al. 2010). The genus is native to the Amazon River system of Brazil, southern Colombia, Amazonian Ecuador, and northeastern Peru; the Rio Tocantins basin in central Brazil; and the Essequibo River of Guyana (Castello and Stewart 2010; FishBase 2015). Arapaima is also established outside its native range in South America in Peru and Bolivia (Ortega et al. 2007; Miranda-Chumacero et al. 2012) and possibly Brazil (Menezes 1953 reported in Alves et al. 2007) and Thailand (FAO 2015; FishBase 2015). Arapaima are currently being cultured in Brazil, Peru, and other countries in South America because of its desirability as a food fish and the decline in wild populations from overexploitation (Castello and Stewart 2010).

Arapaima occurs across a variety of freshwater aquatic habitats within its native range but is characteristic of large, floodplain-associated rivers surrounded by tropical forest (Kramer et al. 1978; Quieroz 2000; Castello and Stewart 2010). Arapaima is an obligate air-breather (Kramer et al. 1978; Stevens and Holeton 1978) and may occur naturally in hypoxic conditions (Quieroz 2000; Arantes et al. 2013). Temperatures within the tropical native range remain warm year-round (Quieroz 2000; see also Kottek et al. 2006), best temperature for growth being 25–29°C (FishBase 2015) or 24–31°C (Garcia et al. 2008). Arapaima is not able to tolerate temperatures below 16°C (Garcia et al. 2008; Lawson et al. 2015). Arapaima is a substrate-spawner with male parental care (Quieroz 2000; Castello 2008b). Minimum age of maturity is 3–5 years (Arantes et al. 2010). Minimum size at maturity for males is 115–124 cm TL and for females is 145–154 cm TL (Godinho et al. 2005). Mature oocytes in wild females age 5–10 ranged from 11,700–25,600 (Quieroz 2000).

The genus *Arapaima* has been considered monotypic since 1868; with Arapaima *Arapaima gigas* as the sole valid species. Recent morphological research suggests cryptic diversity and that there may be at least five valid members of the genus (Stewart 2013a, 2013b). Four of these five species are known only from a single specimen, three of which were collected in the 1700s or 1800s, including *A. gigas* (Stewart 2013b). Our assessment used available data from throughout the range of *A. gigas* and is therefore an assessment of the genus *Arapaima*. Subsequent clarification of taxonomic uncertainty or the development of additional data pertinent to risk can then be used to modify risk screens or assessments as warranted.

Assessment process.—The first component of the assessment was a detailed synopsis of the literature on Arapaima including information on taxonomy, biology, ecology, invasion history, and potential range and impacts in Florida (Hill 2013). This component followed a standardized format used in several previous evaluations of nonnative fishes (Hardin and Hill 2012). Information came from key word searches of internet databases, including Biosis and Google Scholar and from searches of U.S. and international invasive species databases. Gray literature was used when it provided information unavailable in the primary literature or prominent databases. Risk screens typically require only highly directed literature and database reviews designed to provide information to answer specific questions. This synopsis provided far more detailed information than was necessary to successfully complete a risk screen but was included in the overall assessment to provide considerable additional information of interest in evaluating Arapaima.

The second component, the risk screen, was completed using the Fish Invasiveness Screening Kit (FISK) version 2 (Lawson et al. 2013). The FISK was developed from the Australian Weed Risk Assessment model (Pheloung et al. 1999) to evaluate the invasiveness risk of nonnative freshwater fishes in the United Kingdom (Copp et al. 2005, 2009). Comprehensive explanations of FISK methodology are available in the literature (Copp et al. 2005, 2009; Lawson et al. 2013; see also Copp 2013), as are recent applications (e.g., Hill et al. 2014). The FISK is a semiquantitative risk screening tool consisting of 49 questions covering aspects of biology and ecology, history of invasiveness, and climate match. Answers to individual FISK questions generate a score, generally −1 to 2, or modify the scores of other questions. The sum of the question scores (range, −15 to +57) yields a total FISK score, higher scores equating to higher risk (L. Vilizzi, Muğla Sıtkı Koçman University, personal communication). Threshold values determine risk categories, high risk being values of ≥19 (Copp et al. 2009). Scores >0 but <19 (medium risk) suggest that mitigation is likely necessary and in some cases that further evaluation of specific risk factors is warranted. Scores ≤0 indicate low risk. Each answer also receives a certainty rating and questions further allow for information gaps with a possible answer of "don't know" (Copp et al. 2005). The free FISK tool is available online as a Microsoft Excel application from the Centre for Environment, Fisheries and Aquaculture Science (CEFAS 2014).

Three FISK assessments, one statewide and two regional, were completed for Arapaima in April 2013 by J.E.H. The complete statewide assessment is presented, although for brevity the regional assessments were left out because only climate match questions were answered differently (Table 1). A coauthor with training in risk assessment (K.M.L.) reviewed the assessments, as done in some previous applications of FISK (Lawson et al. 2013; Hill et al. 2014). In the southeastern USA, Florida encompasses a region ranging from the warm temperate coastal plain of the Florida Panhandle through the subtropical wetlands of south Florida (Kottek et al. 2006). Florida was further subdivided into regions based on climate and geography, and assessments were completed for south and central Florida to better capture the regional nature of risk. South Florida was defined as the region including Lake Okeechobee southward encompassing the coastal freshwater canal system of southeast Florida, the warmest portion of the state. Central Florida was defined as the region north of south Florida and south of the Suwannee-Santa Fe River basin. Separate assessments were not completed for north Florida or the Florida Panhandle (the Suwannee-Santa Fe River basin and the regions north and west) because the climate and temperature tolerance data strongly indicated that Arapaima would be unable to survive winters in these regions.

RESULTS AND DISCUSSION

Arapaima Risk

The assessment process indicated that Arapaima is unlikely to survive and establish in open waters of most of Florida, risk primarily occurring in south or southeast Florida. The overall FISK score for Arapaima in Florida using a moderate climate match was 9, indicating medium risk. Factoring in a high climate match for south Florida yielded a FISK score of 11 for the region, representing the maximum risk score for any region. A corresponding low climate match for central Florida reduced the FISK score for that region to 7. Factors that increased FISK scores for Arapaima included its large body size, predatory trophic classification, air-breathing ability, parental care, history of establishment outside of its native range, and impacts on native species outside its native range (Table 1). Factors that reduced the overall score included a moderate to low climate match, no known dangers to human health, no transmission of pathogens declared reportable by the World Organization for Animal Health (OIE 2014) not already found in Florida, inability to hybridize with native Florida species, and a relatively long generation time (Table 1).

Risk of Arapaima to Florida is a function of the probability that these fish would be introduced into the environment to survive, reproduce, and cause negative effects (ANSTF 1996; Orr 2003). Arapaima has few attributes that make it likely to escape from culture facilities. For example, it is an air-breather but has no specialized morphology to allow it to disperse overland (Kramer et al. 1978; e.g., Swamp Eel *Monopterus albus*, Brown Hoplo *Hoplosternum littorale*, and Walking Catfish *Clarias batrachus*). Overwinter survival in most of Florida is unlikely. If Arapaima were to escape or be purposefully released into waters within a suitable climate, such as southeast Florida canals, the species is likely to survive and reproduce. Large body size and evidence of movement within river systems in its native range suggest a high potential for dispersal through connecting water bodies (Castello 2008a; Miranda-Chumacero et al. 2012). Anglers also might facilitate dispersal to create fishing opportunities. Because of its large

TABLE 1. FISK version 2 assessment for Arapaima for Florida. The Q ID column corresponds to question identification codes in FISK. Answer codes are N = no, Y = yes, and ? = don't know. Certainty codes are 1 = very uncertain, 2 = moderately uncertain, 3 = moderately certain, and 4 = very certain.

Q ID	Question	Answer	Justification	Certainty
1.01	Is the species highly domesticated or widely cultivated for commercial, angling or ornamental purposes?	N	Cultured but relatively new industry mostly centered in South America (FAO 2012).	2
1.02	Has the species established self-sustaining populations where introduced?	Y	Peru and Bolivia upstream of natural barriers to migration (Miranda-Chumacero et al. 2012). Peru outside native range (Ortega et al. 2007). Northeastern and southeastern Brazil reservoirs (Quieroz 2000; Lazzaro et al. 2003; Miranda-Chumacero et al. 2012). Thailand "probably established" (FAO 2015). Failed or probably not established in other locations where introduced.	4
1.03	Does the species have invasive races/varieties/ subspecies?	N	No evidence of invasive segments.	3
2.01	Is the species reproductive tolerance suited to climates in the risk assessment area (1-low, 2-medium, 3-high)?	2	Found naturally in two Koppen–Geiger zones—equatorial fully humid and equatorial monsoonal (see Kottek et al. 2006). Equatorial monsoonal is found only in extreme SE Florida. A portion of southern and southwest Florida has climate type equatorial winter dry. FishBase (2015) lists 25–29°C for its temperature range but uses only aquarium literature as a source. Garcia et al. (2008) state that Arapaima does not tolerate temperatures <16°C.	2
2.02	What is the quality of the climate match data (1-low, 2-medium, 3-high)?	2	Koppen–Geiger maps (Kottek et al. 2006) but not an exact match.	3
2.03	Does the species demonstrate broad climate suitability?	N	Tropical air-breathing species unlikely to tolerate cooler temperatures. Evidence of cold sensitivity.	3
2.04	Is the species native to, or has established self-sustaining populations in, regions with similar climates to the RA area?	Y	Similar to southeast Florida.	4
2.05	Does the species have a history of being introduced outside its natural range?	Y	Various databases (see Q1.01).	4
3.01	Has the species established one or more self-sustaining populations beyond its native range?	Y	Bolivia and Peru (Miranda-Chumacero et al. 2012); Thailand ("probably established"; FAO 2015); perhaps other locations.	4
3.02	In the species' introduced range, are there impacts to wild stocks of angling or commercial species?	Y	Anecdotal evidence of negative impacts on native fishes in Bolivia (Miranda-Chumacero et al. 2012). Anecdotal reference to Portuguese-language reports from the 1950s about impacts in reservoirs in northeast Brazil (see Quieroz 2000).	1
3.03	In the species' introduced range, are there impacts to aquacultural, aquarium or ornamental species?	N	No evidence. Potentially wild-caught ornamentals in Bolivia (?).	3
3.04	In the species' introduced range, are there impacts to rivers, lakes or amenity values?	N	No evidence.	3
3.05	Does the species have invasive congeners?	N	No evidence.	3
4.01	Is the species poisonous/venomous, or poses other risks to human health?	N	Listed as harmless in FishBase (2015). No evidence of risks to human health.	4
4.02	Does the species out-compete with native species?	N	No evidence.	2

(*Continued on next page*)

TABLE 1. Continued.

Q ID	Question	Answer	Justification	Certainty
4.03	Is the species parasitic of other species?	N	Not a parasite.	4
4.04	Is the species unpalatable to, or lacking, natural predators?	N	Small juveniles are vulnerable to large predatory fishes and caimans. Desirable food fish for humans.	4
4.05	Does the species prey on a native species previously subjected to low (or no) predation?	Y	Large body size suggests that Arapaima can prey on native species of a size not frequently subjected to predation pressure (cf. Flathead Catfish *Pylodictis olivaris*). However, the likely limited range of southeast Florida has other large predatory fishes such as Common Snook *Centropomis undecimalis* and Tarpon *Megalops atlanticus*.	1
4.06	Does the species host, and/or is it a vector, for one or more recognized nonnative infectious agents?	N	No OIE-listed diseases (OIE 2014). FishBase (2015) lists several parasites in natural populations.	3
4.07	Does the species achieve a large ultimate body size (i.e., >15 cm total length) (more likely to be abandoned)?	Y	One of the largest freshwater fishes; 290 cm total length (Arantes et al. 2010) and 200 kg (FishBase 2015).	4
4.08	Does the species have a wide salinity tolerance or is euryhaline at some stage of its life cycle?	N	Freshwater species. No reports found of tolerance to elevated salinity or use of brackish water habitats.	3
4.09	Is the species able to withstand being out of water for extended periods (e.g., minimum of one or more hours)?	Y	Air-breather (Stevens and Holeton 1978).	3
4.10	Is the species tolerant of a range of water velocity conditions (e.g., versatile in habitat use)	Y	Found mostly in slow-moving rivers and backwaters (Quieroz 2000; Castello 2008a; Arantes et al. 2013), can use flowing waters to disperse (Miranda-Chumacero et al. 2012).	3
4.11	Does feeding or other behaviours of the species reduce habitat quality for native species?	N	No evidence.	4
4.12	Does the species require minimum population size to maintain a viable population?	?	Considered data deficient by the IUCN (World Conservation Monitoring Centre 1996; has been listed previously as vulnerable), the Arapaima is considered overfished in many regions (Castello and Stewart 2010). No evidence found for population collapse not caused by over-fishing.	3
5.01	If the species is mainly herbivorous or piscivorous/carnivorous (e.g., amphibia), then is its foraging likely to have an adverse impact in the RA area?	Y	Piscivore. Thought to have negative impacts on native fishes in Bolivia (Miranda-Chumacero et al. 2012). Anecdotal reports from northeastern Brazil (see Quieroz 2000). Feeds on a variety of macrocrustaceans and occasionally on reptiles (Quieroz 2000).	4
5.02	If the species is an omnivore (or a generalist predator), then is its foraging likely to have an adverse impact in the RA area?	N	Primarily piscivorous (Quieroz 2000).	3
5.03	If the species is mainly planktivorous or detritivorous or algivorous, then is its foraging likely to have an adverse impact in the RA area?	N	Not in these trophic groups.	4
5.04		N	Not in this trophic group.	4

(*Continued on next page*)

TABLE 1. Continued.

Q ID	Question	Answer	Justification	Certainty
	If the species is mainly benthivorous, then is its foraging likely to have an adverse impact in the RA area?			
6.01	Does the species exhibit parental care and/or is it known to reduce age-at-maturity in response to environment?	Y	Parental care (Quieroz 2000; Castello 2008b)	4
6.02	Does the species produce viable gametes?	Y	Natural populations and aquaculture.	4
6.03	Is the species likely to hybridize with native species (or use males of native species to activate eggs) in the RA area?	N	No close relatives in Florida.	4
6.04	Is the species hermaphroditic?	N	No evidence of hermaphroditism.	3
6.05	Is the species dependent on the presence of another species (or specific habitat features) to complete its life cycle?	N	No evidence.	3
6.06	Is the species highly fecund (>10,000 eggs/kg), iteropatric or has an extended spawning season relative to native species?	N	10,000–20,000 eggs for an 80-kg female (FAO 2012).	4
6.07	What is the species' known minimum generation time (in years)?	4	FishBase (2015) life history tool.	3
7.01	Are life stages likely to be dispersed unintentionally?	N	Unlikely to be dispersed via unintentional pathways	3
7.02	Are life stages likely to be dispersed intentionally by humans (and suitable habitats abundant nearby)?	Y	Desirable food fish and sport fish. Limited potential range of suitable habitats.	4
7.03	Are life stages likely to be dispersed as a contaminant of commodities?	N	Distinctive species unlikely to be dispersed accidentally with other commodities.	4
7.04	Does natural dispersal occur as a function of egg dispersal?	N	Arapaima spawns in a nest on the substrate (Quieroz 2000; Castello 2008b).	4
7.05	Does natural dispersal occur as a function of dispersal of larvae (along linear and [or] 'stepping stone' habitats)?	?	No information found. Unlikely.	3
7.06	Are juveniles or adults of the species known to migrate (spawning, smolting, feeding)?	Y	Juveniles are thought to disperse. Adults known to make lateral migrations and move with floodwaters (Castello 2008a).	3
7.07	Are eggs of the species known to be dispersed by other animals (externally)?	N	No evidence. Eggs guarded by adults (Castello 2008b).	3
7.08	Is dispersal of the species density dependent?	?	No information	3
8.01	Are any life stages likely to survive out of water transport?	Y	Air-breathing (Stevens and Holeton 1978)	3
8.02	Does the species tolerate a wide range of water quality conditions, especially oxygen depletion and temperature extremes?	Y	Air-breather so can survive hypoxic conditions (Kramer et al. 1978; Stevens and Holeton 1978)	4
8.03	Is the species readily susceptible to piscicides at the doses legally permitted for use in the risk assessment area?	Y	Likely susceptible to rotenone. May have been collected using rotenone in native range (Galacatos et al. 1996).	2
8.04	Does the species tolerate or benefit from environmental disturbance?	?	May benefit from flooding. Reproduction in native range during this time (Godinho et al. 2005; Castello 2008b).	2
8.05	Are there effective natural enemies of the species present in the risk assessment area?	?	Some predators but unknown if "effective" at resisting establishment or limiting population size.	2

body and gape size, predation impacts are likely if Arapaima were to become abundant. Overfishing occurs in the native range due to high demand as a food fish and vulnerabilities in its life history and behavior (Castello et al. 2011). Thus, there is potential for control, perhaps eradication, by directed removals. The medium risk categorization by FISK is appropriate because the potential for establishment and impacts within a portion of the risk assessment area are countered by strong risk mitigation factors, such as low cold tolerance and potential for control.

Considerable information was available for Arapaima due to its historic importance in fisheries and increasing use in aquaculture in South America. Plentiful data increases certainty in risk assessments and screens. Nevertheless, data gaps are common even for well-studied species as found in previous risk assessments, including Black Carp *Mylopharyngodon piceus* (Nico et al. 2005), Barramundi Perch (Hardin and Hill 2012), and Barcoo Grunter *Scortum barcoo* (Lawson et al. 2013). These data gaps, which are discovered during a risk assessment, become important areas of future research. Literature reviews also elucidate gaps, providing a wider range of information than risk screens require. For example, the species synopsis provided key insights into human use, habitat requirements, ecologically similar native species, and potential economic and social impacts. Some data deficiencies were evident for Arapaima though not severe enough to call the results of the overall assessment into question. The main research needs identified from the species synopsis and risk screen were related to taxonomic diversity, cold tolerance, invasion history, potential impacts, and control methods. Of these data needs, cold tolerance was determined to be of most importance because it most directly related to potential establishment in Florida.

Assessment Procedure

Standardization of approaches may be a desirable goal for facilitating direct comparisons among risk assessments or streamlining research and management activities. However, multiple risk-based approaches can provide agencies with tools specific to their complex range of information and management needs. The present Arapaima evaluation was composed of a detailed literature review and FISK, which saved time, money, and personnel effort over to a comprehensive risk assessment. Using screening tools in a stand-alone manner decreases resource needs even further and will be adequate for some situations (e.g., Hill et al. 2014). Rapid screening tools are perhaps more commonly used as a preliminary step to help managers determine if additional evaluation is necessary (Copp et al. 2005; Koop et al. 2011) or as a component to a more complex risk analysis scheme (e.g., Copp et al., in press).These rapid screens such as FISK are beneficial because they can be completed in about 1 d (see also Koop et al. 2011) and can be completed by just one assessor, although two or more assessors and a reviewer can improve the final product (e.g., Almeida et al. 2013; Lawson et al. 2013; Tarkan et al. 2014). A risk management component would follow risk assessment activity and may itself vary in cost and complexity from in-house efforts of one or two staff members to multi-agency and multi-stakeholder participation. Similarly, risk management can be tailored to suit situation-specific needs.

Effective risk-based procedures are transparent (ANSTF 1996; NRC 2002). The transparency allows for a better understanding of the uncertainties that are inherent in risk assessment (NRC 2009). Certainty in answering the questions was high in our assessment; 84% of responses were more certain than not (41% of responses very certain, 43% moderately certain, 12% moderately uncertain, and 4% very uncertain). The most uncertain answers were for questions related to potential impacts and invasion history, which is common and hinders risk assessment efforts (Hill et al. 2014). In risk assessment, uncertainty is often handled in a qualitative manner (Orr 2003); however, quantitative assessment of uncertainty seems more appropriate and should be the focus of future efforts (Koop 2012). To remediate at least some uncertainties in risk screens resulting from data deficiency, comprehensive literature reviews provide key information and ready access to pertinent literature. Scoring outputs of risk screens or assessments that assign species to risk categories are useful but may be less important than the data contributing to the score. The presentation of justification and certainty levels for answers to all questions provided by FISK output allows managers to examine the information and certainty directly rather than rely simply on a composite score (Lawson et al. 2013). Managers may therefore make decisions specific to their needs, risk philosophy, and cost–benefit analysis rather than follow a prescribed course of action.

MANAGEMENT IMPLEMENTATION

Agency staff reviewed the species synopsis and FISK assessment, provided comments and questions that were addressed by the assessors, and engaged in discussion with the assessors concerning recommendations and next steps. The first step was to decide if the assessment process provided adequate information to proceed with risk management or if additional assessment efforts were needed. The assessment addressed the main risk and mitigation factors and placed Arapaima into the context of current regulation and historical fish invasions in Florida. The agency determined that a preliminary decision could be made pending clarification of Arapaima cold tolerance, the main factor that would determine the ability of the species to successfully establish and its potential range. Subsequent experiments confirmed the suspected cold sensitivity of individuals imported into Florida for culture (Lawson et al. 2015). Taken together, the species synopsis, risk screen, and additional data on cold tolerance led to the decision that further assessment was not warranted and that enough information was available for risk management.

Mitigation is generally considered for species such as Arapaima that score in the medium-risk category in risk assessments or screens (e.g., ANSTF 1996). The level of mitigation depends on the details of the traits and circumstances that led to the medium-risk categorization, the regulatory framework in place to mitigate risk, and any countering risk-mitigating factors of a nonregulatory nature. The main regulatory options identified were to maintain the status quo as a conditional species, place additional conditions on culture, reduce conditions on culture, or elevate Arapaima to the prohibited list thereby preventing legal culture. No additional nonregulatory options were identified beyond industry education. Risk management in this case was conducted using in-house expertise and interaction with the assessors.

Given that Arapaima is unlikely to survive in Florida waters outside of south Florida, current conditional species regulations and Florida Aquaculture Best Management Practices (FDACS 2007) were viewed as providing adequate risk mitigation (i.e., status quo). Conditional species regulations were put into place specifically to prevent the escape of potentially problematic species from aquaculture facilities. As a conditional species, Arapaima must be cultured with infrastructure and practices that prevent its escape, including at minimum that all levees, tanks, and control elevations are maintained at least 30.5 cm above the 100-year floodplain, that no effluent leave the facility or that any effluent goes through screens or filters adequate to prevent the passage of all life stages, and that the facility maintain security and supervise visitors (FDACS 2007; FWC 2015). Additional steps can be taken to prevent escape of cultured stock into the noncaptive environment such as bird-netting over tanks and ponds, indoor culture, and use of predatory fishes in detention and retention systems (FDACS 2007). The cold sensitivity of Arapaima provides an additional risk mitigating factor from an operational point of view in that outdoor, pond culture in nearly all of Florida will be seasonal rather than year-round, a factor that will considerably self-limit outdoor-based facilities.

Increasing or decreasing the mitigation level of regulations on Arapaima could be considered based on the outcomes of regionally specific variations in climate match. The cold-sensitivity of Arapaima suggests the potential to ease restrictions on culture to reflect the low risk of establishment in north Florida and the Florida Panhandle, and perhaps in portions of central Florida. However, no specific benefit was identified for easing restrictions regionally. The relative climate match to southeast Florida might cause consideration of limiting culture to indoor tanks only, if concerns over potential impacts in the canals are sufficient to exceed risk tolerance. This latter option would reflect a low tolerance for risk and would depend on the ability of current conditional species regulations to prevent escape of cultured Arapaima. The risk assessment and supporting information did not suggest a need to elevate Arapaima to the prohibited list. This action would prevent all culture even outside of southeast Florida, the region with the highest potential for establishment. Based on economics and the availability of land, development of large-scale commercial pond production of Arapaima is unlikely in southeast Florida.

Ultimately the FWC determined that (1) a combination of a detailed synopsis and risk screen was sufficient to inform their decision making, and (2) current conditional species regulations provided adequate risk mitigation. Although FWC has a historical record of comprehensive risk analysis, the agency saved time and funding by developing background information and a preliminary estimate of risk prior to engaging in a more comprehensive analysis. Rapid screens alone might be adequate in select situations. Nevertheless, full-scale risk analysis is still needed for complex cases or where uncertainty is high, and it is unlikely that rapid screens can supplant them from the manager's tool kit. A flexible policy regarding the assessment and management of the risks of nonnative fishes would save agencies time and money. In this way, a risk assessment procedure can be tailored to different situations and risk environments, leading to more informed decision making.

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REFERENCES

Almeida, D., F. Ribeiro, P. M. Leunda, L. Vilizzi, and G. H. Copp. 2013. Effectiveness of FISK, an invasiveness screening tool for non-native freshwater fishes, to perform risk identification assessments in the Iberian Peninsula. Risk Analysis 33:1404–1413.

Alves, C. B. M., F. Vieira, A. L. B. Magalhaes, and M. F. G. Brito. 2007. Impacts of non-native fish species in Minas Gerais, Brazil: present situation and prospects. Methods and Technologies in Fish Biology and Fisheries 6:291–314.

ANSTF (Aquatic Nuisance Species Task Force). 1996. Generic nonindigenous aquatic organism risk analysis review process. ANSTF, Risk Assessment and Management Committee, Washington, D.C.

Arantes, C. C., L. Castello, M. Certa, and A. Schilling. 2013. Environmental influences on the distribution of Arapaima in Amazon floodplains. Environmental Biology of Fishes 96:1257–1267.

Arantes, C. C., L. Castello, D. J. Stewart, M. Certa, and H. L. Quieroz. 2010. Population density, growth and reproduction of Arapaima in an Amazonian river-floodplain. Ecology of Freshwater Fish 19:455–465.

Branquart, E. 2007. Guidelines for environmental impact assessment and list classification of non-native organisms in Belgium. Belgian Biodiversity Platform, Brussels.

Castello, L. 2008a. Lateral migration of *Arapaima gigas* in floodplains of the Amazon. Ecology of Freshwater Fish 17:38–46.

Castello, L. 2008b. Nesting habitat of *Arapaima gigas* (Schinz) in Amazonian floodplains. Journal of Fish Biology 72:1520–1528.

Castello, L., and D. J. Stewart. 2010. Assessing CITES non-detriment findings procedures for *Arapaima* in Brazil. Journal of Applied Ichthyology 26:49–56.

Castello, L., D. J. Stewart, and C. C. Arantes. 2011. Modeling population dynamics and conservation of Arapaima in the Amazon. Reviews in Fish Biology and Fisheries 21:623–640.

CEFAS (Centre for Environment, Fisheries and Aquaculture Science). 2014. FISK—Fish Invasiveness Screening Kit (v2.03 calibrated). Available: http://www.cefas.defra.gov.uk/our-science/ecosystems-and-biodiversity/non-native-species/decision-support-tools.aspx. (April 2015).

Chapman, F. A., S. A. Fitz-Coy, E. M. Thurnberg, and C. M. Adams. 1997. United States of America trade in ornamental fish. Journal of the World Aquaculture Society 28:1–10.

Copp, G. H. 2013. The Fish Invasiveness Screening Kit (FISK) for non-native freshwater fishes—a summary of current applications. Risk Analysis 33:1394–1396.

Copp, G. H., R. Garthwaite, and R. E. Gozlan. 2005. Risk identification and assessment of non-native freshwater fishes: a summary of concepts and perspectives on protocols for the UK. Journal of Applied Ichthyology 21:371–373.

Copp, G. H., I. C. Russell, E. J. Peeler, F. Gherardi, E. Tricarico, A. Macleod, I. G. Cowx, A. D. Nunn, A. Occhipinti-Ambrogi, D. Savini, J. Mumford, and J. R. Britton. In press. European non-native species in aquaculture risk analysis scheme—a summary of assessment protocols and decision support tools for use of alien species in aquaculture. Fisheries Management and Ecology. DOI: 10.1111/fme.12074.

Copp, G. H., L. Vilizzi, J. Mumford, G. M. Fenwick, M. J. Godard, and R. E. Gozlan. 2009. Calibration of FISK, an invasiveness screening tool for non-native freshwater fishes. Risk Analysis 29:457–467.

FAO (Food and Agriculture Organization of the United Nations). 2012. *Arapaima gigas* (Schinz, 1822). FAO, Fisheries and Aquaculture Department, Cultured Aquatic Species Information Programme, Rome. Available: http://www.fao.org/fishery/culturedspecies/Arapaima_gigas/en. (June 2015).

FAO (Food and Agriculture Organization of the United Nations). 2015. Database on introductions of aquatic species. FAO, Fisheries and Aquaculture Department. Rome. Available: http://www.fao.org/fishery/introsp/search/en. (April 2015).

FDACS (Florida Department of Agriculture and Consumer Services). 2007. Aquaculture best management practices rule—January 2007. FDACS, Tallahassee.

FishBase. 2015. *Arapaima gigas* (Schinz, 1822) Arapaima. Available: http://www.fishbase.org/summary/Arapaima-gigas.html. (April 2015).

Fuller, P. L., L. G. Nico, and J. D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society, Special Publication 27, Bethesda, Maryland.

FWC (Florida Fish and Wildlife Conservation Commission). 2015. Florida's exotic fish and wildlife. FWC, Tallahassee. Available: http://www.myfwc.com/nonnatives. (April 2015).

Galacatos, K., D. J. Stewart, and M. Ibarra. 1996. Fish community patterns of lagoons and associated tributaries in the Ecuadorian Amazon. Copeia 1996:875–894.

Garcia, L. O., C. E. Copatti, F. Wachholz, W. P. Filho, and B. Baldisserotto. 2008. Freshwater temperature in the state of Rio Grande do Sul, southern Brazil and its implication for fish culture. Neotropical Ichthyology 6:275–281.

Godinho, H. P., J. E. Santos, P. S. Formagio, and R. J. Guimarães-Cruz. 2005. Gonadal morphology and reproductive traits of the Amazonian fish *Arapaima gigas* (Schinz, 1822). Acta Zoológica (Stockholm) 86:289–294.

Hardin, S., and J. E. Hill. 2012. Risk analysis of Barramundi Perch *Lates calcarifer* aquaculture in Florida. North American Journal of Fisheries Management 32:577–585.

Hill, J. E. 2011. Emerging issues regarding non-native species for aquaculture. Southern Regional Aquaculture Center, Publication 4305, Stoneville, Mississippi.

Hill, J. E. 2013. Risk screen of Arapaima *Arapaima gigas* for Florida. Florida Fish and Wildlife Conservation Commission, Final Report, Tallahassee, Florida.

Hill, J. E., L. L. Lawson Jr., and S. Hardin. 2014. Assessment of the risks of transgenic fluorescent ornamental fishes to the United States using the Fish Invasiveness Screening Kit (FISK). Transactions of the American Fisheries Society 143:817–829.

Hill, J. E., and P. Zajicek. 2007. National aquatic species risk analysis: a call for improved implementation. Fisheries 32:530–538.

Koop, A. 2012. Special applications of pest risk analysis—weed risk assessment. Pages 237–255 *in* C. Devorshak, editor. Plant pest risk analysis: concepts and application. CAB International, Wallingford, UK.

Koop, A. J., L. Fowler, L. P. Newton, and B. P. Caton. 2011. Development and validation of a weed screening tool for the United States. Biological Invasions 14:273–294.

Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel. 2006. World map of the Koppen–Geiger climate classification updated. Meteorlogische Zeitschrift 15:259–263.

Kramer, D. L., C. C. Lindsey, G. E. E. Moodie, and E. D. Stevens. 1978. The fishes and the aquatic environment of the central Amazon basin, with particular reference to respiratory patterns. Canadian Journal of Zoology 56:717–729.

Lawson, L. L. Jr., J. E. Hill, L. Vilizzi, S. Hardin, and G. H. Copp. 2013. Revisions of the Fish Invasiveness Screening Kit (FISK) for its application in warmer climatic zones, with particular reference to peninsular Florida. Risk Analysis 33:1414–1431.

Lawson, L. L. Jr., Q. M. Tuckett, K. M. Lawson, C. A. Watson, and J. E. Hill. 2015. Lower lethal temperature for Arapaima *Arapaima gigas*: potential implications for culture and establishment in Florida. North American Journal of Aquaculture 77:496–501.

Lazzaro, X., M. Bouvy, R. A. Ribeiro-Filho, V. S. Oliviera, L. T. Sales, A. R. M. Vasconcelos, and M. R. Mata. 2003. Do fish regulate phytoplankton in shallow eutrophic northeast Brazilian reservoirs? Freshwater Biology 48:649–668.

Miranda-Chumacero, G., R. Wallace, H. Calderon, G. Calderon, P. Willink, M. Guerrero, T. M. Siles, K. Lara, and D. Chuqui. 2012. Distribution of Arapaima (*Arapaima gigas*) (Pisces: Arapaimatidae) in Bolivia: implications in the control and management of a non-native population. BioInvasions Records 1:129–138.

Nico, L. G., J. D. Williams, and H. L. Jelks. 2005. Black Carp: biological synopsis and risk assessment of an introduced fish. American Fisheries Society, Special Publication 32, Bethesda, Maryland.

NISC (National Invasive Species Council). 2008. 2008–2012 National invasive species management plan. Available: http://www.doi.gov/invasivespecies/upload/2008-2012-National-Invasive-Species-Management-Plan.pdf. (April 2015).

NRC (National Research Council). 1983. Risk assessment in the federal government: managing the process. National Academies Press, Washington, D.C.

NRC (National Research Council). 2002. Predicting invasions of nonindigenous plants and plant pests. National Academies Press, Washington D.C.

NRC (National Research Council). 2009. Science and decisions: advancing risk assessment. National Academies Press, Washington D.C.

OIE (World Organization for Animal Health). 2014. Aquatic animal health code (2014). OIE, Paris.

Orr, R. 2003. Generic nonindigenous aquatic organisms risk analysis review process. Pages 415–431 *in* G. M. Ruiz and J. T. Carlton, editors.

Invasive species: vectors and management strategies. Island Press, Washington, D.C.
Ortega, H., H. Guerra, and R. Ramirez. 2007. The introduction of nonnative fishes into freshwater systems of Peru. Methods and Technologies in Fish Biology and Fisheries 6:247–278.
Pheloung, P. C., P. A. Williams, and S. R. Halloy. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57:239–251.
Quieroz, H. L. 2000. Natural history and conservation of pirarucu, *Arapaima gigas*, at the Amazonian varzea: red giants in muddy waters. Doctoral dissertation. University of St. Andrews, St. Andrews, UK.
Stevens, E. D., and G. F. Holeton. 1978. The partitioning of oxygen uptake from air and from water by the large obligate air-breathing teleost pirarucu (*Arapaima gigas*). Canadian Journal of Zoology 56:974–976.
Stewart, D. J. 2013a. Re-description of *Arapaima agassizii* (Valenciennes), a rare fish from Brazil (Osteoglossomorpha: Osteoglossidae). Copeia 2013:38–51.
Stewart, D. J. 2013b. A new species of *Arapaima* (Osteoglossomorpha: Osteoglossidae) from the Solimões River, Amazonas State, Brazil. Copeia 2013:470–476.
Tarkan, A. S., F. Guler Ekmecki, L. Vilizzi, and G. H. Copp. 2014. Risk screening of non-native freshwater fish at the frontier between Asia and Europe: first application in Turkey of the Fish Invasiveness Screening Kit. Journal of Applied Ichthyology 30:392–398.
Trushenski, J., T. Flagg, and C. Kohler. 2010. Use of hatchery fish for conservation, restoration, and enhancement of fisheries. Pages 261–293 *in* W. A. Hubert and M. C. Quist, editors. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.
USEPA (U.S. Environmental Protection Agency). 1998. Guidelines for ecological risk assessment. USEPA, Office of Research and Development, Washington, D.C.
Verbrugge, L. N. H, G. van der Velde, A. J. Hendriks, H. Verreycken, and R. S.E. Leuven. 2012. Risk classification of aquatic non-native species: application of contemporary European assessment protocols in different biogeographical settings. Aquatic Invasions 7:49–58.
World Conservation Monitoring Centre. 1996. *Arapaima gigas* in the IUCN Red List of threatened species, version 2015.2. Available: http://www.iucnredlist.org/details/full/1991/0. (August 2015).
Zajicek, P., S. Hardin, and C. Watson. 2009a. A Florida marine ornamental pathway risk analysis. Reviews in Fisheries Science 17:156–169.
Zajicek, P. W., T. Weier, S. Hardin, J. R. Cassiani, and V. Mudrak. 2009b. A triploid Grass Carp risk analysis specific to Florida. Journal of Aquatic Plant Management 47:15–20.