Risk analysis in aquaculture:
A step-by-step introduction with worked examples

RISK ANALYSIS IN AQUACULTURE: A STEP-BY-STEP INTRODUCTION WITH WORKED EXAMPLES

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   [Disclaimer: This article was written prior to the current employment of G.V. Dana at the US Department of State. The views expressed in this article are those of the author(s), and do not necessarily reflect those of the US Department of State or the US Government.]

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Citation

This publication should be cited as: Lind CE, Dana GV, Perera RP and Phillips MJ. 2015. Risk analysis in aquaculture: A step-by-step introduction with worked examples. WorldFish, Penang, Malaysia. Manual: 2015-08.

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INTRODUCTION

This publication is based on materials covered and outputs generated during the Workshop on Risk Assessment Methodologies and Tools for Aquaculture in Sub-Saharan Africa, which was jointly held by WorldFish and FAO in Siavonga, Zambia on 28 June–2 July 2010. The workshop was delivered as a training exercise to 17 participants from seven sub-Saharan countries and was designed to highlight current methodologies and tools available for environmental risk analysis in aquaculture development. A key focus of the workshop was to encourage participants to consider hypothetical but realistic scenarios and to discuss issues relevant to evaluating the environmental risks of a given activity or scenario. This publication presents selected scenarios from the workshop and the outcomes of the deliberative process as developed by the participants. The full workshop prospectus and agenda, including the participants list, can be downloaded at [http://www.worldfishcenter.org/resource_centre/FAO-WFC-Zambia-RA-Workshop-Prospectus.24.June.2010.pdf] This publication is factual but not comprehensive, therefore any statements or estimations of risk do not represent the actual risks arising from the described scenario. It is intended to serve as an easily readable introduction to risk analysis, highlighting worked examples that will provide guidance on how a risk analysis may be approached in a similar situation.

Scenario: Transfer of *Oreochromis niloticus* from Malaysia (GIFT strain) to Zambia for aquaculture

A proposal is received from a private farmer by regulatory authorities in Zambia for introducing an improved strain of Nile tilapia *Oreochromis niloticus* from Malaysia (GIFT strain) to a fish farm in Zambia for aquaculture purposes.

Oreochromis niloticus is a member of the family Cichlidae. It is native to Africa and parts of the Middle East. It is found in coastal rivers of Israel; in the Albert Nile to the Nile Delta; in Jebel Marra; and in West Africa with a natural distribution that covers the basins of Benue, Chad, Gambia, Niger, Senegal and Volta. The maximum size is 60 cm, with a maximum recorded weight of 4.4 kg. It lives up to 9 years (Trewevas 1983). Other life history traits can be found in Fishbase.[1]

The GIFT (genetically improved farmed tilapia) strain of Nile tilapia is a domesticated strain that has been selectively bred for improved growth and survival traits. GIFT populations have a growth rate which is 60–80% greater than unselected Nile tilapia populations. The GIFT strain comes from brood stock which originated in four wild populations (Egypt, Ghana, Kenya and Senegal) and four domesticated strains (Israel, Singapore, Taiwan and Thailand). The Nile tilapia has been widely introduced for aquaculture, with many existing strains now widely distributed through countries and ecosystems in tropical regions globally. The GIFT strain has been widely farmed throughout Asia and the Pacific regions, but is not being cultured in Africa.

Note: Red dot indicates the location of farm that will receive the proposed introduced fish.
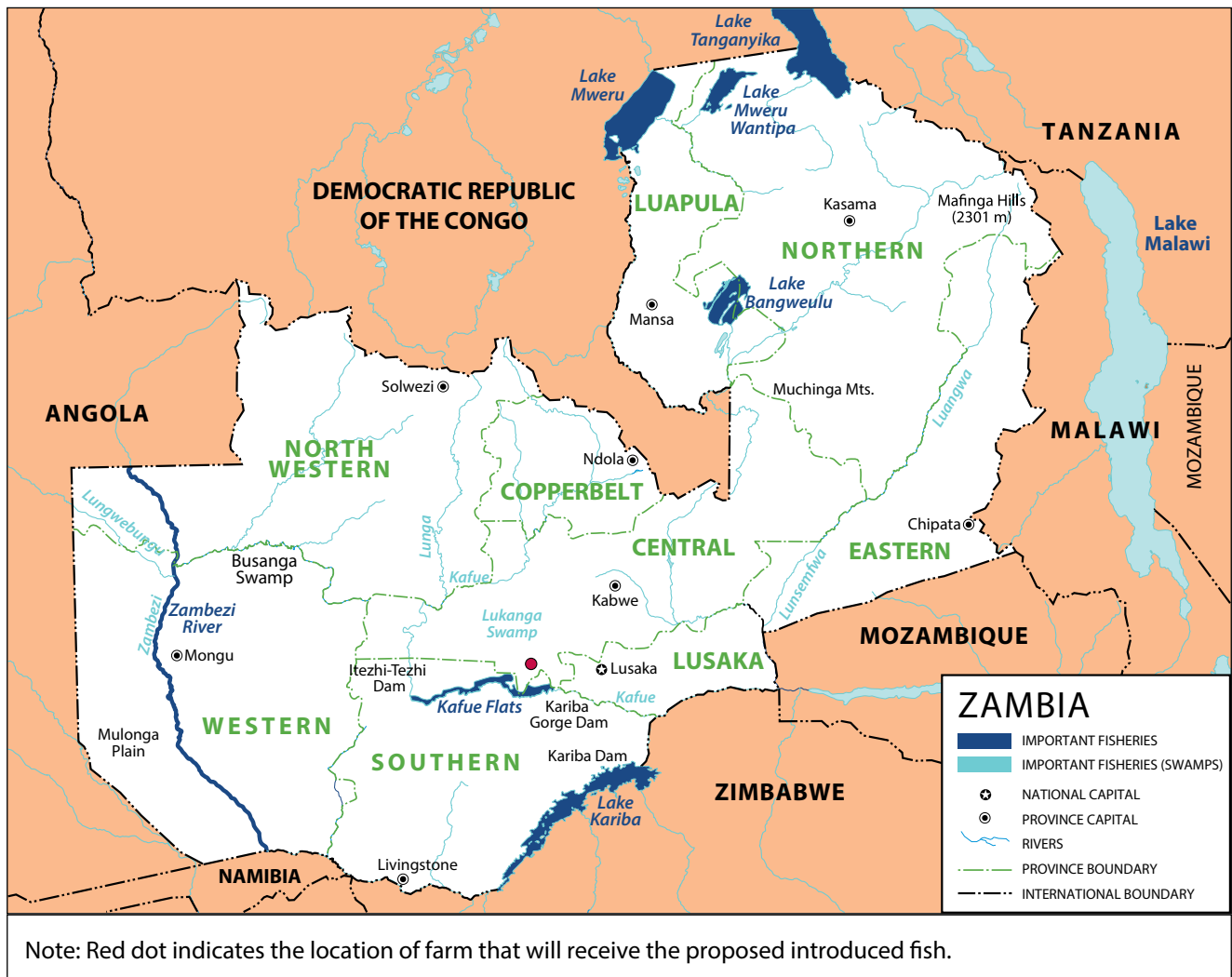
Figure 1. Map of Zambia, highlighting important fisheries areas.

The species occurs in a wide variety of freshwater habitats such as rivers, lakes, sewage canals and irrigation channels. It is mainly diurnal and feeds largely on phytoplankton or benthic algae. Several countries report ecological impacts after its introduction, due to competition with native species and genetic concerns, although the spread of free-living (non-captive) tilapias to areas outside their native ranges has had both both positive and negative effects. Some free-living populations of tilapia that were introduced as alien species for fisheries enhancement or aquaculture provide important sources of food and income, e.g. in Papua New Guinea and Sri Lanka. However, concerns have also been raised over the negative impact of escaped and purposefully released alien tilapia on biodiversity. The numerous documented accounts of interspecific hybridization amongst different tilapia species through artificial or natural mating, has raised significant concerns about the potential genetic impacts of hybridization and genetic introgression of introduced tilapias in Africa.

In this scenario, the species is being considered for introduction into a hatchery and ponds in a watershed near Kafue (near Lusaka) in Zambia. The core breeding nucleus of GIFT is currently maintained by WorldFish at a research station in Kedah state, Malaysia, and would be the origin of fingerlings in the proposed scenario. Fry of Nile tilapia will be introduced and will be reared until they are mature and will be used for subsequent breeding. The original animals will be kept in ponds and tanks in the hatchery/farm complex, but subsequent generations of fry may be distributed to farmers. No special confinement measures are planned, except for the normal farming practices (high pond dikes to avoid flooding losses, care in handling etc.) to avoid losses of an economically important crop. Figure 1 shows the location of the farm.

The surrounding environments are wetlands, a lake and small rivers that drain into the Zambezi River. Flooding is an occasional problem. The location is subject to some disturbance and has a diverse fish fauna (see details in IUCN and associated reports in references). The three-spot tilapia (*O. andersonii*) and the Kariba tilapia (*O. mortimeri*) are also present in freshwater systems of Zambia. These species

each have current or potential commercial significance for fisheries and aquaculture in Zambia, but may be prone to adverse impacts from the presence of *O. niloticus*.

This hypothetical scenario will serve as a basis for a risk analysis, with a focus on the potential genetic impacts of introducing GIFT from Malaysia for aquaculture in Zambia.

Risk analysis overview

Environmental risk analysis is a broad and diverse field. It was first used in ecotoxicology and chemical contamination, but risk analysis approaches are currently being used to address many other environmental issues. Such issues include assessing the risks of pathogen spread, or potential ecological and genetic impacts caused by non-native species introductions. As the field of risk analysis has progressed and evolved, several generalized risk analysis frameworks have emerged that are widely promoted by various governments, organizations and institutions. Although there may be slight variations among the different frameworks and guidelines for risk analysis, in most instances, analogous elements and stages common to all are clearly discernible. The major stages of risk analysis are: (i) scoping or problem formulation, (ii) hazard identification, (iii) risk assessment or characterization, (iv) risk management and (v) risk communication. The worked example outlined in this document follows this general approach, and is based on the risk analysis principles and methodologies described in detail in in the following publications:

- Arthur JR, Bondad-Reantaso MG, Campbell ML, Hewitt CL, Phillips MJ and Subasinghe RP. 2010. *Understanding and applying risk analysis in aquaculture: A manual for decision-makers.* FAO Fisheries and Aquaculture Technical Paper 519/1. 113pp.
- Burgman MA. 2005. *Risks and decisions for conservation and environmental management.* Cambridge, UK: Cambridge University Press. 488pp.
- FAO. 2008. *FAO Technical Guidelines for Responsible Fisheries. Aquaculture development 3. Genetic resource management.* 125pp.
- GESAMP. 2008. *Assessment and communication of environmental risks in coastal aquaculture.* Reports and Studies GESAMP No. 76: 198pp. FAO, Rome.
- Kapuscinski AR, Li S, Hayes KR, Dana G. 2007. *Environmental Risk Assessment of Genetically Modified Organisms. Volume 3. Methodologies for Transgenic Fish.* CAB International, Oxfordshire, UK. 304pp.

Scoping the risk analysis

Clearly defining the problem or issue to be assessed is one of the most fundamental components in a risk analysis. All subsequent reasoning and logical argument of the assessment are based on this important step. Successful completion of this step will facilitate an explicit statement of the goals and unambiguously define the boundaries of an analysis.

The 'scoping' or problem formulation stage can benefit from further separation into smaller components. Here, we outline several common steps that can contribute towards clearly and explicitly defining a risk analysis and can significantly improve its transparency and defensibility. The following sections outline the different problem formulation stages of stakeholder identification, defining boundaries and objectives, describing a conceptual model, and devising assessment end points and measurement end points of a risk analysis.

Stakeholder identification

The incorporation of stakeholders' views and opinions is a key element of modern environmental risk analyses. Since stakeholders of any given socio-ecological system are invariably those who will bear the burden of any potential adverse impact(s) arising from a proposed activity or introduction, their input is considered to be critical in achieving a defensible and trustworthy analysis of risks. This step identifies the stakeholders relevant to the introduction of GIFT in Zambia, as described in Section 1.

Specific questions that an analyst might ask in order to identify important stakeholders are as follows.

- Who are the competent regulatory authorities?
- Who is initiating the proposal? (research institution or development agency or some other partnership)
- Who will buy the fish?
- Who are the people or groups that may be affected by introductions to natural waters?
- Are there any other stakeholders?

During this step, the working group could use a range of available resources such as:

- maps of the receiving environment
- description of aquaculture systems and the community sectors who are likely to adopt it
- other reference materials available in the literature

An example of a potential list of stakeholders relevant to the scenario described in Section 1 is shown in Box 1.

Boundaries and objectives

It is not always possible to evaluate every single risk in one assessment. Often this is because of limitations in time or financial resources needed to conduct an all-encompassing assessment. In acknowledging such limitations, it is important to delineate what an analysis will and will not investigate. The outcome of this step should result in concise and explicit statement(s) that accurately describes the intent and the scope of the analysis, while avoiding vague or ambiguous terms and phrasing.

Box 1. Potential stakeholders relevant to the introduction of GIFT to Zambia for aquaculture

- Zambian Department of Fisheries
- Environmental Council of Zambia
- Fish consumers
- Fish famers
  - hatcheries, breeders
  - producers, multipliers
- Fish traders
- Fishing communities
- Neighboring countries
  - Angola
  - Botswana
  - DRC
  - Malawi
  - Mozambique
  - Tanzania
  - Zimbabwe
- International and regional bodies
  - Food and Agriculture Organization of the United Nations (FAO)
  - World Organization for Animal Health (OIE)
  - Southern African Development Community (SADC)
- Local politicians
- NGOs dealing with development
  - Integrated Rural Development and Nature Conservation (IRDNC)
- Conservation groups
  - World Wide Fund for Nature (WWF)
  - African Wildlife Foundation (AWF)
- Research bodies
  - University of Zambia
  - WorldFish
- Fishers' groups or organizations
  - Recreational fishing organizations
  - Zambia Sport Fishing Association
- Competent authorities
  - Malaysia
  - Zambia

Specific questions that an analyst might ask when defining the boundaries and objectives include the following.

- What are the geographic boundaries of the analysis?
- What temporal scale will be assumed when considering potential environmental impacts?
- Can the 'domain' of environmental risk or impacts be refined?
  - e.g. disease risks, genetic risks or ecological risks
- Is there a specific life-cycle stage of the subject organism that we are concerned with?
- Are there budget or time restrictions for conducting the analysis?

During this step, a range of resource materials to help to define the boundaries and objectives of the analysis can be used. These include:

- maps of receiving environment (watersheds, natural or man-made barriers)
- natural distribution of tilapia species in Zambia
- hatchery manuals (e.g. *GIFT Technology Manual, SPC Hatchery Manual*).

This step will include consideration of the importation and subsequent movement of Nile tilapia (GIFT strain) and how long impacts may take to materialize or be caught during a monitoring program. An example of the hypothetical boundaries and objectives for the scenario described in Section 1 is shown in Box 2.

Box 2. Boundaries and objectives of a risk analysis for the importation of GIFT into Zambia

Domain (type of impacts): The risk analysis will focus on the potential genetic impacts of introduced Nile tilapia on native tilapia species. It will target direct genetic impacts only, namely, the risk of hybridization and genetic introgression.

Geographic scope: The analysis will be restricted to the potential risks that may occur within the Kafue River (Zambia) and the Middle and Lower Zambezi River system (Zambia, Zimbabwe and Mozambique).

Temporal scope: The analysis will consider the potential impacts that are likely to occur within a 10-year time frame. Shorter (one year) and longer (>20 years) time frames were also considered, but after discussion, it was felt this would they would either be too short for detectable impacts to show up, or too long to make realistic and confident predictions of risk.

Statement of risk analysis objective: Combining the above factors, the stated objective for the risk analysis was devised as follows:

"To assess the risk of adverse impacts of genetic introgression and hybridization from Malaysian GIFT with native tilapia species in the Kafue River and middle and lower Zambezi River systems if introduced for aquaculture use."

Conceptual modeling

Every risk analysis that is conducted is based on some conceptual understanding of the system it is investigating. Yet, an explicit description of how an analyst understands or interprets a system and its components is often absent in an analysis. This can provide the foundation upon which logical arguments and reasoning are based downstream in the analysis, such as evaluating the likelihood or consequence of any given event. By describing a conceptual 'model' of the system being investigated, it allows a reader (e.g. decision-maker, scientific expert or other stakeholder) to follow the logic and reasoning of the analyst. This offers additional transparency to the analysis and provides an opportunity to identify any possible inaccuracies or inconsistencies. A conceptual model can be presented in many forms, although is most often presented as a graphical representation of a system (such as an influence diagram) accompanied by supporting text (Suter 1999; Landis 2003).

In this step, a conceptual model of the potential receiving system for introduction of Nile tilapia will be developed which considers the components of the receiving environment and their relationships. Elements that commonly appear in conceptual models include: other native fish species; introduced species; crustaceans; amphibians; plants; microorganisms; livestock; and abiotic components such as water flow rate, water quality and water quantity. Values for abiotic components are not required, but could be included in the model as interacting with biotic factors.

Potential reference materials should target information about biotic and abiotic components of potential receiving environments, such as:

- biodiversity surveys or databases
    - e.g. FishBase, IUCN vulnerable species lists
- studies of potential receiving environments (e.g. water bodies)
- stakeholder interviews.

During this step, the working group should use the generic material available on conceptual modeling, and resource materials such as:

- generic risk analysis resource materials
- studies of potential receiving waters
    - Zambia - FAO Fishery and Aquaculture Country Profile
    - Zambia - FAO Aquaculture Sector Overview
    - FishBase (Zambia data)
- species profiles from various sources (FAO factsheets, FishBase, IUCN vulnerability lists, other databases) which includes the following information:

    - taxonomy
    - closely related species present in the receiving environment (same family)
    - geographical distribution (native and introduced, within Africa only)
    - biological tolerance (water parameters: salinity, temperature etc.)
    - natural diet
    - aquaculture practices (hatcheries, farms, ponds, cages; extensive, intensive etc.)
- articles on the freshwater ecology of Zambia.

An example of a conceptual model for the scenario described in Section 1 is shown in Box 3.

METHODOLOGY AND RISK ANALYSIS APPROACH

Box 3. Conceptual model of the potential interactions and linkages that may be affected by genetic impacts associated with the introduction of GIFT to Zambia

An example conceptual model (amongst several variants) devised by the working group describing the relationships amongst GIFT, native tilapias and major stakeholders of the receiving system is shown below. The conceptual map was developed collaboratively by workshop participants who worked with a facilitator.

Positive effect   Negative effect   Uncertain effect
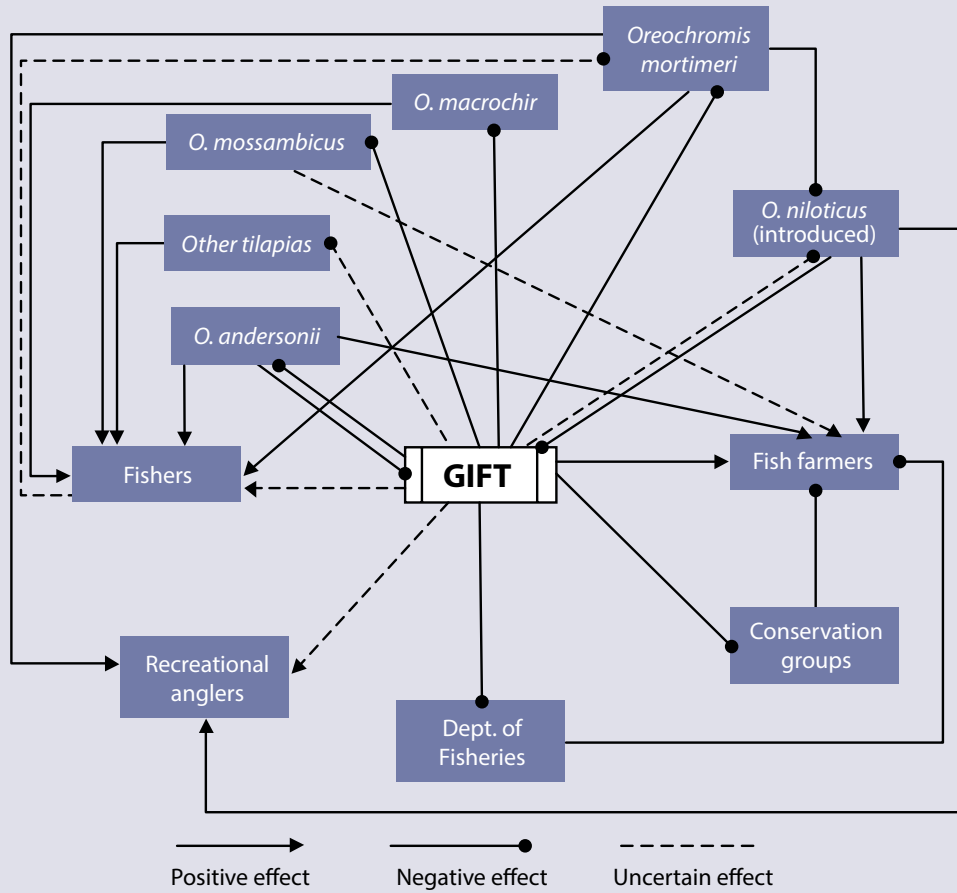
The model presented above highlights the potential interactions between GIFT and elements of the receiving system that may be affected by the introduction of GIFT into Zambia. Central to this is the assumption that GIFT can interbreed with the four key *Oreochromis* spp. native to the region under investigation (Box 2). The stakeholder groups that may be negatively affected by the introduction of GIFT include: the Zambian Department of Fisheries (through an increased workload due to additional risk management, monitoring and regulation of introduced GIFT) and conservation groups listed in Box 1 (by potentially compromising their efforts to conserve native tilapia species in Zambia). The introduction of a more productive fish strain such as GIFT is likely to be a positive activity for fish farmers, recreational anglers and professional fishers, if escaped fish are caught by fishing. However it is recognized that fisheries catches may decline if escaped GIFT negatively impact other tilapia populations. The main mechanism of genetic impact between GIFT and other native tilapias is through hybridization and genetic introgression, and if resource competition by escaped GIFT results in reduced population sizes of other tilapia populations, their effective population size (Ne) may also be impacted. The fault-tree diagram in Box 5 constitutes our conceptual understanding of how escaped GIFT can lead to genetic introgression, and is a conceptual model.

Assessment end points and measurement end points

Assessment end points can be defined as a "formal expression of the environmental values to be protected" (Kapuscinski et al. 2007), and are essential components of a risk analysis. It gives the analysis focus and can lead to approaches that are hypothesis driven. Assessment end points in environmental risk analysis should reflect a valued component of a system and are inherently subjective. The analyst should not depend only upon themselves to decide which assessment end points the analysis will target, and stakeholder input and validation should become a key component of this step. Following Suter (2002), assessment end points should be biologically relevant, operationally feasible, important to society, unambiguously defined, susceptible to the hazard, predictable, and measureable. They should also be related to the conceptual model of the system. The purpose of this step is to identify the assessment end points for the risk analysis for introduction of Nile tilapia. A measurement end point (or monitoring end point) is the metric used to monitor changes in the assessment end point (Kapuscinski et al. 2007). The end point should be something around which a decision can be made and that is measurable, and can inform a "risk acceptance criteria" discussion at a later stage (i.e. how much change in the end point is "acceptable" to stakeholders). An assessment end point may be for example: "decreased freshwater biodiversity" (preferable to simply "biodiversity"), which may be monitored or measured by changes in a species richness index (the measurement end point).

Important questions an analyst should address when determining end points include the following.

- What are the key elements of the socio-ecological system that are valued by stakeholders and are potentially impacted by the proposed activity?
  - e.g. biodiversity, fisheries catch, genetic diversity of species X
- Are the end points biologically relevant, operationally feasible, important to society, unambiguously defined, susceptible to the hazard, predictable, and measureable?

Key information sources that may be useful when defining end points are:

- stakeholder meetings, interviews or workshops
- government policies
- international conventions or guidelines (e.g. FAO Code of Conduct for Responsible Fisheries (1995), Cartagena Protocol of the Convention on Biological Diversity (2000), ICES Codes of Practice (1988, 2005). See Bartley et al. (2005) for a review)
- a clear and well-defined conceptual model of the receiving system
- expert consultation or literature reviews for defining monitoring end points.

To facilitate a decision to either accept or reject a proposed technology (such as a GIFT introduction), it must be determined what level of risk is acceptable or not for the various assessment end points. It is critical that this step involve stakeholder inputs in determining acceptable levels of risk (occasionally referred to as ALOR). It is important to note that what constitutes an acceptable risk is likely to differ from country to country or regionally, depending on the proposed scenario. Regulatory standards or policy frameworks (such as those mentioned above) may often provide sound guidance to what is an acceptable risk, however, stakeholder consultation is strongly recommended at this stage of the risk analysis process in order to provide robustness and defensibility to subsequent decision-making processes.

The assessment and measurement end points determined for the scenario of GIFT introduction into Zambia are presented in Box 4.

Box 4. Assessment and measurement end points for a risk analysis of the potential genetic impacts of introducing GIFT to Zambia for aquaculture

Following a 'silent brainstorming' and subsequent discussion, three recurring assessment end points emerged (with associated measurement end points) from the group, reflecting valued components of the potentially impacted system. These were used to devise the assessment end points that will guide the next stages of the risk analysis process and provide focus to the analysis.

A. Assessment end point: *Purity of native tilapia species*
   • Rationale: Tilapia are a valued group of native species in Zambia. Hybridization between species is documented to increase the likelihood of extinction of a species (Rhymer and Simberloff 1996). Native tilapia are deemed an important component of healthy aquatic ecosystems in Zambia and it would be undesirable to have this compromised.
   • Measured by: Proportion of hybrids in population, occurrence of hybrids

B. Assessment end point: *Genetic diversity of native tilapias*
   • Rationale: Tilapia are a valued group of native species in Zambia. Genetic diversity is a key factor contributing to population resilience and survival (Booy et al. 2000). It may also provide an exploitable genetic resource for potential aquaculture industries in the future (Pullin 1988; Lind et al. 2013), which could be important for Zambian aquaculture in the years ahead.
   • Measured by: Molecular genetic diversity indices, allele frequencies

C   Assessment end point: *Maintenance of subsistence fisheries*
   • Rationale: Tilapias constitute a major component of consumed fish in Zambia and sub-Saharan Africa. For reasons of food security and upholding the livelihoods of fisher folk, it is deemed highly important that subsistence fisheries are maintained.
   • Measured by: Catch per unit effort rates, socioeconomic indices of subsistence fishers

Hazard Identification

In the context of environmental risk analysis, a hazard is "an act or phenomenon that has the potential to produce harm or other undesirable consequences to what humans value" (Kapuscinski et al. 2007). The hazard identification stage should enable us to identify, characterize and prioritize hazards. There are many different techniques and approaches to identify hazards in risk analysis (e.g. Hayes 2002, 2003; Carey et al. 2007) which can range from unstructured brainstorming to sophisticated exercises. Whereas some approaches are more 'formalized' and time-consuming, they are less likely to result in potentially important hazards being overlooked than less rigorous, quicker approaches. The purpose of this step is to identify the hazards associated with the introduction of Nile tilapia with special reference to the potential genetic impacts of the introduction. In this case one may consider:

• the escape of fish into the wild ("a hazard") which may lead to hybridization or genetic introgression, or other adverse genetic effects (a "harm") on native wild or cultured stocks;
• an escaped fish encountering a wild fish, which may lead to interbreeding;
• the native tilapia in the region and their conservation status.

During this step, potentially useful information could include:

• life-cycle information of Nile tilapia and other native tilapia from FishBase (Froese and Pauly 2011);
• freshwater ecological studies of Zambia
• examples of fault tree diagrams;
• IUCN Red List of Threatened Species (www.iucnredlist.org);
• studies demonstrating crossbreeding ability amongst tilapia species or hybridization in the wild.

By examining the above information, this step could create a list of potential species that may be at risk of harm due to the introduction of GIFT into Zambia. If an analysis with greater resolution is necessary, it may be worthwhile considering the chain of events that must occur for a genetic impact (such as hybridization) to occur. To assist the visualization and conceptual understanding of how genetic impacts may arise in the case of GIFT introduction into

Box 5. Hazards identified that may lead to genetic impacts from the introduction of GIFT into Zambia, and a fault tree diagram highlighting the chain of events that must happen for genetic introgression to occur

The potential hazards identified in this step were identified through a facilitated brainstorming, based on the assumption that GIFT could only have direct genetic impacts on other tilapia species (sources: FishBase; Froese and Pauly 2011; IUCN Red List)

- Interaction of GIFT with *Oreochromis andersonii* (native to Zambia)
- Interaction of GIFT with *O. macrochir* (native to Zambia)
- Interaction of GIFT with *O. mortimeri* (native to Zambia)
- Interaction of GIFT with *O. mossambicus* (native to Lower Zambezi River)
- Interaction of GIFT with "other tilapias"
    - *Tilapia rendalli* (very common in the region)
    - *O. mweruensis* (occurring only in marginal areas within the geographical boundaries of analysis)
    - *O. tanganicae* (occurring only in marginal areas within the geographical boundaries of analysis)

Further examination of the published literature, for example, may also help to identify potential hazards that may have been overlooked during a group discussion.

Fault tree exercise:
Exercise to elaborate in further detail the chain of events that are necessary for the escape of introduced GIFT fish to impact assessment end point 1 or 2 (from Box 4) through introgression

Figure and event chain adapted from Kapuscinski et al. (2007). Further reading on faulttrees can be found in Hayes (2002)

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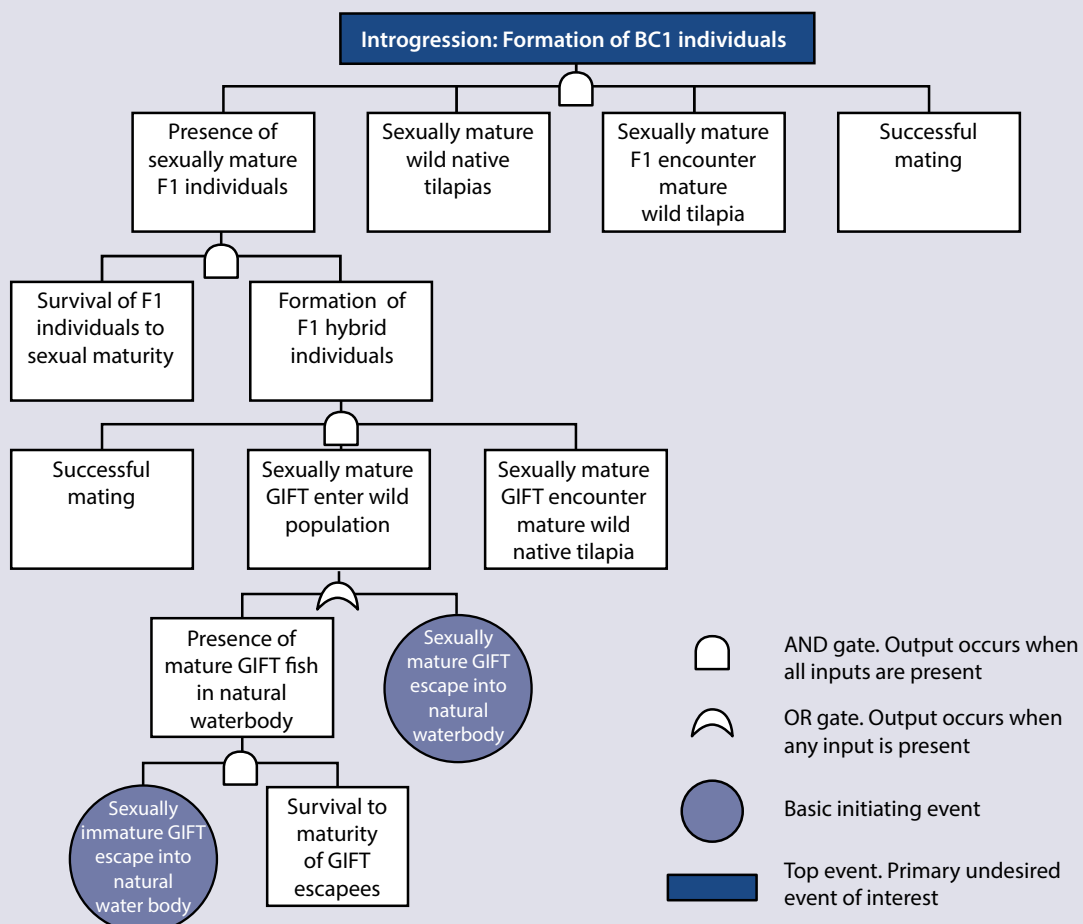
Zambia, a fault tree diagram of events from the point of fish escape to a potential impact will be considered as well (Box 5). The purpose of hazard ID is to identify a range of hazards; if the hazards identified are too numerous to be practically evaluated, it may be necessary to prioritize a list of hazards for further evaluation during risk assessment. It may be useful for the analyst (or analysis team) to discuss a variety of hazards; where on the event chain they fall, what the harms might be along the way; and how each hazard may relate to previously identified assessment and measurement end points and the conceptual model. To enhance transparency of an analysis, it is important to document potential hazards that were discussed or identified but deemed to be less important or as high priority as others and not evaluated in further steps.

Risk assessment

There are multiple methodologies described in the literature for evaluating risk within an environmental risk analysis context (Burgman 2005; Kapuscinski et al. 2007; Vose 2008). These methodologies can range from highly statistical quantitative approaches, to more subjective, opinion-based judgments to inform qualitative and semi-quantitative approaches to risk analysis.

To evaluate the risk of each hazard identified in the previous step, we will use a qualitative approach based on "expert" opinion. The qualitative approach to risk assessment is amongst the most simple and flexible approaches for estimating risk, but it is highly prone to several types of bias and suffers several flaws (Burgman 2001). These shortcomings must be well understood and addressed as thoroughly as possible when taking this approach. Hayes et al. (2007) outline several ways to help maintain the scientific credibility of qualitative and semi-quantitative risk assessment. It is beyond the scope of this document to discuss in detail the various additional approaches to risk assessment; however, further information can be found in the key references listed in section 2.1.

Exposure and effects
This step attempts to evaluate the exposure to the selected hazards and the effects of this exposure on the various end points identified in earlier stages of the risk analysis. Qualitative and semi-quantitative risk assessments attempt to estimate risk of a particular hazard by multiplying qualitative rankings of the

likelihood that a hazard occurs, with the ranking of consequence (i.e. severity) of the subsequent impact, given the hazard has occurred.
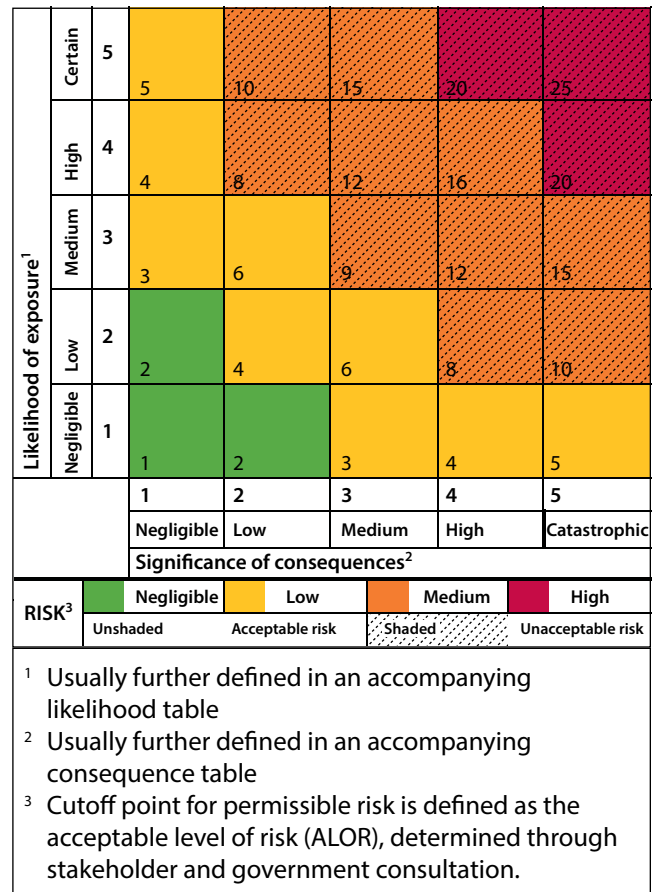
Figure 2. Example of a risk evaluation matrix, highlighting differing severity of likelihood, consequence and risk categories, and a cutoff point of an acceptable level of risk (ALOR).

[1] Usually further defined in an accompanying likelihood table
[2] Usually further defined in an accompanying consequence table
[3] Cutoff point for permissible risk is defined as the acceptable level of risk (ALOR), determined through stakeholder and government consultation.

Likelihood and consequence scores are based on clearly defined categories that increase on nominal scales (e.g. from least to most likely, ranging from 1 to 5). The combination of the likelihood and consequence scores is the risk (risk = likelihood x consequence). There are many examples of likelihood and consequence categories in the literature, for example, those outlined by Hewitt et al. (2006). The likelihood and consequence tables used to address the genetic risks of GIFT introduction into Zambia can be seen in Box 6. The risk scores for each hazard can be evaluated using a risk matrix, which helps in the categorization of differing levels of risk. Risk matrices also have various shortcomings that should be well understood (Cox et al. 2005; Cox 2008). A risk evaluation matrix may look like the following:

Questions may be asked for any hazard identified, but we need to ensure that the consequences "to what" are clearly defined (e.g. consequences in terms of numbers of non-native fish in the system, consequences to genetic integrity of native fish and introduced fish, consequences to water quality, etc.).

Box 6. Evaluating and estimating components of risk regarding the potential genetic impacts caused by a proposed GIFT introduction into Zambia

A semi-quantitative risk assessment was conducted on hazards potentially affecting each of the three assessment end points outlined above. Each "expert assessor" gave their respective likelihood and consequence estimates for four hazards per assessment end point.

The hazards assessed were:

- The interaction of GIFT with *Oreochromis andersonii*
- The interaction of GIFT with *O. macrochir*
- The interaction of GIFT with *O. mortimeri*
- The interaction of GIFT with *O. mossambicus*

Other potential hazards identified in Box 5 were not considered in this risk assessment because priority was given to the most commercially significant species of the genus *Oreochromis*. Of the six *Oreochromis* species in the IUCN Red List of Threatened Species (www.iucnredlist.org) that are present in Zambia, two were classified as "Least concern" and are not considered in this risk assessment. Hazards not included in this assessment may warrant further investigation in an extended analysis in the future.

Each hazard was independently given a likelihood score (range 1–5) and a consequence score (range 1–5) by six different "expert assessors". A risk score was calculated as the product of the likelihood and consequence scores (possible range of 1–25). The following tables were used to guide the scoring.

Likelihood Score	Description
1. Rare	May occur only in exceptional circumstances
2. Unlikely	Could occur at some time
3. Possible	Might occur at some time
4. Likely	Will probably occur in most circumstances
5. Almost certain	Is expected to occur in most circumstances

Table 1. Likelihood table used for risk assessment.

Consequence Score and Rating	End point A Purity of native tilapia populations	End point B Genetic diversity of native tilapia populations	End point C Maintenance of subsistence fisheries
1. Very low	0.0–2.5% occurrence of hybrids in population	0.0–1% change in allele frequencies	0.0–5% reduction catch per unit effort
2. Low	2.6–5.0% occurrence of hybrids in population	1.01–3% change in allele frequencies	6–10% reduction catch per unit effort
3. Moderate	5.1–7.5% occurrence of hybrids in population	3.01–5% change in allele frequencies	11–20% reduction catch per unit effort
4. High	7.6–10 % occurrence of hybrids in population	5.01–7% change in allele frequencies	21–40% reduction catch per unit effort
5. Extremely high	>10% occurrence of hybrids in population	>7% change in allele frequencies	>40% reduction catch per unit effort

* Note that these definitions are hypothetical and may not reflect actual values or relative consequences in a real-life scenario with similar consequences. Ideally each consequence category would be validated through stakeholder input and consultation and supported by published literature if available.

Table 2. Definition of consequence scores for each end point assessed.*

Several key sources of information were used by the group to determine the likelihood and consequence scores for each hazard to the three end points (Table 3). Likelihood-consequence scores of each assessor were summarized and graphically represented using "Subjective Risk Assessment" software from ACERA.[2] This software is not necessary to calculate simple risk scores, but it provides a useful and simple tool to identify (and potentially reduce) uncertainty in the scores of different assessors and the range of different risk scores that have been nominated by the various 'experts' consulted. Additionally, its ability to display those assessors who score similarly and those who differ, provides a prompt to ask why is this so? Is it, for instance, because one has had the read pertinent literature and another has not, or is it because of a genuine difference of opinion? A carefully moderated discussion help resolve uncertainty due to misunderstanding or misinterpretation of data or unawareness of literature, and risk scores may be subsequently modified to more appropriately describe risk. Screenshots are shown in Figure 4.

Topic or issue	Key information	Publication or source
Conservation status of native tilapia species	*Oreochromis andersonii:* Vulnerable *O. macrochir:* Vulnerable *O. mortimeri:* Critically endangered *O. mossambicus:* Near threatened	IUCN Red List of Threatened Species www.iucnredlist.org
Native range overlap with proposed activity	*Oreochromis andersonii:* Yes *O. macrochir:* Yes *O. mortimeri:* Marginally *O. mossambicus:* Downstream only	IUCN Red List of Threatened Species www.iucnredlist.org; see Appendix for maps
Evidence of hybridization with *O. niloticus* is possible	*Oreochromis andersonii:* yes, in the wild; Evidence that *O. andersonii* x *O. macrochir* hybrids are viable from artificial crosses *O. macrochir:* Yes, artificially; F2 are sterile *O. mortimeri:* None found. Evidence that *O. macrochir* x *O. mortimeri* hybrids are possible from artificial crosses *O. mossambicus:* Yes, in the wild and artificially	Leveque 1997; Deines et al. 2014; http://goo.gl/v5wEH; Wohlfarth 1994; Micha et al. 1996; Gregg 1998 Leveque 1997; Wohlfarth 1994; D' Amato et al. 2006
Importance as a commercial species	*Oreochromis andersonii:* Important aquaculture and angling species *O. macrochir:* Commercial fishery; commonly used for aquaculture *O. mortimeri:* Previously the dominant tilapia species caught in Lake Kariba, now being replaced by the introduced *O. niloticus* *O. mossambicus:* Important aquaculture species globally; important commercial fishery species in countries where it has been introduced, however, local importance in Zambia is uncertain. Likely to be a common by-catch	Gopalakrishnan 1988; Froese and Pauly 2011 FAO 2004–2011; Froese and Pauly 2011 Darwall et al. 2009 (see Figure 3) FAO 2004–2011; Froese and Pauly 2011
Documented occurences of introduced *O. niloticus* in Zambia	Kafue Flats [Common in lower reaches (eastern), rare or absent in upper river sections (north and western)]; Lake Kariba; Northern, Copperbelt; Northwestern, Central and Lusaka Provinces	Schwanck 1995; Canonico et al. 2005 (and references therein); Darwall et al. 2009

Table 3. Key publications and sources of information used that may influence and support likelihood and consequence scores.
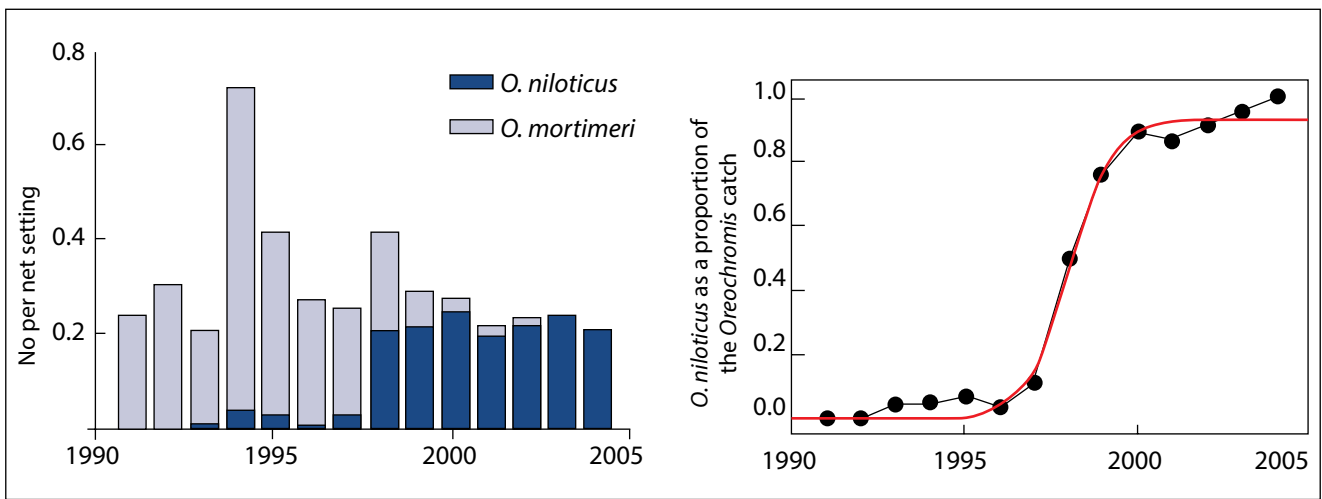
Figure 3. Example of data that could be used to inform risk assessment scoring. This figure highlights the replacement of *O. mortimeri* by introduced *O. niloticus* in gill net catches in Lake Kariba, Zambia. Source: Darwall et al. (2009)

Figure 4. Screenshots from "Subjective Risk Assessment" tool (ACERA), as used for the assessment of GIFT introduction into Zambia.

In reference to Figure 4, each hazard is entered separately (Figure 4A); in this case, the alphabetical prefix before each species name refers to the three different assessment end points. Multiple assessors can participate (Figure 4B), and each will enter their likelihood and consequence scores for each hazard individually (Figure 4C). In cases where there is uncertainty, a range of values can be entered. Risk scores for each hazard can be summarized in several ways, for example, as a bar chart (Figure 4D) showing the range of scores across all assessors (red bars) and the average score (black dot) for each hazard. A large range in risk score could indicate high uncertainty and thus provides a tool to identify and address this.

The prefix code of each hazard (in the screenshots) refers to a consequence specific to the following assessment end points A) 'Purity' of native tilapia species; B) Genetic diversity of native tilapias; C) Maintenance of subsistence fisheries. (NOTE: Due caution is required when directly comparing relative risk scores across assessment end points. This is because for each assessment end point, a different consequence table was used.) The risk scores for the various hazards were not measured against and an acceptable level of risk (ALOR) criterion, as this was not determined by the group. A key observation from the risk assessment excersise in this instance is the large variation in risk scores for most hazards assessed (Figure 4D). This represents uncertainty, which would not be easily identifiably if, for example, only average risk scores were used. In this worked excercise, if we assume the ALOR is acceptable for all risk scores below 10, in using only the average score (without considering the range) for the hazard of GIFT hybridization with *O. macrochir* (A-O. macr in Figure 4D) one would deem that this was an acceptable risk. However, in considering the full range of risk scores for this hazard, it is difficult to ignore that at least one assessor judged this hazard to be of the highest possible risk (score 25). The question must then be asked why is this so? Is it because one assesor is more informed than others? Or perhaps misinformed? A frank and well facilitated discussion amongst assessors should proceed to determine whether this discrepancy in risk scores is due to misunderstanding of an issue (for instance, not knowing about a recent publication), or whether it is a *bona fide* difference of opinion despite sound understanding of the issue. If it is the former, risk scores may be reassessed and adjusted if necessary. If it is the latter, and risk scores are not swayed even after discussion and knowledge sharing, it is still perfectly acceptable. The particular issue is uncertain and it is important that this uncertainty should be carried through the remainder of the assessment. A similar approach should ideally be taken for all hazards assessed. In taking this approach, several of the flaws of qualitative or semi-quantitative risk analysis can be minimized or avoided. In some cases, it may also be possible to put statistical parameters around the uncertainty of expert opinions and formulate a more sophisticated, probablistic approach to treating uncertainty and its implications for risk-based decision-making (for further reading on this topic see Vose 2008).

Uncertainty analysis

Risk analysis will always involve a degree of uncertainty. Uncertainty can arise in several different forms, which are broadly categorized in the table below. Wherever possible, it is always preferable to minimize uncertainty in a risk analysis. However, in some instances the nature of an uncertain factor cannot be reduced, even if further data is collected (see Table 4). This step involves an analysis of uncertainty and modifying any identified sources to reduce it (or capture it), wherever possible. The types of uncertainty should be identified, thus allowing stakeholders to understand the assumptions being made.

Source of Uncertainty	Brief Description	Example Relevant to Aquaculture
Linguistic		
Ambiguity	Word or phrase can take on multiple meanings	A "genetically enhanced" fish could be a selectively bred or transgenic fish
Context dependence	Context or relativity of a term is not understood	"Long-term", "small-scale" or "highly productive" are all context dependent terms
Underspecificity	Unwanted generality of a term	The statement "catfish will be imported into Fiji" is underspecified with respect to the importation (is it a one-off or a continued, periodic importation?) and the geographic area (will it be imported and used on every Fijian island, or only some?)
Vagueness	Occurs when definitive interpretation or categorization is unclear, especially in borderline cases	A concern of a fish introduction may be that it could cause "algal blooms" and subsequently, "fish kills". Both these terms are vague, as it is unclear what would be the cut off of what does and does not constitute an algal bloom or fish kill. The magnitude of either in this instance is important, since there is always some amount of algae or fish death in a waterbody.
Variability	Naturally occurring variation in a process or quantity	Anything that can fluctuate naturally within a system, such as water temperature, fish population size or abundance. Variability is better understood but cannot be reduced by collecting additional data.
Incertitude		
Measurement error	Difference between measured and true value of a quantity, caused by imperfections in observation or equipment	You may be interested in knowing the heterozygosity of an individual if concerned with genetic impacts. Molecular markers can be used to estimate heterozygosity but unless the full genome sequence is known, any estimate is likely to be slightly different from the true value.
Model uncertainty	Incomplete understanding or oversimplification of the potential interactions of the system under investigation	Is usually more important in quantitative risk assessment than qualitative. For example, it may not be known whether an escaped fish will consume all, some, or no species of native aquatic invertebrates and if this will have a positive, negative, or negligible effect on other aquatic communities. A clear conceptual model can help identify or highlight model uncertainty.
Subjective judgment	Uncertainty caused by the subjective interpretation of data or observation	A controlled aquarium trial may show an aquaculture species outcompetes a native species for food or habitat. Uncertainty from subjective judgment may occur if two individuals interpret differently how this result could apply to a natural environment.
		Based on Burgman (2005) and Hayes et al. (2007)

Table 4. Common sources of uncertainty encountered in risk analysis.

The genetic aspects (or others, such as ecological) of the introduction will likely involve several uncertainties; this may include:

- Subjective judgments
- Lack of data or information
- Variability in the data
- Causality – relations between cause and effect

- Problem formulation – have we solved the right problem?
- Linguistic uncertainty in the language used throughout the risk analysis

Box 7 outlines elements of the worked example that may hold identifiable or reducible uncertainty throughout the risk analysis process.

Box 7. Addressing uncertainty

Uncertainties in the risk analysis process were identified by the group in the working group exercises. This is not a comprehensive assessment of all possible uncertainty within this case study, but highlights some areas that may be important or reducible

Boundaries and objectives
- No obvious uncertainties were identified by the group for this section. A peer-review or broader stakeholder consultation may find otherwise and could be useful if further minimizing uncertainty in this section is a high priority.

Conceptual modeling
- Several uncertainties were identified during the conceptual modeling exercise and are indicated by dashed lines in the influence diagram presented in the conceptual modeling section above. This is a source of model uncertainty. A broader stakeholder consultation or comprehensive review of the literature may reduce this. If not, it could be identified as a future priority for further research.

- When individuals were tasked with creating their own conceptual model, several variants were independently devised (not presented here). This highlights potential model uncertainty and is indicative of differences in the participants' understanding of how components of the receiving system interact. This could be reduced by further group discussion, keeping in mind that it is not always a goal to reach consensus on a single conceptual model, especially in highly uncertain situations.

Assessment and measurement end points
- Uncertainty as to how the purity of native tilapias (end point A) may differ from the genetic diversity of native tilapias (end point B) was identified. It was recognized that the differences in these two end points are subtle but important, and the analysis would benefit from a detailed explanation of why this is so.

Hazard identification
- Recognition that there may be additional mechanisms and pathways that could be included in the described event/ fault tree and contribute towards the occurrence of genetic introgression was flagged as a potential source of model uncertainty.

Risk assessment
- The precise distribution of the different *Oreochromis* species was unclear amongst participants, introducing uncertainty in estimates of exposure likelihoods within the geographic boundaries of the analysis.
- Likelihood table would benefit from further description to distinguish categories better.
- Similarly, cut offs for different levels on the consequence tables could be cross-referenced with supporting documentation to ensure that the listed 'ranges' appropriately reflect the consequence level.
- A large range in group participants' risk estimates is present for the majority of hazards assessed. Given the subjective and qualitative nature of this particular risk assessment, the range in risk estimates observed here is likely to be due to high epistemic uncertainty (specifically, incertitude and subjective judgment) of the systems and processes that may result in genetic impacts. This type of uncertainty can be significantly reduced through a group discussion that probes why some persons believe a particular hazard is high-risk (consequence or likelihood) and others do not. Following such discussion, participants' risk estimates would then be re-evaluated and adjusted if deemed appropriate.

Risk management

Here we consider what can be done to reduce risk, either by reducing the likelihood of the hazard happening or mitigating the consequences of the hazard once they are realized. Management objectives will depend on the stage of entry, spread, and/or establishment of the organism in the receiving environment (e.g. one may be addressing whether a certain activity will increase the spread of an already established organism). It is generally true that risk management initiatives for aquatic organisms will be more effective in minimizing the likelihood component of risk than attempting to minimize consequence. Minimizing the consequences of an escaped fish may be possible, but actions such as pest control to reduce feral fish populations can be laborious and costly (and in many cases ineffective). Therefore, reducing the likelihood of the fish escaping in the first place would be a more cost-effective approach to risk management, and addresses the risk at its source.

Stakeholder consultations can also significantly benefit the development of risk management options, by providing feedback as to whether or not a suggested approach is likely to be feasible in a given region. For example, complex pest management approaches implemented in developed countries (such as electric fish barriers or strict licensing restrictions) may be prohibitively expensive or may be too demanding in some regions.

In addition to identifying and implementing risk management measures for a given activity, a suitable monitoring program should be put in place. The output of a risk analysis is only a prediction, irrespective of how much data is available for the risk assessment. Validating this prediction through an adequate monitoring program is a critical step towards sound environmental management and ensuring a risk analysis is effective at minimizing potential dverse impacts. For example, an analyst may recommend that installing mesh screens on all pond outlets would be an effective risk management approach to minimize escapes but if there is no monitoring strategy to confirm this as an effective strategy (e.g. by checking compliance of farmers or reliability of screens), the effort to minimize risk is essentially futile.

Risk management measures for addressing genetic risk related to the introduction of Nile tilapia might consider:

- documentation and controls on movement of live Nile tilapia for farming purposes
- A reporting system for escapes
- creating zones for aquaculture activities, away from important wild populations
- improved technology to reduce escape risks
- development of targeted Nile tilapia fisheries
- development of sterile fish production systems.

Risk management options for monitoring its effectiveness for the scenario of introducing GIFT into Zambia for aquaculture are outlined in Box 8.

Box 8. Risk management options for minimizing the likelihood or consequence of potential harms caused by the introduction of GIFT to Zambia for aquaculture

Minimizing likelihood of hazards:

The best approach to reduce the likelihood of all hazards assessed would be to minimize as much as possible or eliminate escape events from farm facilities. This could be achieved through the incorporation of:

- mesh screening on all farm system outlets, suitable enough to stop juvenile or larval?) fish
- farm sites situated onshore (pond or tank systems) and away from flood prone areas
- double netted cages, if farmed offshore (but see previous)
- bird netting
- chemical barriers between farm ponds and open waterways, such as high pH ponds
- a settlement or evaporation pond for water effluent, or allow effluent to dissipate through natural seepage over open fields
- secure fencing around the farm perimeter to prevent accidental 'escape' by theft.

Additionally, reducing the likelihood that a particular component of the genetic impact event chain (see event/ fault tree in Box 5) could occur will necessarily reduce the likelihood of that impact occurring. For instance, an F1 hybrid cannot occur if successful reproduction between GIFT and a native tilapia does not happen, which will terminate the chain of events leading to genetic introgression. Accordingly, in this case study the following could minimize the likelihood of genetic introgression occurring:

- farming in an area away from potential mating sites, reducing the likelihood of successful mating;
- farming in an area where a particular native species is not present, minimizing the likelihood of an escaped fish encountering a native counterpart;
- investigate the use of technologies to produce sterile tilapia (such as induced triploidy) so that viable F1 offspring cannot occur. This technology may not yet be suitable for commercialized production and therefore is unlikely to have immediate application as a risk management strategy.

Minimizing consequence of hazards:

Using the consequence tables as guidance, the consequences of particular hazards could be reduced if:

- receiving native tilapia populations are large, thereby requiring larger number of escapees to change the % hybrids, alter the allele frequency or genetic diversity of the population (N.B. this is not necessarily compatible with previous suggestion of farming away from native tilapia populations);
- tilapia is farmed in a region were native tilapia populations are not already classified as 'vulnerable' or are under threat from other development pressures and overfishing;
- tilapia is farmed in a region where subsistence fishers do not depend on tilapias for their catch.

Monitoring potential impacts:

Monitoring approaches could include:

- implementation of an escape reporting system;
- molecular genetic surveys;
- regular checking of fishing catches for hybrids;
- native tilapia population abundance monitoring;
- implementing a permit system, whereby only farmers satisfying certain requirements (such as having containment measures) can obtain a permit to farm Nile tilapia.

Risk communication

A clear risk communication strategy is a key component of risk analysis. It can serve as a mechanism to inform stakeholders of the outcomes and findings of an analysis, and can help to inform and guide the analysis. Risk communication may include broad-scale activities, such as public announcements of the conduct of a risk analysis, or it may solicit highly targeted inputs from important stakeholders to assist in the formulation of elements such as assessment end points, conceptual models or a risk assessment. Both factors will contribute

towards the transparency and defensibility of any risk analysis, the benefits of which have been highlighted in previous sections. A good risk communication strategy will help to increase public trust and acceptability of important decisions that are subsequently based upon the outcomes of a risk analysis.

This step considers the risk communication approaches that should be developed with reference to stakeholder identification in earlier steps. Elements of what could contribute towards a risk communication strategy are highlighted in Box 9.

Box 9. Example of an approach for a risk communication strategy for GIFT introduction into Zambia

Elements of a risk communication strategy are presented in the following table:

What	Who	When	How
Informing proposal initiator of the conduct of a risk analysis	Dept. of Fisheries Competent authorities	Initial proposal for introduction	Government policy briefs or fact sheets
Obtaining initial stakeholder input on valued components of the system and acceptable level of risk	All affected stakeholders	After boundaries and objectives have been defined but before the risk assessment has been conducted	Targeted letters to major stakeholders; stakeholders register as an interested or affected party, followed by workshop or meeting
Specialist scientific input from outside RA team	Scientific experts and scientific community	During and after completion of risk assessment stage, before final decision or recommendation is made	Peer review; symposia or workshop meeting
Community education of environmental impacts of introduced species	Dept of Education, Dept of Fisheries, conservation groups	Ongoing	Community events, agriculture field days, school excursions, aquaculture extension officers

During group discussions, it was collectively agreed and endorsed that all stakeholders need to be informed of all the potential impacts of a given proposal. However, how to balance stakeholder input and communication with the ability or right of the proposal initiators to withhold confidential or commercially sensitive information was discussed. It is expected that this could be a key challenge and a reality for most risk communication strategies, and warrants careful and due attention.

CONCLUSION

This document provides a brief and generalized introduction to the specific steps of an environmental risk analysis, and through the use of worked examples in each step, we trust it can help to highlight the key components in an easily readable format. Throughout the process, we recommend that future risk analyses should place particular emphasis on the importance of stakeholder input (and should document it) and should properly treat uncertainty, minimizing it where possible (e.g. linguistically) or capture it when it is not possible to minimize it any further. Additional examples of the key steps of a risk analysis are presented in Appendix II and III, which highlight alternative risk scenarios, such as hazards from aquaculture activities that may pose ecological or pathogenic risks. This document is not intended to be comprehensive but the many references and methodologies highlighted throughout can contribute significantly towards the conduct of a transparent, honest and defensible risk analyses, and are highly recommended for further guidance.

NOTES

[1] FishBase is the largest online database of finfish species on the internet.

[2] Australian Centre of Excellence for Risk Analysis: http://www.acera.unimelb.edu.au

REFERENCES

Arthur JR, Bondad-Reantaso MG, Campbell ML, Hewitt CL, Phillips MJ and Subasinghe RP. 2010. Understanding and applying risk analysis in aquaculture: A manual for decision-makers. FAO Fisheries and Aquaculture Technical Paper 519/1: 113pp.

Bartley, D.M.; Bhujel, R.C.; Funge-Smith, S.; Olin, P.G.; Phillips, M.J. (eds.). 2005. International mechanisms for the control and responsible use of alien species in aquatic ecosystems. Report of an Ad Hoc Expert Consultation. Xishuangbanna, People's Republic of China, 27–30 August 2003. Rome, FAO. 195pp.

Booy G, Hendriks RJJ, Smulders MJM, van Groenendael JM and Vosman B. 2000. Genetic diversity and the survival of populations. *Plant Biology* 2:379–395.

Burgman MA. 2001. Flaws in subjective assessments of ecological risks and means for correcting them. *Australian Journal of Environmental Management* 8(4):219–226.

Burgman MA. 2005. *Risks and Decisions for Conservation and Environmental Management.* Cambridge, UK: Cambridge University Press.

Canonico GC, Arthington A, McCrary JK and Thieme ML. 2005. The effects of introduced tilapias on native biodiversity. *Aquatic Conservation: Marine and Freshwater Ecosystems* 15(5):463–483.

Carey JM, Beilin R, Boxshall A, Burgman MA and Louisa Flander L. 2007. Risk-based approaches to deal with uncertainty in a data-poor system: Stakeholder involvement in hazard identification for marine national parks and marine sanctuaries in Victoria, Australia. *Risk Analysis* 27(1):271–81.

[CBD] Convention on Biological Diversity. 2000. Cartagena Protocol on Biosafety to the Convention on Biological Diversity: text and annexes. Secretariat of the Convention on Biological Diversity, Montreal, Canada. Available at: http://bch.cbd.int/protocol/text/

Cox LA. 2008. What's wrong with risk matrices? *Risk Analysis* 28(2):497–512.

Cox LA, Babayev D and Huber W. 2005. Some limitations of qualitative risk rating systems. *Risk Analysis: An Official Publication of the Society for Risk Analysis* 25(3):651–62.

D'Amato ME, Esterhuyse MM, Waal BCW, Brink D and Volckaert FAM. 2006. Hybridization and phylogeography of the Mozambique tilapia *Oreochromis mossambicus* in southern Africa evidenced by mitochondrial and microsatellite DNA genotyping. *Conservation Genetics* 8(2):475–488.

Darwall WRT, Smith KG, Tweddle D and Skelton P, eds. 2009. *The Status and Distribution of Freshwater Biodiversity in Southern Africa.* Gland, Switzerland: IUCN and Grahamstown, South Africa: SAIAB.

Deines AM, Bbole I, Katongo C, Feder JL and Lodge DM. 2014. Hybridisation between native *Oreochromis* species and introduced Nile tilapia *O. niloticus* in the Kafue River, Zambia. *African Journal of Aquatic Science* 39(1):23–34.

[FAO] Food and Agriculture Organization of the United Nations. 1995. Code of Conduct for Responsible Fisheries. 41pp. FAO, Rome.

[FAO] Food and Agriculture Organization of the United Nations. 2008. *FAO Technical Guidelines for Responsible Fisheries. Aquaculture Development 3. Genetic Resource Management.* 125pp. FAO, Rome.

Froese R and Pauly D. 2011. FishBase. World Wide Web electronic publication. www.fishbase.org, version (06/2011)

GESAMP. 2008. *Assessment and Communication of Environmental Risks in Coastal Aquaculture.* Reports and Studies GESAMP No. 76: 198 pp. FAO, Rome.

Gopalakrishnan V. 1988. Role of tilapia (*Oreochromis andersonii*) in integrated farming systems in Zambia. *In* Pullin RSV, Bhukaswan T, Tonguthai K and Maclean JL, eds. The Second International Symposium on Tilapia in Aquaculture, Bangkok, Thailand, 16–20 March 1987, 15:21–28. ICLARM, The WorldFish Center. Bogor, Indonesia: CIFOR.

Gregg R. 1998. Introgressive hybridization of tilapias in Zimbabwe. *Journal of Fish Biology* 52(1):1–10.

Hayes KR, Regan HM and Burgman MA. 2007. Introduction to the concepts and methods of uncertainty analysis. *Environmental Risk Assessment of Genetically Modified Organisms: Methodologies for Transgenic Fish* 3:188–208.

Hayes KR. 2002. Identifying hazards in complex ecological systems. Part 1: Fault-tree analysis for biological invasions. *Biological Invasions* 4(3):235–249.

Hayes KR. 2003. Biodiversity sector ecological implications of GMOs. Robust methodologies for ecological risk assessment. Final report: Inductive hazard analysis for GMOs (April).

Hewitt CL, Campbell ML and Gollasch S. 2006. *Alien Species in Aquaculture. Considerations for Responsible Use. World.* Gland, Switzerland and Cambridge, UK: IUCN.

Kapuscinski AR, Hayes KR, Li S and Dana G, eds. 2007. *Environmental Risk Assessment of Genetically Modified Organisms. Volume 3: Methodologies for Transgenic Fish.* Oxfordshire, UK: CAB International.

[ICES] The International Council for the Exploration of the Sea. 1988. Codes of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms. Cooperative Research Report, No. 159. 44pp.

[ICES] The International Council for the Exploration of the Sea. 2005. ICES Code of Practice on the Introductions and Transfers of Marine Organisms. 30pp.

[IUCN] International Union for the Conservation of Nature Red List. web resource: http://www.iucnredlist.org/ (accesible April 2014)

Landis WG. 2003. Ecological risk assessment conceptual model formulation for nonindigenous species. *Risk Analysis* 24(4):847–58.

Lévêque C. 1997. *Biodiversity Dynamics and Conservation: The Freshwater Fish of Tropical Africa.* Cambridge University Press.

Lind CE, Brummett RE and Ponzoni RW. 2012. Exploitation and conservation of fish genetic resources in Africa: Issues and priorities for aquaculture development and research. *Reviews in Aquaculture* 4: 125-141.

Micha J-C, Cuvelier R, Tilquin CH, Muraille B and Bourgois M. 1996. Comparitive growth of hybrids (F1, F2 and F3) of *Oreochromis niloticus* (L.) and *O. macrochir* (Blgr.). *In* Pullin RSV, Lazard J, Legendre M, Kothais JBA and Pauly D, eds. The Third International Symposium on Tilapia in Aquaculture, 354–360. ICLARM Conference Proceedings.

Pullin RSV, ed. 1988. Tilapia genetic resources for aquaculture. Proceedings of the Workshop on Tilapia Genetic Resources for Aquaculture 23-24 March 1987 Bangkok, Thailand. ICLARM

Conference Proceedings 16. 108 p. International Center for Living Aquatic Resources Management, Manila. Philippines. http://ideas.repec.org/b/wfi/wfbook/1762.html.

Rhymer JM and Simberloff D. 1996. Extinction by hybridization and introgression. *Annual Review of Ecology and Systematics* 27(1):83–109.

Schwanck EJ. 1995. The introduced *Oreochromis niloticus* is spreading on the Kafue floodplain, Zambia. *Hydrobiologia* 315(2):143–147.

Suter II GW. 1999. Developing conceptual models for complex ecological risk assessments. *Human and Ecological Risk Assessment* 5(2):375–396.

Suter II GW. 2002. Generic assessment end points are needed for ecological risk assessment. *Risk Analysis* 20(2):173–8.

Trewevas E. 1983. Tilapiine fishes of the genera *Sarotherodon, Oreochromis and Danakilia.* British Museum Natural History, London. 583p

Vose D. 2008. *Risk Analysis: A Quantitative Guide.* 3rd ed. West Sussex, England: John Wiley & Sons.

Wohlfarth GW. 1994. The unexploited potential of tilapia hybrids in aquaculture. *Aquaculture Research* 25(8): 781–788.

Appendix I. *Oreochromis* species ranges in Zambia

Legend:
range type (native)

Extant

Probably extant

national boundaries

lakes, rivers, canals

salt pans, intermittent rivers

Source. IUCN (International Union for Conservation of Nature)

Map 1.   Species range of *Oreochromis andersonii*

Legend:
range type (native)

Extant   national boundaries

Probably extant   lakes, rivers, canals

salt pans, intermittent rivers

Source. IUCN (International Union for Conservation of Nature)

Map 2. Species range of *Oreochromis macrochir*

Legend:

range type (native)

- Extant
- Probably extant

― national boundaries

⬤ lakes, rivers, canals

⬤ salt pans, intermittent rivers

Source. IUCN (International Union for Conservation of Nature)

Map 3. Species range of *Oreochromis mortimeri*

Legend:
range type (native)

■ Extant	—— national boundaries
■ Probably extant	⬤ lakes, rivers, canals
	⬤ salt pans, intermittent rivers

Source. IUCN (International Union for Conservation of Nature)

Map 4. Species range of *Oreochromis mossambicus*

Appendix II. Additional examples of key stages of a risk analysis

Scenario: Ecological risks from an introduction of an improved strain of Nile tilapia (*Oreochromis niloticus*) from Asia to Zambia

Using the scenario outlined in Section 1 of the main document, the following highlights the outputs of key risk analysis steps that might arise when considering potential ecological risks of introducing and improved strain of Nile tilapia from Asia to Zambia. As with the example presented in the main body text, the outputs presented here should not be taken as comprehensive and thorough, and are given for demonstrative purposes only.

Step 1: Scoping a risk analysis

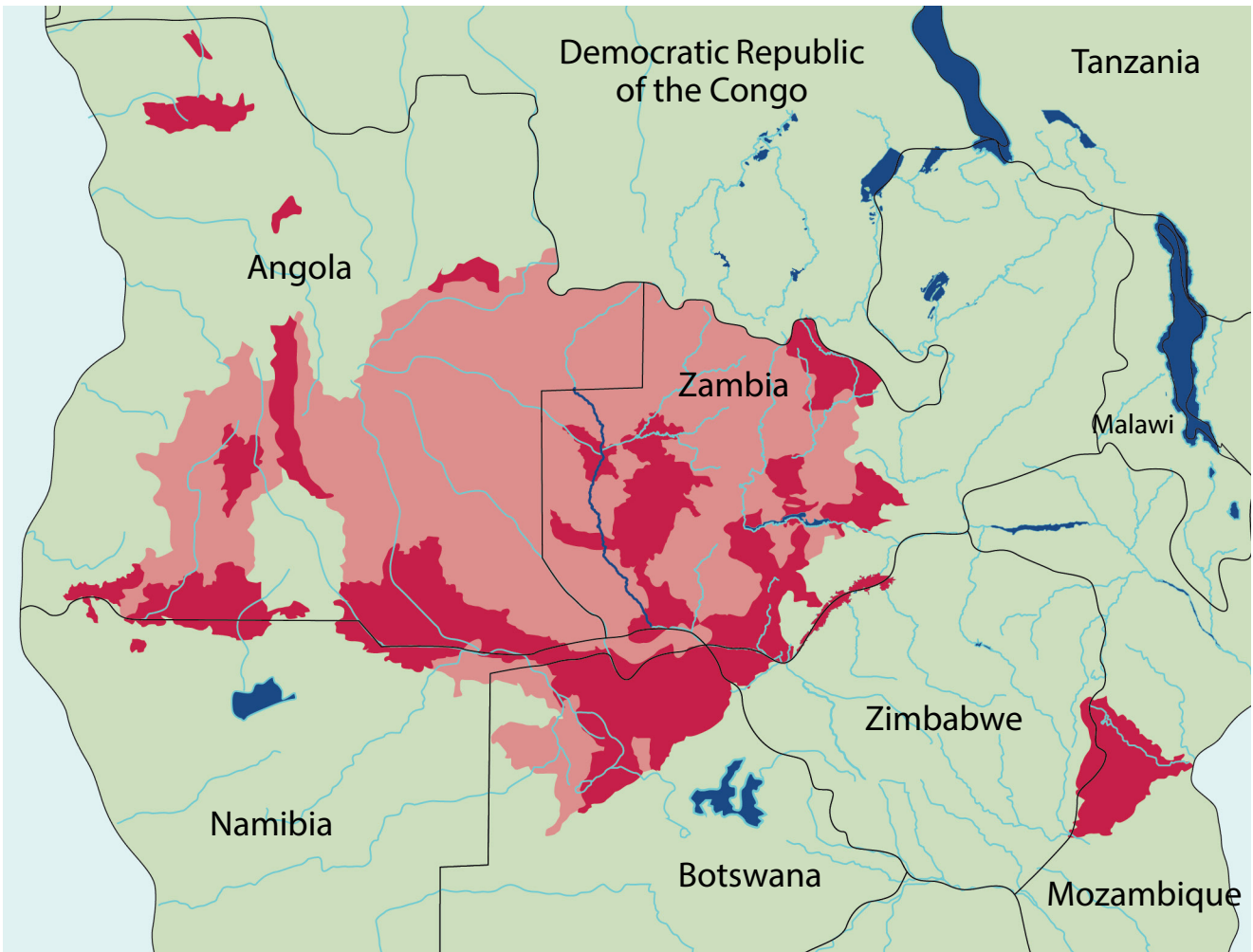**Stakeholder identification**
Possible stakeholders identified by workshop participants:

- Department of Fisheries, Ministry of Livestock and Fisheries
- Environmental Council of Zambia
- Commercial aquaculture farmers
- Zambia Wildlife Authority
- Local fishers
- Research institutes (e.g. UNZA, NISIR)
- Environmental NGOs
- Traditional leaders
- Market associations
- Pharmaceutical industry/veterinarians
- Consumer organizations
- Zambezi River Authority
- National Food and Nutrition Commission
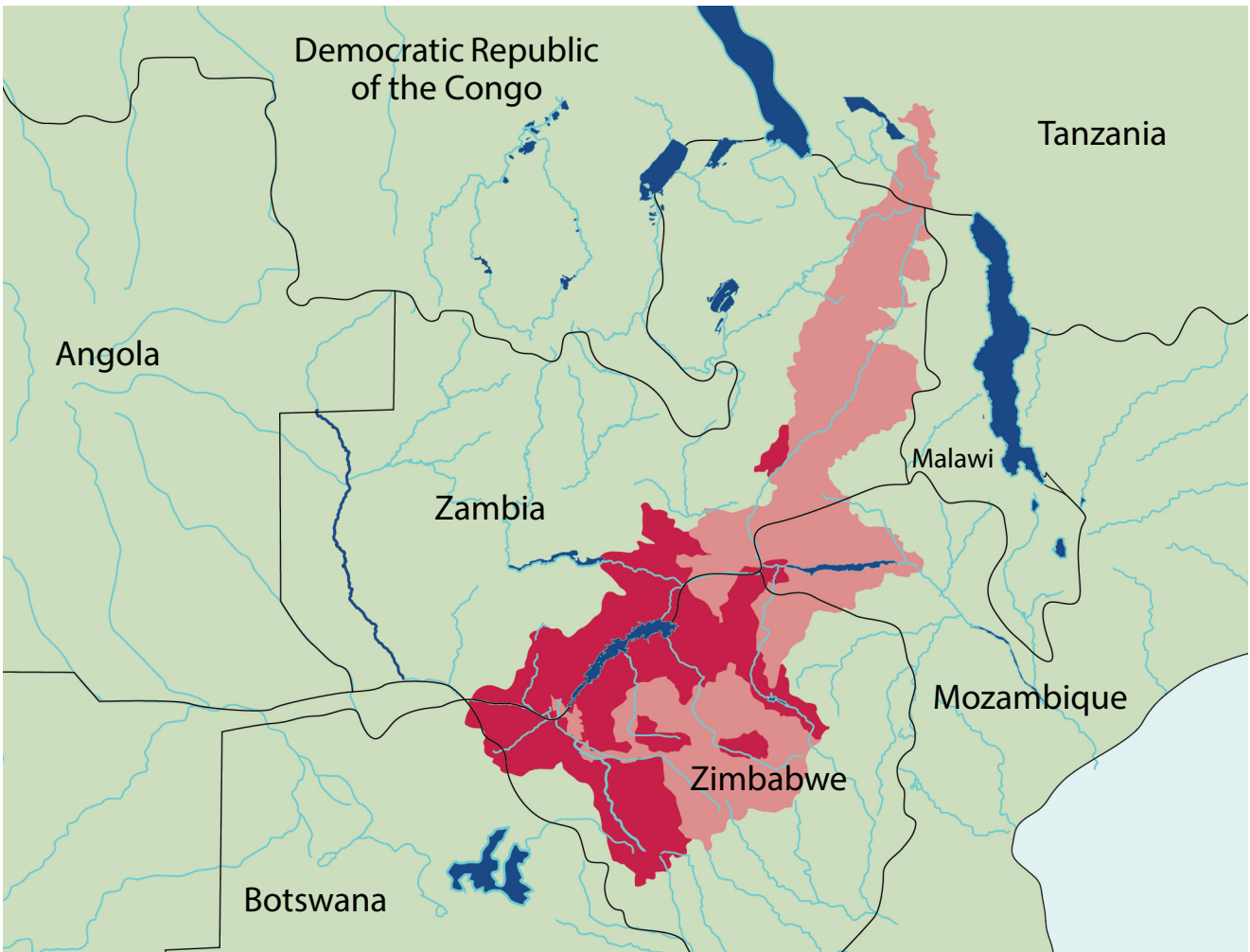- Initiator of the proposal (WorldFish and African research institutes)

Boundaries and objectives
Possible boundaries and objectives identified by workshop participants:

Domain: Focus on ecological impacts of the proposed introduction. However, participants recognized that there might be economic impacts from the introduction, resulting from consumer preference for GIFT versus native tilapia. Depending on consumer preference, fishers farming or harvesting the "unpopular" species could suffer economically from reduced demand for their product. This impact should be bracketed and investigated by the relevant authority.

Geographic area: The analysis should be limited to a) the Lower Kafue River 100 km, or b) the Mid-Lower Zambezi basin

Temporal scope: Analysis should encompass the next 5 years, as that is the time frame necessary before adverse effects are visible. Native tilapias reproduce relatively quickly, and other population level changes have been seen 2 years after other introductions.

Conceptual modeling
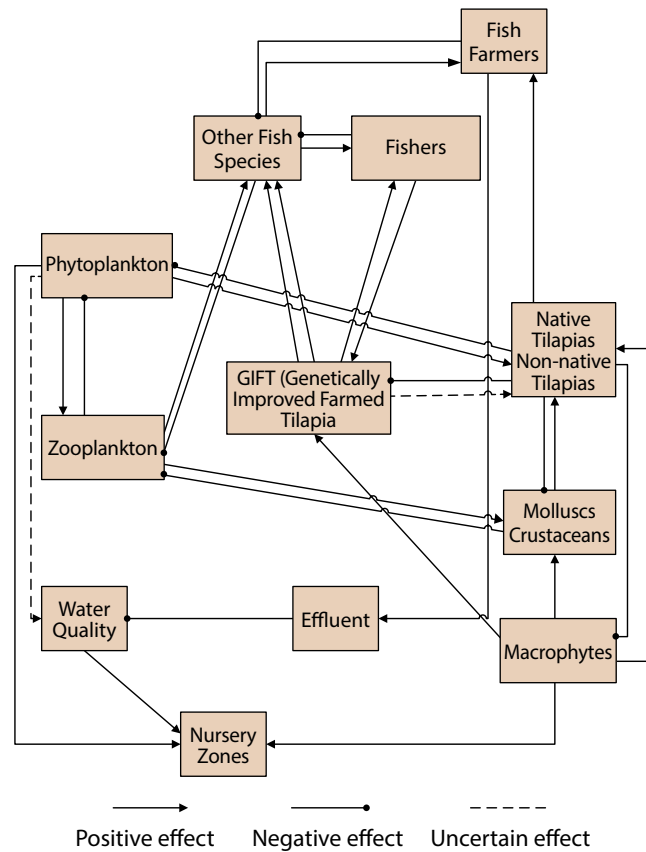
Figure 5. Example of conceptual model developed by workshop participants.

Assessment end points

Example assessment end points identified by workshop participants

- Indigenous tilapia (the entity we value)
  - Sustained population levels in terms of composition and abundance of indigenous tilapia species (what we can measure)
    - CPUE, stock assessment, distribution patterns, disease prevalence (specific measurement metrics or tools)
- Nursery grounds (the entity we value)
  - Integrity of the nursery grounds in terms of % vegetative cover, number of juveniles that survive/year (what we can measure)
    - CPUE, stock assessment, vegetative composition (specific measurement metrics or tools)
- Fisherpersons and fish farmers (the entity we value)
  - Increase the number of Fish Farmers while maintaining the number of Fisherpersons in terms of sustainable production and MSY (what we can measure)
    - Catch assessment surveys, stock assessment (specific measurement metrics or tools)
- Aquatic biodiversity (the entity we value)
  - Species composition and richness and appropriate roles and relationships between species (what we can measure)
    - Species richness index, functional status of different species (specific measurement metrics or tools)
- GIFT (the entity we value)
  - Increasing population numbers in terms of % mortality/time and % growth/time (what we can measure)
    - Survival rates and growth rates, catch assessment surveys (specific measurement metrics or tools)
- Water quality (the entity we value)
  - Maintain baseline water quality in terms of pH, dissolved oxygen and turbidity (what we can measure)
  - Physical and chemical parameters (specific measurement metrics)

APPENDIX II. ADDITIONAL EXAMPLES OF KEY STAGES OF A RISK ANALYSIS

Assessment end point=Indigenous Tilapia spp.
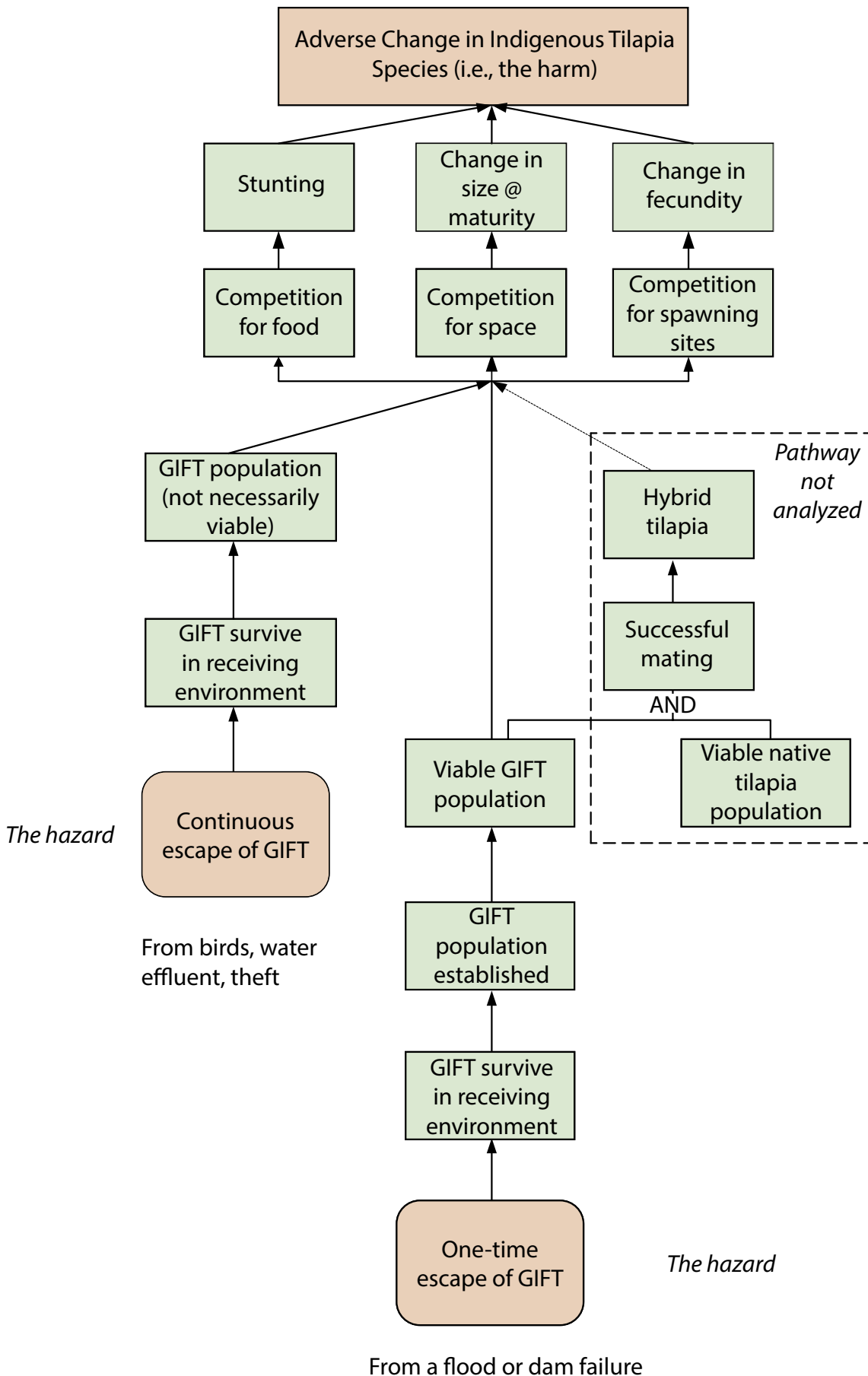
Figure 6. Participants' example of an event tree from escape of GIFT to adverse change in native tilapia species.

Step 3: Risk assessment

Exposure and effects

Participants identified the following three hazards to use as examples for qualitative risk estimation in this next stage.

Hazard 1: Establishment of GIFT and consequences on native tilapia spp. richness and composition
Hazard 2: Establishment of GIFT and consequences for sustainable harvest of native tilapia
Hazard 3: Establishment of GIFT and consequences for nursery habitats.

Each participant assigned likelihood (L) and consequence (C) scores for the three hazards listed above, based on the likelihood and consequence categories presented in Tables 6 and 7–9, respectively.

	Hazard 1			Hazard 2			Hazard 3		
Participant	**L**	**C**	**Risk**	**L**	**C**	**Risk**	**L**	**C**	**Risk**
Peter	4	4	16	4	4	16	~~2~~ 4*	2	~~4~~ 8
Tim	4	4	16	~~2~~ 4	4	~~8~~ 16	~~2~~ 4	2	~~4~~ 8
Malin	4	3	12	4	4	16	4	3	12
Betty	5	4	20	5	2	10	5	3	15
JJM	4	3	12	4	5	20	4	~~1~~ 2	~~4~~ 8
Moono	4	4	16	4	4	16	4	3	12
* Scores with a strike-through denote revised values after group deliberation									

Table 5. Hazards Table

Likelihood score	Description
1. Rare	May occur only in exceptional circumstances
2. Unlikely	Could occur at some time
3. Possible	Might occur at some time
4. Likely	Will probably occur in most circumstances
5. Almost certain	Is expected to occur in most circumstances

Table 6. Likelihood table

Consequence scale	Description
1	Change in species richness or species composition not readily detectable (<10%). Recovery is expected in days (for microbes).
2	Change in species richness or species composition are <20%. Recovery is expected in days to months. No loss of species or populations. No local extinctions.
3	Change in species richness or species composition are <30%. Recovery time in months to decades. Loss of at least one species or populations. Local extinction events.
4	Change in species richness or species composition are <70%. Recovery time in decades. Loss of several species or populations Multiple local extinction events; one regional extinction.
5	Change in species richness or species composition are >70%. Recovery is not expected. Loss of multiple species of populations. Significant local extinctions. Global extinction of at least one species.

Table 7. Consequences for species richness and/or composition

Species richness: the number of species in a given area.
Species composition: the relative abundance of different species (or of different functional groups of species).

Consequence score	Description
1	0.0 –5% reduction catch per unit effort
2	6 –10% reduction catch per unit effort
3	11–20% reduction catch per unit effort
4	21–40% reduction catch per unit effort
5	>40% reduction catch per unit effort

Table 8. Consequences for sustainable fisheries production

Consequence scale	Description
1	No significant changes in habitat types. No new habitat type observed. Populations of habitat forming species not affected (<1% change). No change in area or space available No change in vegetative cover or other shelter
2	Measurable changes to habitat type. New habitat type observed. <10% reduction in population abundance of habitat forming species <10% reduction in area or space <10% change in vegetative cover or other shelter
3	<30% of habitat area affected or removed. Moderate changes to habitat type. New habitat types observed. Possible loss of habitat type. <30% reduction in population abundance of habitat forming species <30% reduction in area or space <30% change in vegetative cover or other shelter
4	<70% of habitat area affected or removed. Major changes to habitat type. New habitat types observed. <70% reduction in population abundance of habitat forming species. <70% reduction in area or space <70% change in vegetative cover or other shelter
5	>70% of habitat area affected or removed. Significant changes to habitat type. No preexisting habitat types exist. >70% reduction in population abundance of habitat forming species. >70% reduction in area or space >70% change in vegetative cover or other shelter

Table 9. Consequences for nursery zones

Step 4: Uncertainty analysis

Example uncertainties identified by workshop participants at each ERA step
Boundaries and scope:

- The definitions of ecological and environmental are different, so ensure that participants understand which type of assessment they are conducting. Ecological is strictly limited to distributions, abundance and relations of organisms and their interactions with the environment.
- The mandate and scope of the analysis could be constrained, depending on the entity tasked with the assessment and their authority and jurisdiction.

Conceptual modeling:

- Definitions of native fish could be misunderstood. Participants changed "native" to "indigenous".
- There were different pathways and mental models, which necessarily contained different components and potential assessment end points. Using a different conceptual model could change the focus or results of an analysis.
- Genetically Improved Farmed Tilapia is not a GMO as it was not created by recombinant DNA technology. It was created through selective breeding. It is important to make that clear.
- Definition of Nursery Zones was clarified.

Assessment end points:

- There was uncertainty about what comprises the end point aquatic biodiversity. It does not include hippos and crocodiles.
- Clarified the definition of biodiversity and discussed whether biodiversity itself as a concept is a feasible end point.
- Clarified the definition of "sustainable" in sustainable fisheries end point.

Hazard ID:

- There are alternative pathways to reach the same adverse effect (or harm), primarily through hybrid tilapia. Lack of clarity or analysis could introduce model uncertainty.
- Clarified the difference between a "viable" versus "established" population for the purposes of our event tree.

Risk assessment:

- Definitions of likelihood need to be quantified
- Need to define what is meant by "major", "significant", etc.

Step 5: Risk management

Participants evaluated the different ways that GIFT tilapia could escape from two systems: hatcheries and ponds, and possible risk management measures.

System	Escape route	Potential risk management measures
HP	Floods	Official demarcation of elevation at which hatchery can be placed, using high water beacons
		Coordinated dam management to regulate water levels below reservoirs
		Inspections and enforcement of zoning
P	Theft	Provide adequate pay and compensation to workers
		Ensure safe working conditions
		Maintain adequate fencing
		Institute a tracking system for persons entering and leaving the facility
		Conduct fish population checks
		Provide incentives for productivity or safety
		Track movement of fingerlings between facilities
HP	Birds	Netting
		Scarecrows
		Drummers or noisemakers
		Persons keeping watch and scaring away birds
HP	Effluent	Install screens that are micrometer mesh
		Sedimentation ponds (at least three)
		Dry and aerate sedimentation pond sand before disposal
		Dispose of effluent on land or agricultural lands
HP= Hatcheries and ponds		

Table 10. Risk management

Step 6: Risk communication

Participants evaluated how and when to communicate with each stakeholder group during an ERA.

Stakeholder group	Boundaries and scope	Conceptual modeling	Assessment end points	Hazard Id	Risk assessment	Uncertainty analysis	Risk mgmt
Dept of Fisheries	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Environmental Council	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Commercial aquaculture farmers	Δ	Δ	Δ	◊	◊	◊	Δ
Zambia Wildlife Authority	*	*	*	*	*	*	*
Local fishers	Δ	Δ	Δ	Δ	◊	◊	◊
Research institutes	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Env NGOs	√	√	√	√	√	√	√
Traditional leaders	Δ	◊	◊	◊	◊	◊	◊
Fish Markets	Inform of final decision via extension officer or fish trader associations						
Pharmaceuticals	*	*	*	*	*	*	*
Consumer orgs	Inform of final decision via meeting or trade shows						
Zambezi River Authority							◊ via formal contacts
Ntl Food and Nutrition Comm	Inform of final decision via meetings or trade shows						
Initiator of proposal	◊	◊	◊	◊	◊	◊	◊
Δ = Essential involvement ◊ = Consultation √ =Auditors * = Case by case basis							

Table 11. Risk communication

Appendix III. Additional examples of key stages of a risk analysis.

Scenario: Pathogen risks from the introduction of African catfish, *Clarias gariepinus*, from Nigeria to Zambia for aquaculture. This example highlights a scenario considering potential pathogen risks of an aquaculture activity. A brief description of the scenario considered is outlined below:

1. Consider a proposal to import a stock of an improved strain of catfish from a country in west Africa (Nigeria) to a country in east Africa (Uganda). The potential impact from the unintentional transfer of aquatic pathogens has raised concern, in terms of risks to aquaculture (current and planned), capture fisheries and freshwater ecosystems. As the relevant authority in the importing country, you are required to assess the pathogen risks associated with the proposal and to make a recommendation on whether or not to allow the translocation and, if allowed, determine the conditions (risk management measures) under which importation can occur.
2. The proposed import is for 10,000 fingerlings of the African Catfish (*Clarias gariepinus*) for a commercial grow-out enterprise in Lake Kariba.
3. Assume that there is no current catfish aquaculture (pond or cage) in Lake Kariba.
4. Consider only the pathogen risks.
5. Assume that there is insufficient information to determine Nigeria's health status with respect to the hazards identified.
6. Assume that the importing country (Zambia) is free of the agents of concern or that the health status is not known.

The following presents the step-by-step approach used to consider the pathogen risks associated with this proposed activity, following the principles outlined in the main document. The method used has been adapted from that used by the Government of Australia Department of Agriculture in conducting import risk analysis for animal and plant commodities.

Step 1: Scoping a risk analysis

Stakeholder Identification
Task: Within the discussion group begin identifying important stakeholders and stakeholder groups. Stakeholders are interested or affected persons or parties.

Working group output
Directly affected groups

*   Fish farmers – Importer and exporter, local/Zambian, other farmers
*   Angling/Sports groups
*   Capture fisheries groups
*   Consumer associations/seafood retailers
*   Feed (fish) companies
*   Fish transport companies

Government agencies

*   Environmental Council of Zambia
*   Exporting country authorities
*   Governments of other countriesinvolved – shared watersheds/ neighbours
*   Local authorities/politicians
*   Local community – traditional leaders
*   Operational/ extension staff
*   Public health authorities
*   Veterinary and fisheries authorities (Zambia) – Minister's office, Environment, Foreign Affairs and other national Government Departments/Ministries;

Information sources

- Technical expertise – diagnosticians, diagnostic labs, universities, research centers, other experts (including clinicians or fish pathologists)
- International NGOs (e.g. FAO, IUCN, OIE, WWF, WorldFish)
- Pharmaceutical/vaccine companies

Boundaries and objectives
Task:

Identify:

1. *The possible geographic scope of the analysis. Important questions to ask include a) whether the analysis is of a particular region or natural area (e.g., a watershed), and b) what type of aquatic systems are important (e.g., streams, rivers, ponds).*
2. *The possible temporal scope of the analysis. Important questions include how far into the future one would need to look to see impacts materialize.*
3. *The possible type of impacts analyzed. Important questions include whether an analysis will focus on ecological impacts only.*

Working group output
The working group determined that the geographic scope of the assessment would be the whole country, i.e. the risk assessment would determine the risks to the whole country. In this context, the geographical extent would be limited to the waters where host species susceptible to the pathogen of concern exist.

The working group decided that there are two elements to the temporal scope:

The period of time for which the likelihood of disease entry and exposure would be determined – this was decided at one year. This would allow for seasonal changes in   environmental, biological and industry factors.

No specific timeframes were set around the period of time over which impacts of disease establishment and spread would be considered as these may be immediate or prolonged. Generally, 20 years was considered would   coverall any type of impact.

The need for consistency in these timeframes between different risk assessments was considered essential to ensure consistency and comparability of risk assessments, and consistent application of a country's ALOP.

The group determined that consistency with WTO and OIE membership required consideration of the types of impacts for pathogen risk assessments as per the international OIE standard, namely:

Direct consequences
Aquatic animal infection, disease, production losses and facility closures Adverse, and possibly irreversible, consequences to the environment Public health consequences.

Indirect consequences
Surveillance and control costs Compensation costs Potential trade losses Adverse consumer reaction.

Conceptual modeling using an influence diagram

1. Using the influence diagram attached as a reference, complete an influence diagram of the receiving system for your case study. Choose five elements from the attached list of socio-ecological components to add to your influence diagram.
2. Add any additional components not on the list that you think might be important to include.
3. Draw in the appropriate types of lines to represent possible relationships between your components.
4. Add additional components from group discussion to your conceptual model (optional).

Working group output

The working group recognized that development of conceptual diagram would be of benefit in the consequence assessment component of the risk assessment. The group first identified the following components of the receiving system as being appropriate for consideration in terms of the consequence assessment part of the pathogen risk assessment:

Biotic

- Pathogen
- Wild *Clarias* species
- Other fish species
- Vertebrate predators
- Zooplankton
- Phytoplankton
- Benthos

Abiotic

- Detritus
- Water quality

Socioeconomic

- Recreational fishing/tourism
- Capture fisheries
- Vessel maintenance industry
- Fish consumers
- Surveillance/ control/ containment costs
- Scientific support

The relationships between these elements are represented in the figure below:

Figure 7. Conceptual model of the receiving environment and potential interactions relevant to pathogen transfer.

Step 2: Hazard ID

1. Use the hazard identification table format in the handout to identify 10 potential hazards based on the OIE Code and other materials provided.
2. Refine selection of these pathogens by applying the refinement criteria (below) and identify those pathogens considered to required detailed risk assessment. Consider:
   a. if the disease agent (hazard) is associated with (may be present in) the commodity,
   b. if the agent is exotic to the receiving environment/country (or is under a control programme), and
   c. if it could cause significant impact.
3. Select a single disease agent on which to undertake a risk assessment.

Working group output
A hazard identification exercise was conducted using the OE listed diseases and information available on the Internet as well as the knowledge of the participants.

The hazard identification table is provided below.

The group decided that for purposes of the workshop, detailed risk assessment would be conducted on *Edwardsiella ictaluri*, which causes enteric septicaemias of catfish (ESC)

Pathogen	Exotic to country/ environment or controls in place?	Pathogen associated with the commodity/ species?	Potential to cause significant disease in the importing country/ environment?	Retained for risk assessment?
Edwardsiella ictaluri	YES	YES	YES	YES
Flavobacterium columnare	NO	YES	YES	NO
Epizootic ulcerative syndrome (Aphanomyces invadans)	NO (Controls in place)	YES	YES	YES
Gyrodactylus rysavyi	NO	YES	NO	NO
Ichthyophthirius multifiliis	NO	YES	NO	NO
Saprolegniasis	NO	YES	NO	NO
Gnathostomiasis	NO	YES	YES (Zoonotic)	NO
Diplostomum	NO	YES	NO	NO
Aeromonas hydrophila	NO	YES	NO	NO
Channel catfish virus disease	YES	YES	YES	YES
Edwardsiella tarda	YES	YES	YES	YES

Table 12. Hazard Identification Table.

Step 3: Risk assessment: *Edwardsiella ictaluri*

Task:

1. Identify exposure groups.
2. Draw commodity distribution pathway diagram (from source population to exposure groups).
3. Construct (based on the commodity distribution diagram) release and exposure pathway diagrams that identify key risk determinant steps of pathways.
4. Determine consequences (impacts) in terms of animal health, environmental and socio-economic impacts that would occur in the event of successful pathogen entry and exposure.
5. Estimate overall unrestricted risk.

Working group output
Estimation of the Likelihood of Entry and Exposure

Two exposure groups were identified:
• farmed catfish in Lake Kariba
• wild catfish in Lake Kariba

The following commodity distribution pathway diagram was constructed, incorporating release and exposure pathways.

The bold arrows represent pathways of release, exposure or establishment and spread that are considered most significant.

RELEASE

SOURCE POPULATION
(LIVE JUVENILE FISH IN EXPORTING COUNTRY)

ARRIVAL AT PORT OF ENTRY IN ZAMBIA

EXPOSURE

SATELLITE HATCHERY/QUARANTINE

FARM CAGES IN LAKE KARIBA

ILLEGAL SALE TO OTHER FARMS

ESTABLISHMENT AND SPREAD

HUMAN FOOD WASTE

RELEASE/ESCAPE OF INFECTED FISH INTO THE LAKE

PROCESSING EFFLUENT

DISPOSAL OF MORTS

FOMITES

Release/escape etc

SUSCEPTIBLE WILD FISH IN LAKE KARIBA

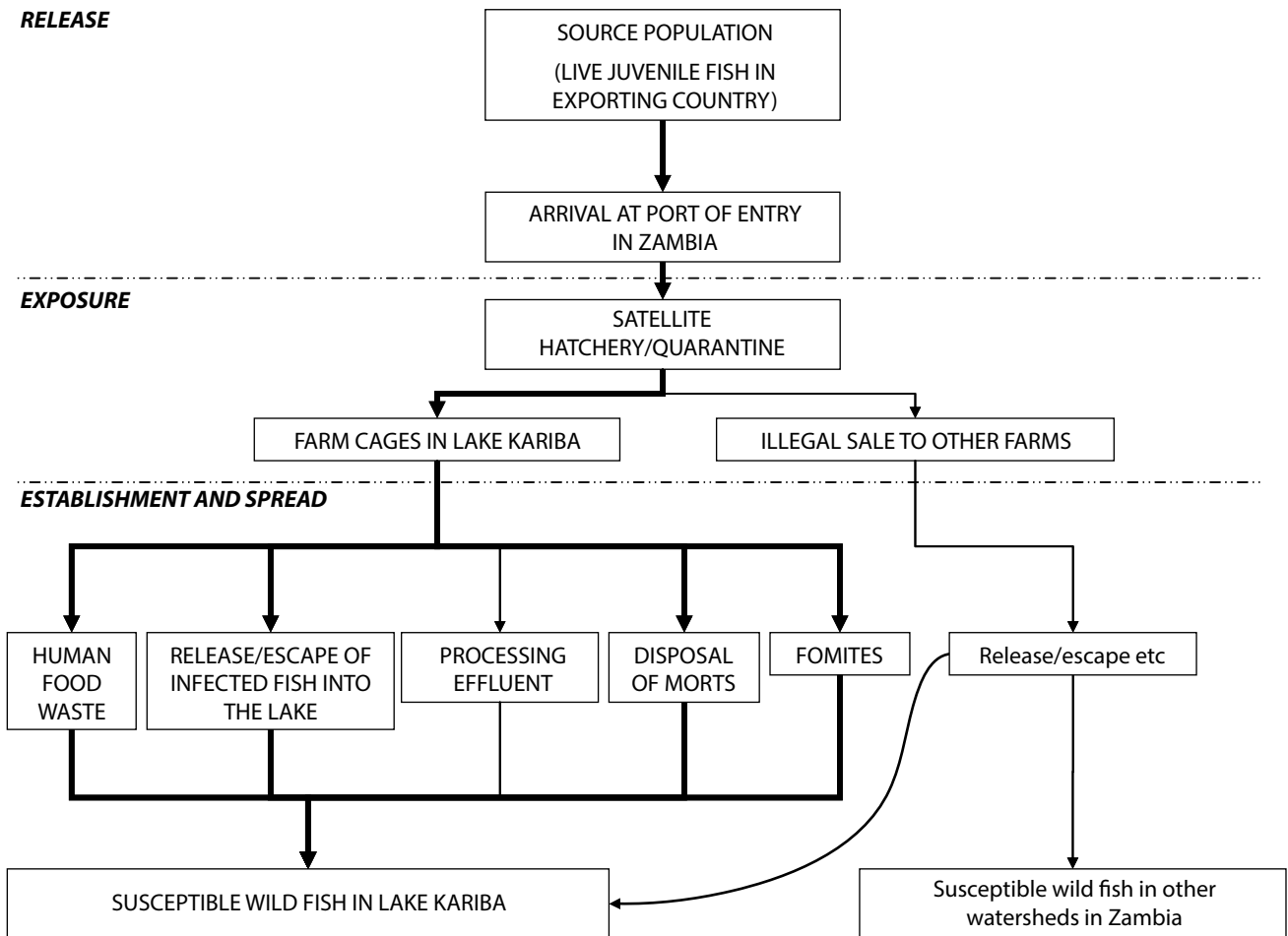Susceptible wild fish in other watersheds in Zambia

Figure 8. Commodity distribution pathway diagram.

The following biological and commodity factors were considered relevant to the determination of release and exposure likelihoods:

Biological factors

- There is (an assumed) carrier state
- Transmission by faecal/oral exposure, predation and direct contact
- The pathogen can remain viable in water for over a week
- The stocking density of fish in cages is high – farm conditions increased likelihood of disease spread and spread to fish in the vicinity of the cages
- There is broad range of susceptible fish species in Lake Kariba
- The pathogen is highly transmissible
- Catfish fingerlings pose the same risk as adult fish

Commodity factors

- Commodity of concern is live fish, which can carry the pathogen
- Large number of fish to be imported –10,000
- All imported fish to be put in a single site – large point source of infectious material
- Waste disposal a source of spread (mot fish are killed at the farm and sold for drying, smoking or cooking).
- The production cycle is about 6 months.

Likelihood estimations were made using Tables 1 and 2 below.

Likelihood	Descriptive definition
High	The event would be very likely to occur
Moderate	The event would occur with an even probability
Low	The event would be unlikely to occur
Very low	The event would be very unlikely to occur
Extremely low	The event would be extremely unlikely to occur
Negligible	The event would almost certainly not occur
Likelihoods for the release and exposure assessment were combined using the matrix of 'rules' for combining descriptive likelihoods shown in Table 2.	

Table 13. Nomenclature for qualitative likelihoods

	High	Moderate	Low	Very low	Extremely low	Negligible
High	High	Moderate	Low	Very low	Extremely low	Negligible
Moderate		Low	Low	Very low	Extremely low	Negligible
Low			Very low	Very low	Extremely low	Negligible
Very low				Extremely low	Extremely low	Negligible
Extremely low					Negligible	Negligible
Negligible						Negligible

Table 14. Matrix of 'rules' for combining descriptive likelihoods

The overall likelihood of release was determined to be HIGH.
The overall likelihood of exposure was determined to be HIGH.

The overall Likelihood of Entry and Exposure was determined to be:

Release x Exposure = HIGH x HIGH = HIGH

Estimation of the likelihood of establishment and spread

Because of time limitation, only a single outbreak scenario was considered; namely, that there is an outbreak in the farm as a result of import juveniles carrying the pathogen, and that the disease spreads other farm cage fish and to other susceptible wild fish species in Lake Kariba.

The working group considered that the likelihood of establishment and spread would be high if prevalence in the farmed fish was greater than 5% or that farm practices favored transmission (e.g. mortalities were not removed promptly or of environmental conditions caused stress). If, however, good farm practices were in place (e.g. good biosecurity practices aimed at reducing transmission) as is likely to be the case or if prevalence of infection remained below 5%, then the likelihood of establishment and spread would be MODERATE.

Estimation of impacts

Because of time limitations, a simplistic approach was taken to estimating impacts, examining qualitatively the potential biological, economic and social impacts of disease establishment and spread.

The overall estimation of impacts associated with the outbreak scenario was determined to be MODERATE because:

- Wild vertebrate predator populations that fed on catfish would be affected.
- Catfish were considered important to the natural ecology of the lake.
- Harvest of wild catfish populations important to the local subsistence fishery would be affected.
- There was no documented evidence that *E. ictaluri* caused significant wild fish kills, but taking a precautionary approach, it was assumed that this could happen.
- International trade implications resulting form the establishment of ESC in Lake Kariba were determined to be minimal.

Estimation of likely consequences

The likely consequences were determined using table 3

Likelihood of establishment or spread		Negligible	Very low	Low	Moderate	High	Extreme
	High	Negligible	Very low	Low	Moderate	High	Extreme
	Moderate	Negligible	Very low	Low	Moderate	High	Extreme
	Low	Negligible	Negligible	Very low	Low	Moderate	High
	Very low	Negligible	Negligible	Negligible	Very low	Low	Moderate
	Extremely low	Negligible	Negligible	Negligible	Negligible	Very low	Low
	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Very low
		Negligible	**Very low**	**Low**	**Moderate**	**High**	**Extreme**
		Consequences of establishment or spread					

Table 15. Matrix for estimating the 'likely consequences' for each outbreak scenario

The Likely consequences were determined to be (using table 3):

Likelihood of Establishment and Spread x Impacts = MODERATE x MODERATE = MODRATE

Unrestricted risk estimation
The overall unrestricted risk for the farmed fish exposure group was determined using table 4

Step 4: Uncertainty analysis

		Negligible impact	Very low impact	Low impact	Moderate impact	High impact	Extreme impact
Likelihood of entry and exposure	High likelihood	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
	Moderate likelihood	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
	Low likelihood	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk	High risk
	Very low likelihood	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk
	Extremely low likelihood	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk
	Negligible likelihood	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk
		Negligible impact	Very low impact	Low impact	Moderate impact	High impact	Extreme impact
		Consequences of entry and exposure					

Table 16. Risk estimation matrix

The overall unrestricted risk for the farmed fish exposure group was estimated to be (using table 4):

Likelihood of Entry and Exposure x Likely Consequences = HIGH x MODERATE = MODERATE

Task:
1. Identify uncertainties in the following steps of the risk analysis process that your group has just completed: Boundaries and Scope, Hazard ID, and Risk Assessment.
2. Refer to the handout of definitions of different types of uncertainty if you get stuck.
3. Write down 2–3 examples of uncertainty at each designated risk analysis step:

Boundaries and scope

Hazard ID

Risk assessment

Are there any other steps you think might also contain uncertainty?

Step 5: Risk management

Task:

1. Determine need for risk management – comparing unrestricted risk against ALOP.
2. List risk management options.
3. Determine restricted risk for some options or combination of options.
4. Determine least trade-restrictive option or combination of options.

Working group output

Appropriate level of protection or acceptable level of risk using the methodology provided is *VERY LOW.*

Thus, using table 4, the unrestricted risk (MODERATE) is considered too high and as requiring risk management.

Potential risk management measures that would reduce the likelihood of release (from HIGH to):

1.	Quarantine observation	MODERATE
2.	Specific pathogen free stock (tested free over time)	LOW
3.	Pathogen free zone/compartment	LOW
4.	Pre-export treatment	MODERATE
5.	Pre-export batch testing	LOW
6.	Limit life stage imported to eggs or broodstock to quarantine facility	NEGLIGIBLE
7.	Pre-export stress testing	HIGH (no change)

Potential risk management measures that would reduce the likelihood of exposure (from HIGH to):

8.	Treatment post-arrival	MODERATE
9.	Quarantine observation (post-arrival)	MODERATE
10.	Post-arrival batch testing	LOW
11.	Post-import facility management/biosecurity	MODERATE

The following risk management measures or combinations of measures were considered to reduce the overall risk (ie the restricted risk) to an acceptable level.

- Option 6 would reduce the overall risk to NEGLIGIBLE
- Options 5 and 10 would reduce the overall risk to VERY LOW
- Options 2 and 3 would reduce the overall risk to VERY LOW
- Options 2 and 10 would reduce the overall risk to VERY LOW
- Options 3 and 10 would reduce the overall risk to VERY LOW

Step 6: Risk communication

Working group output

The working group identified three groups of stakeholders for risk communication as per the first exercise and corresponding modes of communication with each group:

STAKEHOLDER GROUP	MODES OF COMMUNICATION
• Directly affected stakeholders, e.g. capture fisheries groups or tourism groups	• Radio, newspaper • Extension services • Community meetings • 'Mobile loudspeaker' announcements • Internet • Industry association newsletters
• Government agencies e.g. Environmental Council of Zambia or the competent authority in potential exporting countries	• Email/list server • Letters from local government authority
• Technical groups, e.g. university academics and diagnostic laboratories/diagnosticians.	• Email/letters • Industry association newsletters

Table 17. Risk communication

For each phase of the risk analysis process, the working group identified who would be consulted (TARGET AUDIENCE) and the topic of consultation as follows:

PHASE OF ANALYSIS	TARGET AUDIENCE	TOPIC
PRE-SCOPING	government agencies: public health, environment, foreign affairs, provincial governments; chief veterinary officer	• commodity description • end-use • source country
SCOPING	all stakeholders	• commodity description • end-use • source country
HAZARD ID	all stakeholders	• draft list of hazards • technical issues
RISK ASSESSMENT/MANAGEMENT	all stakeholders	• draft assessment and proposed management measures
IMPLEMENTATION	importers exporters competent authorities in exporting countries	• detailed import requirements

Table 18. Risk analysis

This publication should be cited as:
Lind CE, Dana GV, Perera RP, Phillips MJ. 2015. Risk analysis in aquaculture: A step-by-step introduction with worked examples. WorldFish, Penang, Malaysia. Manual: 2015-08.

About the CGIAR Research Program on Livestock and Fish
In developing countries, poor people, especially women and children, consume very little meat, milk and fish. This contributes to nutrient deficiencies and poor physical and cognitive development for children; and poor health and livelihood outcomes for adults. Additionally, the productivity of small- and medium-scale livestock and fish producers and marketing systems in developing countries lags far behind those in other parts of the world.

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