Biodiversity Risk and Benefit Assessment for Rainbow trout (*Oncorhynchus mykiss*) in South Africa

Prepared in Accordance with Section 14 of the Alien and Invasive Species Regulations, 2014 (Government Notice R 598 of 01 August 2014), promulgated in terms of the National Environmental Management: Biodiversity Act (Act No. 10 of 2004).

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EXECUTIVE SUMMARY

Internationally, alien species provide a valuable food source and an economic opportunity in both the fisheries and aquaculture sectors (Bartley 2006). In South Africa, aquaculture is composed of a blend of indigenous and non-indigenous species. However, breeding and domestication of indigenous species requires time, technological and financial resources, whilst there are already alien species with proven aquaculture potential that could be utilized for food production and job creation. There is, however, an environmental risk associated with the uncontrolled introduction and use of alien species and consideration must be given to the potential benefits and risks associated with their use. Internationally, mechanisms and management practices exist to assist with the responsible use and control of alien species in aquaculture and fisheries.

This Biodiversity Risk and Benefit Assessment (BRBA) has been conducted and documented in relation to the import, propagation and grow out of Rainbow trout (*Oncorhynchus mykiss*) in South Africa.

The Department of Environment, Forestry and Fisheries (DEFF), as the lead agent for aquaculture management and development, appointed Anchor Environmental in August 2012 to conduct a Biodiversity Risk and Benefit Assessment (BRBA) for the use of Rainbow trout in South Africa. Subsequently (2018), AquaEco has been appointed to review, update and recompile this risk assessment.

The aim of this assessment was to consider the appropriateness (benefit) of the use of the exotic Rainbow trout (*Oncorhynchus mykiss*) for aquaculture in South Africa, in relation to the potential effectiveness of management measures for ecologically sustainable development of the sector. This will assist the Department of Environment, Forestry and Fisheries (DEFF) and other relevant competent authorities in taking informed decisions regarding the promotion and regulation of this alien and invasive species. The document not only serves as a broad high-level assessment to be applied in the context of new applications and regulation of the import and culture of Rainbow trout in South Africa, but also contributes to the development of environmental norms and standards for the culture of the species.

The assessment has been conducted in accordance with the risk assessment framework for such assessments contained in the Alien and Invasive Species (AIS) Regulations (Government Notice R 598 of August 2014) and the National Environmental Management: Biodiversity Act 10 of 2004.

The risk assessment investigated the taxonomy, key characteristics, dietary aspects and history of Rainbow trout culture, while considering its native environment in the Pacific northwest of North America. It was found that Rainbow trout is a highly fecund, persistent and potentially invasive species, but that these traits depend on suitable environmental conditions (especially water temperature).

A detailed methodology was followed in the identification and assessment of risks, which included the scoring of each risk pathway and resulting ecological endpoint in categories of probability, severity, scope, permanence, confidence, potential for monitoring and potential for mitigation.

The identified pathways that could facilitate risks include:

- The pathway of escape, via various potential routes that include:
  - Escape during transit of stock from a supplier;
  - Escape via the inflow water;
  - Escape via the outflow water;
  - Escape due to poor design, system malfunction or poor maintenance;
  - Escape through deliberate human actions such as theft or human error;
  - Escape through predation, where fish are preyed upon and removed as live specimens to the surrounding environment; and
  - Escape caused by natural disasters such as flooding.
- The diverse pathway related to the potential transfer of disease.

The identified risk endpoints include:

- The potential for Rainbow trout to cause physical (abiotic) damage to the aquatic environment;
- The potential for Rainbow trout to cause predator displacement in the environment;

- The potential for Rainbow trout to impact on prey species;
- The potential for Rainbow trout to compete for food, habitat niches and other resources; and
- The potential threat of new or novel diseases carried into the environment by Rainbow trout as a vector – either directly or indirectly.

During the assessment, it was found that the overall ecological risk profile for Rainbow trout was low to moderate, apart from the risk of predation by Rainbow trout on other aquatic species, which is high. The potential for monitoring and mitigation was found to be high, particularly as this related to the prevention of escape.

Key economic and social matters were considered in a balanced manner in conjunction with the potential ecological risks. It was found that Rainbow trout supports a significant commercial aquaculture sector in South Africa. The operation and expansion of a formal and lawful Rainbow trout aquaculture sector will contribute to the ecologically responsible use of this species. This will also be in alignment with government's objectives and policies around aquaculture development, apart from the fact that it will create employment, rare skills and local economic activity.

Several measures have been proposed for the monitoring and mitigation of the potential risks, and these could be included as conditions related to the issue of permits.

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1. INTRODUCTION

This Biodiversity Risk and Benefit Assessment (BRBA) pertains to the import, propagation and grow out of Rainbow trout (*Oncorhynchus mykiss*) in South Africa.

The BRBA has been structured in accordance with the framework provided in the Alien and Invasive Species (AIS) Regulations (Government Notice R 598 of 01 August 2014)[1], promulgated in terms of Section 97(1) of the National Environmental Management: Biodiversity Act 10 of 2004 (NEMBA).

At date of publication, this BRBA will be recognised as a national reference work related to the ecological risks and potential benefits of importing, propagating and growing Rainbow trout in South Africa. In this regard it replaces all preceding risk assessment documents and frameworks for the species.

2. PURPOSE OF THIS RISK ASSESSMENT

The purpose of this BRBA lies primarily in providing an information framework that can aid in determining the ecological risks and potential benefits of importing, propagating and growing Rainbow trout in South Africa. This framework sets out to provide information to assist decision making regarding the use and permitting of this species.

The BRBA aims to accurately depict the potential ecological risks associated with importing, propagating and growing Rainbow trout, and to evaluate these risks in determining possible justification through allowance by permitting.

Although this BRBA has been prepared to meet the requirements for risk assessments in terms of the AIS Regulations, promulgated in terms of NEMBA, it illustrates overarching generic information at a national level relevant to South Africa. The intention is that this framework be used as a decision support tool, for existing and future entrants into the

[1] *Note that at the time of publication revised draft regulations had been circulated for public comment and will be promulgated in due course. This BRBA will require review and update in terms of these revised regulations.*

sector, to which project- and site-specific information must be added when regulatory approval is sought for the import, propagation and grow out of Rainbow trout.

The main objectives of this BRBA are:

- To determine the primary risks associated with the import, propagation and grow out of Rainbow trout in South Africa.
- To determine the potential benefits associated with the import, propagation and grow out of Rainbow trout in South Africa.
- To provide key information related to the characteristics of Rainbow trout for risk and benefit analysis.
- To show the pathways that facilitate risks.
- To illustrate the risks in terms of probability of occurrences, degree of severity (magnitude), extent (scale or scope), longevity (permanence), confidence of the analysis and the potential for mitigation and monitoring.
- To illustrate areas of uncertainty in the determination of risk (confidence).
- To determine whether the ecological risk profile is acceptable in terms of the environment in which these risks will occur.
- To use the determined risk factors to provide guidance around decision making and mitigation.
- To use the determined risk factors to provide guidance to monitoring, research needs and ongoing risk communication.

3. THE RISK ASSESSMENT PRACTITIONERS

The BRBA was originally prepared by Dr Barry Clark of Anchor Environmental. It has been reviewed, updated and recompiled by Mr. E. Hinrichsen from AquaEco (as commisioned by Ecosense). Both authors meet the criteria for risk assessment facilitators (as per Section 15 of AIS Regulations), in that:

- They have practised as environmental assessment practitioners.
- They are independent.

- They are knowledgeable insofar as the NEMBA, the AIS Regulations and other guidelines and statutory frameworks that have relevance, are concerned.
- They are experienced in biodiversity planning in the aquaculture sector and have conducted a range of biodiversity risk assessments.
- They comply with the requirements of the Natural Scientific Professions Act 27 of 2003 and are registered as Professional Natural Scientists with the South African Council for Natural Scientific Professions (SACNASP).

4. NATURE OF THE USE OF RAINBOW TROUT

Rainbow trout (*Oncorhynchus mykiss*) were initially imported into South Africa as fertilised ova in 1897, after which they were domesticated and spawned in captivity by 1899 (Shelton et al 2015). Following the establishment of several hatcheries in the Western Cape, Eastern Cape, Kwa-Zulu Natal and later Mpumalanga, Rainbow trout were routinely spawned and stocked into rivers and dams across South Africa for recreational sport fishing; a practice that continues to this day. Commercial production of Rainbow trout as a table fish started in the 1960's (Stander 2009) and today the farming of Rainbow trout is a well-established industry.

Today, two distinct uses and user groups can be identified for Rainbow trout in South Africa:

- A vibrant fraternity exists around the use of Rainbow and to a lesser extent Brown trout as a recreational angling species, to the extent that the identity and character of entire villages in the Eastern Cape, Kwa-Zulu Natal and Mpumalanga have been shaped by trout and trout fishing.
- Apart from the fact that an aquaculture sector supplies fish to the recreational angling market, a strong aquaculture sector exists in South Africa to produce Rainbow trout as a table fish; almost exclusively for the local market.

As Rainbow trout farming technologies are developed and applied worldwide, several production systems have been developed and are applied in South Africa. Young trout or fingerlings in South Africa originate either from local hatcheries or from the hatching of imported ova. Ova are typically hatched in small raceway or upwell type systems and moved on to fingerling tanks that range in size, design and materials; all of which rely on a high flow rate of good quality water. Fish of various sizes are either sold into the recreational fishing market or grown on for the table fish market in a variety of systems that include ponds, raceways, tanks, floating cages of in thermally regulated intensive bio-secure recirculation systems (FAO 2012). Of these, cage culture poses the highest biosecurity risk (i.e. risk of escape and/or transfer of pathogens and disease to wild populations), while culture in raceways or ponds represent a lesser biosecurity risk, with culture in recirculating systems the lowest biosecurity risk.

5. REASONS FOR FARMING WITH RAINBOW TROUT

The FAO estimates that by 2030, fish farming will dominate global fish supplies. With aquaculture already providing more than half of the global seafood demand, it is now considered likely that marine harvesting and terrestrial rangeland farming has reached its capacity in many parts of the world. Aquaculture and intensified agriculture remain the only alternative to supplying a growing food need, fuelled by an increasing global population (Alexandratos *et al* for the FAO, 2012).

Although the FAO State of World Fisheries and Aquaculture Report (2016) found that Africa accounted for only 2.32 % of global aquaculture production in 2014, the FAO State of World Fisheries and Aquaculture Report (2014) highlighted that Africa showed the fastest continental growth in average annual aquaculture production (11.7 %) between 2000 and 2012. This growth will increasingly lead to the expansion of aquaculture on the African Continent, and particularly in South Africa.

The historical development of aquaculture in South Africa has been slow, and several initiatives have failed. However, South Africa is participating in this global shift that is driven by demand, market and industry globalisation, and rapidly expanding application of advanced agriculture technologies.

The National Aquaculture Policy Framework for South Africa (2013) was developed in response to a realization that the country is faced with rapidly diminishing marine fish stocks, an increasing demand for seafood and a developing global aquaculture sector that has become a significant agro-economic driver and food production alternative.

Rainbow trout, while alien to South Africa, is the leading freshwater fish species in South African aquaculture by tonnage and value. As Rainbow trout are diadromous, the global farmed production for fresh and marine waters was in the region of 761 766 tons per annum in 2015 (FAO, 2016). Rainbow trout is well-known in the global market for farmed salmonid species.

The use of Rainbow trout for recreational fisheries and for the production of table fish has seen the establishment of feral populations in most of the cooler wasters along the southern escarpment (Western Cape and Eastern Cape), eastern escarpments (Eastern Cape, Kwa-Zulu Natal and Mpumalanga) and a few high lying areas west of the greater Drakensburg of South Africa. All feral populations in South Africa have resulted from introductions, whether intentional or accidental, albeit that self-propagating populations have developed in some instances. However, due to climatic constraints, the current range of these fish is limited, and some populations depend on artificial restocking.

6. LEGAL CONTEXT

The Department of Environmental Affairs (DEA) is the mandated authority over the National Environmental Management: Biodiversity Act 10 of 2004 (NEMBA), which sets out the framework, norms, and standards for the conservation, sustainable use, and equitable benefit-sharing of South Africa's biological resources. The AIS Regulations and the AIS List (Government Notice R 864 of 29 July 2016)[2] have been promulgated in terms of this Act, providing enabling instruments for the Act.

These statutory frameworks recognise and categorise indigenous and alien species, some of which have the potential to become invasive when introduced into areas where they did

[2] *Note that at the time of publication revised draft regulations had been circulated for public comment and will be promulgated in due course. This BRBA will require review and update in terms of these revised regulations.*

not occur historically. A range of human activities that could potentially cause the spread and introduction of these alien species into non-native areas, are referred to as restricted activities.

6.1. CATEGORIZATION OF ALIEN AND INVASIVE SPECIES

In order to categorise alien and invasive species it is necessary to define each of these. The respective definitions for alien and invasive species from NEMBA are as follows:

An "*alien species*" is:

a. A species that is not an indigenous species; or
b. An indigenous species translocated or intended to be translocated to a place outside its natural distribution range in nature, but not an indigenous species that has extended its natural distribution range by natural means of migration or dispersal without human intervention.

To inform this definition, an "*indigenous species*" means a species that occurs, or has historically occurred, naturally in a free state in nature within the borders of the Republic, but excludes a species that has been introduced in the Republic as a result of human activity

An "*invasive species*" is defined as any species whose establishment and spread outside of its natural distribution range:

a. threaten ecosystems, habitats or other species or have demonstrable potential
b. may result in economic or environmental harm or harm to human health.

Collectively the NEMBA, the AIS Regulations and the AIS Lists, categorise alien and invasive species, and prescribe the approach that should be taken to each category:

- **Exempted Alien Species** mean an alien species that is not regulated in terms of this statutory framework - as defined in Notice 2 of the AIS List.

- **Prohibited Alien Species** mean an alien species listed by notice by the Minister, in respect of which a permit may not be issued as contemplated in section 67(1) of the Act. These species are contained in Notice 4 of the AIS List, which is referred to as the List of Prohibited Alien Species (with freshwater fish in List 7 of Notice 4).
- **Category 1a Listed Invasive Species** mean a species listed as such by notice in terms of section 70(1)(a) of the Act, as a species which must be combatted or eradicated. These species are contained in Notice 3 of the AIS List, which is referred to as the National Lists of Invasive Species (with freshwater fish in List 7 of Notice 3).
- **Category 1b Listed Invasive Species** mean species listed as such by notice in terms of section 70(1)(a) of the Act, as species which must be controlled. These species are contained in Notice 3 of the AIS List, which is referred to as the National Lists of Invasive Species (with freshwater fish in List 7 of Notice 3).
- **Category 2 Listed Invasive Species** mean species listed by notice in terms of section 70(1)(a) of the Act, as species which require a permit to carry out a restricted activity within an area specified in the Notice or an area specified in the permit, as the case may be.
- **Category 3 Listed Invasive Species** mean species listed by notice in terms of section 70(1)(a) of the Act, as species which are subject to exemptions in terms of section 71(3) and prohibitions in terms of section 71A of Act, as specified in the notice.

6.2. STATUTORY CLASSIFICATION OF RAINBOW TROUT

Further to ongoing discussions between supporters for the unregulated use of Rainbow trout and the Department of Environmental Affairs, Rainbow trout has not been included in Notice 3, List 7 (National List of Invasive Fresh-water Fish Species) in the AIS List (Government Notice R 864 of July 2016)[3]. The only mention of Rainbow trout in these regulations is a specific exclusion of this species in Notice 4, List 7 (Prohibited Freshwater Fish).

[3] *Note that at the time of publication revised draft regulations had been circulated for public comment and will be promulgated in due course. These revised regulations will change the listing status of Rainbow Trout.*

With forthcoming amendments to the lists of species indicated above, it has been proposed that Rainbow trout be categorized as follows, but this has yet to be promulgated:

c. Category 2 (*compulsory permitting*) for freshwater aquaculture facilities.
d. Category 2 (*compulsory permitting*) in National Parks, Provincial Reserves, Mountain Catchment Areas and Forestry Reserves specified in terms of the Protected Areas Act.
e. Category 2 (*compulsory permitting*) for release in rivers, wetlands, lakes and estuaries.
f. Not listed (*exempt*) for discrete catchment systems in which it occurs (including for release in dams), excluding (a), (b) and (c).
g. Not listed (*exempt*) for salt-water aquaculture facilities.

Further proposed prohibitions and exemptions that may apply to Rainbow trout, include:

- It is proposed that Rainbow trout may be exempt for a period of two years from the date upon which national biodiversity regulations are promulgated, provided a person is in possession of a valid provincial permit issued in terms of provincial legislation, where required for Rainbow trout.
- It is proposed that catch and release of Rainbow trout may be exempted in discrete catchment systems in which it occurs.
- It is proposed that the transfer or release of a specimen of Rainbow trout from one discrete catchment system in which it occurs, to another discrete catchment system in which it does not occur; or, from within a part of a discrete catchment system where it does occur to another part where it does not occur as a result of a natural or artificial barrier, may be prohibited.
- It is proposed that release into a discrete catchment system from a salt-water aquaculture facility may be prohibited.

It is proposed that activities currently authorised through an existing permit will be exempted from the requirement of a permit in terms of NEMBA and the AIS Regulations for a period of two years. Moreover, an application for a permit by an existing facility may not necessarily require a full risk assessment. The intention of the proposed regulations will be to prevent Rainbow trout from being introduced into discrete catchment system in which they do not occur, while allowing for recreational use in waters where they already occur.

These proposed regulations point to Rainbow trout as being classified in Category 2 as this relates to the general import, propagation and grow out thereof for aquaculture. Therefore, a risk assessment will be required in such circumstances.

It must be noted that most Provinces have specific Provincial Ordinances that govern the movement and keeping of fish species such as Rainbow trout. The National Government has confirmed that all provinces should regulate the import, propagation and grow out of Rainbow trout in terms of the forthcoming National Regulations, but the repeal of Provincial Ordinances (and compliance therewith) remains a matter under the jurisdiction of each Province.

6.3. LIST OF RESTRICTED ACTIVITIES

While Section 1 in Chapter 1 of the NEMBA defines the restricted activities in relation to alien and invasive species, these activities are expanded upon in Section 6, Chapter 3 of the AIS Regulations. As quoted from the Regulations, these activities include:

<u>From the NEMBA:</u>

- Importing.
- Possessing (including physical control over any specimen).
- Growing, breeding or in any other way propagating or causing a specimen to multiply.
- Conveying, moving or otherwise translocating.
- Selling or otherwise trading in, buying, receiving, giving, donating or accepting as a gift, or in any way acquiring or disposing of any specimen.

From the AIS Regulations:

- Spreading or allowing the spread of any specimen.
- Releasing.
- Transferring or release of a specimen from one discrete catchment in which it occurs, to another discrete catchment in which it does not occur; or, from within a part of a discrete catchment where it does occur to another part where it does not occur as a result of a natural or artificial barrier.
- Discharging of or disposing into any waterway or the ocean, water from an aquarium, tank or other receptacle that has been used to keep a specimen or a listed invasive freshwater species.
- Catch and release of a specimen of an invasive freshwater fish or an invasive freshwater invertebrate species.
- Introducing of a specimen to off-shore islands.
- Releasing of a specimen of an invasive freshwater fish species, or of an invasive freshwater invertebrate species into a discrete catchment system in which it already occurs.

All the restricted activities above could potentially apply to the import, propagation and grow out of Rainbow trout in South Africa. However, import will be excluded where fish are obtained locally (i.e. from local producers).

7. TARGET SPECIES: RAINBOW TROUT

7.1. TAXONOMY

Common Name:	Rainbow trout
Kingdom:	*Animalia*
Subkingdom:	*Bilateria*
Infrakingdom:	*Deuterostomia*
Phylum:	*Chordata*
Subphylum:	*Vertebrata*
Infraphylum:	*Gnathostomata*
Superclass:	*Actinopterygii*
Class:	*Teleostei*
Order:	*Salmoniformes*
Family:	*Salmonidae*
Subfamily:	*Salmoninae*
Genus:	*Oncorhynchus (Suckley, 1861 - Pacific Salmon)*
Species:	*Oncorhynchus mykiss (Walbaum, 1792)*
Taxonomic Code:	161989 (ITIS 2015)

Rainbow trout (*Oncorhynchus mykiss*) has at least eight sub-species:

O.m. aquilarum (Snyder, 1917) - Eagle Lake Rainbow trout
O.m. gairdnerii (Richardson, 1836) - Columbia River Redband trout
O.m. gilberti (Jordan, 1894) - Kern Golden trout, Kern River Rainbow trout
O.m. irideus (Gibbons, 1955) - Coastal Rainbow trout
O.m. mykiss (Walbaum, 1792) - Kamchatkan Rainbow trout
O.m. nelsoni (Evermann, 1908) - San Pedro Martir trout, Baja California Rainbow trout, Nelson's trout
O.m. stonei (Jordan, 1894) - Sacramento Golden trout
O.m. whitei (Evermann, 1906) - Little Kern Golden trout

Other Names:	Trucha Arcoiris, Steelhead, Truite Arc-en-ciel, Redband trout
Synonyms:	*Salmo gairdneri* *Oncorhynchus nerka mykiss* *Parasalmo mykiss* *Salmo mykiss* *Salmo gibbsi* *Oncorhynchus mykiss gibbsi*

7.2. ORIGINATING ENVIRONMENT

Rainbow trout is a cold-water fish that is native to the Pacific northwest of North America (Crawford & Muir 2008), from the Kuskokwim River in Alaska to the Rio Santa Domingo in Mexico. It also occurs in the Mackenzie River drainage (Arctic basin), Alberta and British Columbia in Canada, as well as the endorheic basins of southern Oregon in the USA. In the Western Pacific Rainbow trout have been found from the Kamchatka Peninsula southwards into the Sea of Okhotsk (Froese & Pauly 2017).

Rainbow trout is primarily a freshwater fish that require high quality (unpolluted and well-oxygenated) waters to survive. As a result, it is commonly found in fast flowing streams and open lakes or dams (Picker & Griffiths 2011). However, some populations are migratory, spending most of their life in seawater (often called Steelhead) and returning to freshwater only to spawn (Froese & Pauly 2017). It is unclear whether this migration to the sea is genetic or simply opportunistic, but it appears that any population of Rainbow trout can migrate and survive in the sea (FishBase, 2003). This anadromous behaviour is not currently found in South Africa, albeit that historical records indicate net catches of Rainbow trout from False Bay as a result of fish in the Eerste River

Rainbow trout is generally regarded as the most widely distributed freshwater fish species on the planet. However, some native populations of specific subspecies have declined.

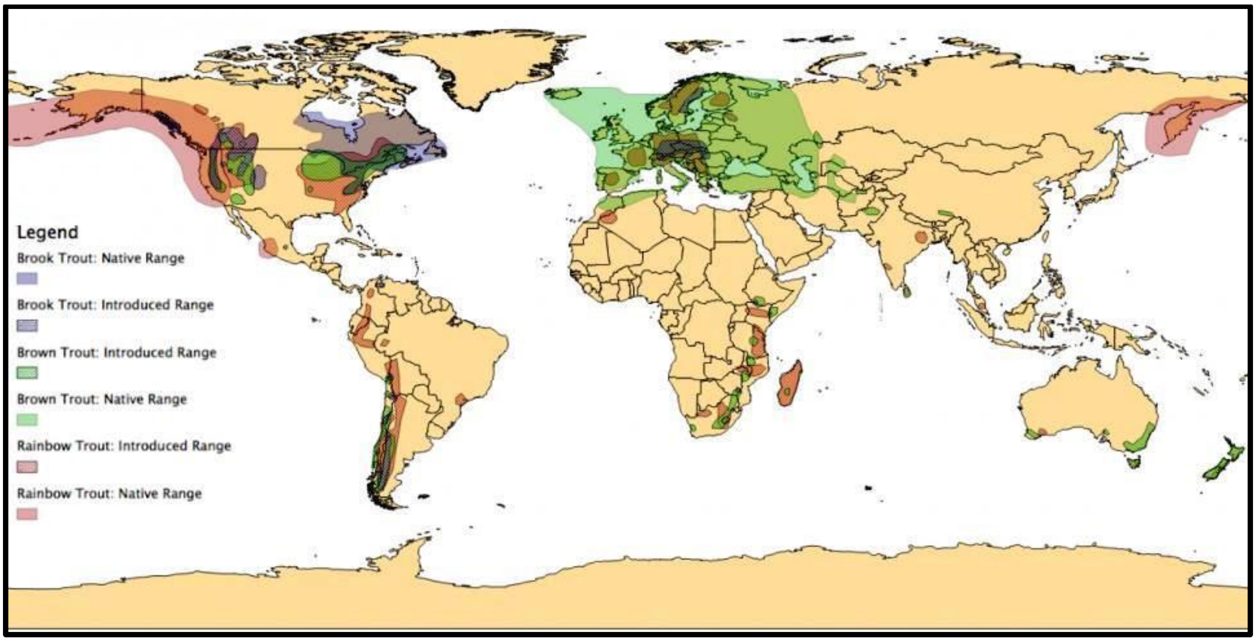

Figure 1: Global map showing the natural and introduced range for Rainbow trout (*Oncorhynchus mykiss*), Brown trout (*Salmo trutta*) and Brook trout (*Salvelinus fontinalis*) (Source: Map from the work of Del Vecchio, 2013).

7.3. KEY PHYSIOLOGICAL CHARACTERISTICS

Rainbow trout has a fusiform body shape that can become more laterally depressed as the body increases in size. The body is covered in small scales and the colour varies according to size, habitat and sexual condition. In freshwater environments these fish tend to be dark green, yellow-green or brown with dark spots on the sides of the body, dorsal fin and tail, and have a metallic pink or red band extending along the body. In marine environments Rainbow trout tend to be silvery, with the top half of the fish darker, and with dark spots above the lateral line. Other physiological characteristics include:

- The mouth is terminal and the lateral line uninterrupted.
- The gill arch has 16 - 17 gill rakers.
- The dorsal fin has 3 - 4 spines and 10 - 12 soft rays.
- The anal fin has 3 - 4 spines 8 - 12 soft rays.
- The caudal fin has 19 soft rays and is shallowly forked.
- Rainbow trout have a small adipose fin between the dorsal and caudal fin.

Rainbow trout can attain a maximum length of 122 cm and weight up to 25 kg (Robins & Ray 1986), with a reported age of up to 11 years (Hugg 1996). The anadromous strains appear to grow faster (FAO 2012). In South Africa, the largest Rainbow trout on record is 5.43 kg (Skelton, 2001), but feral fish rarely exceed 1.5 kg (Picker & Griffiths 2011).

Figure 2: Rainbow trout (Oncorhynchus mykiss).

7.4. REPRODUCTION

The age at which Rainbow trout reaches sexual maturity can vary but is usually attained at one to two years for males and two to three years for females (Skelton 2001). When progressing to sexual maturity the coloration of the fish intensifies; with the pink sides becoming crimson, the fins turning red and the ventral surface becoming grey. Males become especially deep in colour and the form of the head and lower jaw may change. Rainbow trout living in the marine environment will migrate into freshwater streams and rivers for spawning, while trout in lakes and dams will generally move into suitable river and stream habitats.

In the wild, Rainbow trout spawn once a year, usually between May and September in South Africa (Skelton 2001). The female prepares for spawning by excavating a shallow depression (known as a redd) in gravel laden substrates of rivers and streams. When she releases her eggs, the male will simultaneous release milt to effect external fertilisation, before the eggs come to rest in the gravel bed (McDowall 1990; FishBase 2003). Female Rainbow trout can produce 2 000 eggs per kg of body weight. Each egg is red or orange in colour and measures 3 - 7 mm in diameter (FAO 2012), depending on the size and condition of the females (Gall & Crandall 1992). Once spawning is complete, the eggs are left unguarded until they hatch in approximately 4 - 7 weeks (Skelton 2001). When hatched the fry measure 12 - 20 mm and carry a large yolk sac that is absorbed within 2 weeks, before the fry are free swimming.

7.5. DIETARY ASPECTS

Young trout feed predominantly on zooplankton (Cadwallader & Backhouse 1983). Adult Rainbow trout are opportunistic feeders predating on a wide range of invertebrates (terrestrial and aquatic), other fish (Woodford & Impson 2004), fish eggs, amphibians (Gillespie 2001), molluscs and crabs.

7.6. ENVIRONMENTAL TOLERANCES

Rainbow trout can inhabit both lentic and lotic environments, although specific spawning conditions (well oxygenated flowing water and gravel beds) are required to maintain self-sustaining populations. Due to their specific temperature requirements, they only occur in environments with cool and well-oxygenated waters. Their optimal water temperature ranges from 12°C (FishBase 2003) to 14°C (Brungs & Jones 1977), and reproduction generally requires temperatures lower than 14°C (FAO 2012), while optimal spawning temperatures ranges from 10 - 13°C (Piper *et al.* 1982). At temperatures of around 20°C Rainbow trout will seek cooler thermal refugia (Ebersole et al. 2001) and the upper lethal limit is reported to be 26.5°C (Brungs & Jones 1977), albeit that prolonged exposure to waters of 24°C and higher will lead to immunological strain and mortality.

Due to their anadromous nature, Rainbow trout can survive in a range of salinities (Molony 2001). Dissolved oxygen concentrations below 2.5 mg/l is however a major limiting factor (Rowe & Chisnall 1995).

Environmental factors can affect development, causing physical differences between individuals in different environments. Worsening of environmental conditions and increased levels of stress can result in opportunistic pathogens causing disease (Alborali 2006).

7.7. NATURAL ENEMIES, PREDATORS AND COMPETITORS

As is the case with many fish species, the life history strategy of Rainbow trout is based on high fecundity to compensate for significant losses to predation. Although these fish actively avoid predation, they are preyed upon by other fish, birds, reptiles (e.g. monitor lizards), aquatic mammals (e.g. otters) and crustaceans (e.g. crabs).

7.8. POTENTIAL TO HYBRIDISE

Although in other parts of the world hybridisation with congeneric species is a major issue (Allendorf *et al.* 2001 and Fuller 2000), Rainbow trout are not able to hybridise with any local indigenous species in South Africa. The genus *Oncorhynchus* is not found naturally in Southern African waters (Smith and Heemstra, 2003), and thus there are no indigenous *Oncorhynchus* species in the environment that could provide the basis for reproductively compatible populations.

7.9. PERSISTENCE AND INVASIVENESS

Rainbow trout is one of the top ten introduced species of the world (Picker & Griffiths 2011). Rainbow trout have been introduced into more than 90 countries around the world, with farms on every continent except Antarctica. Rainbow trout is considered invasive and one of the most widely distributed fish on the planet, having been introduced to cold and temperature waters around the world for aquaculture and recreational fishing. Wild-caught and hatchery reared Rainbow trout have been transplanted widely, and this species is recognised amongst the world's 100 worst invasive alien species by the International Union for the Conservation of Nature (IUCN, 2000). It should be noted that this global distribution is largely as a result of human intervention and is less attributable to the natural invasive potential of the species.

Where water temperatures remain moderate (i.e. below 25°C) and water quality is good, Rainbow trout is a persistent survivor in a range of aquatic environments (see also Lockwood et al 2007). Trout are however not long-lived, and the establishment of self-sustaining populations depends on seasonal decreases in water temperature to 15°C to allow for spawning, as well as the presence of suitable gravel beds onto which the eggs can be deposited.

In South Africa, Rainbow trout is widely farmed and stocked as a recreational species on the eastern escarpment from Mpumalanga, through the Drakensburg foothills in Kwa-Zulu Natal, the Eastern Cape and in the Western Cape. In areas that offer suitable habitat (primarily linked to water temperature), these fish have become naturalised and persist as self-sustaining populations. Rainbow trout are competitively successful due to their rapid growth, large size, predatory nature and high fecundity.

One local example of the impact of Rainbow trout can be found in the upper reaches of the Buffalo River (Eastern Cape), where the presence of these fish has caused a significant reduction in the numbers of two endangered species, *Sandelia bainsii* and *Barbus trevelyani* (Cambray 2003).

Globalisation has contributed to the spread of many angling and aquaculture species, with introduced species being marketed worldwide, and modern transport options allowing for the relocation of species across physical barriers (Cambray, 2003). The dispersal mechanisms for Rainbow trout are predominately through human actions in that fish are moved for aquaculture, angling and for other reasons attributed to human need and desire. Several countries have reported adverse ecological impacts after the introduction of Rainbow trout; especially insofar as the impact on indigenous fish species through predation, competition, hybridisation and the introduction of disease is concerned. However, in South Africa these impacts are limited mainly to predation on fish that share the habitat preferences of Rainbow trout.

7.10. HISTORY OF TRANSLOCATION AND CULTIVATION

Rainbow trout farming for recreational use and as a table fish was first practised in California around 1879, before spreading around the world in the late 1800's and through the 1900's. Today, the farming of Rainbow trout is more commonly practised in its introduced range than in its native range (Vandeputte *et al.* 2008).

In the 1950's, the development of formulated diets and pelleted feeds led to the rapid expansion of Rainbow trout farming, so that today this sector employs a range of farming techniques and production systems, including:

- Tanks and ponds of various materials;
- Raceways – usually concrete;
- Cage culture systems in existing waterbodies; and
- High density recirculatory systems.

The main limiting factors to the establishment of a viable Rainbow trout farm is water temperature (coupled to climate and temperature control systems), and an adequate volume of water to ensure that the high demands for dissolved oxygen are met.

Globalisation has contributed to the spread of many recreational angling species, with introduced species being marketed worldwide, and modern transport allowing the relocation of these species across physical barriers (Welcomme 1988, Cambray 2003a). Rainbow trout have been introduced to almost all continents except Antarctica, for the purposes of angling and aquaculture (FAO 2012). These introductions have taken place in at least 87 countries (GISD 2018). Several countries have report evidence of self-sustaining populations of Rainbow trout (Candiotto *et al.* 2011). Although invasive, the survival and invasive potential is a complex interplay between the characteristics of the species and the environment. In many South African environments into which Rainbow trout have been introduced they are not invasive given the marginal conditions that do not support survival and a self-sustaining population.

With increasing global application, the production of Rainbow trout in aquaculture has increased steadily since the 1950's and now totals 761 766 tonnes annually (FAO, 2015). The trade in Rainbow trout is now valued at U$ 2.940 billion per annum (FAO, 2015). In South Africa the production is recorded as being approximately 1 500 tonnes per annum, with an estimated value of U$ 4.7 million.

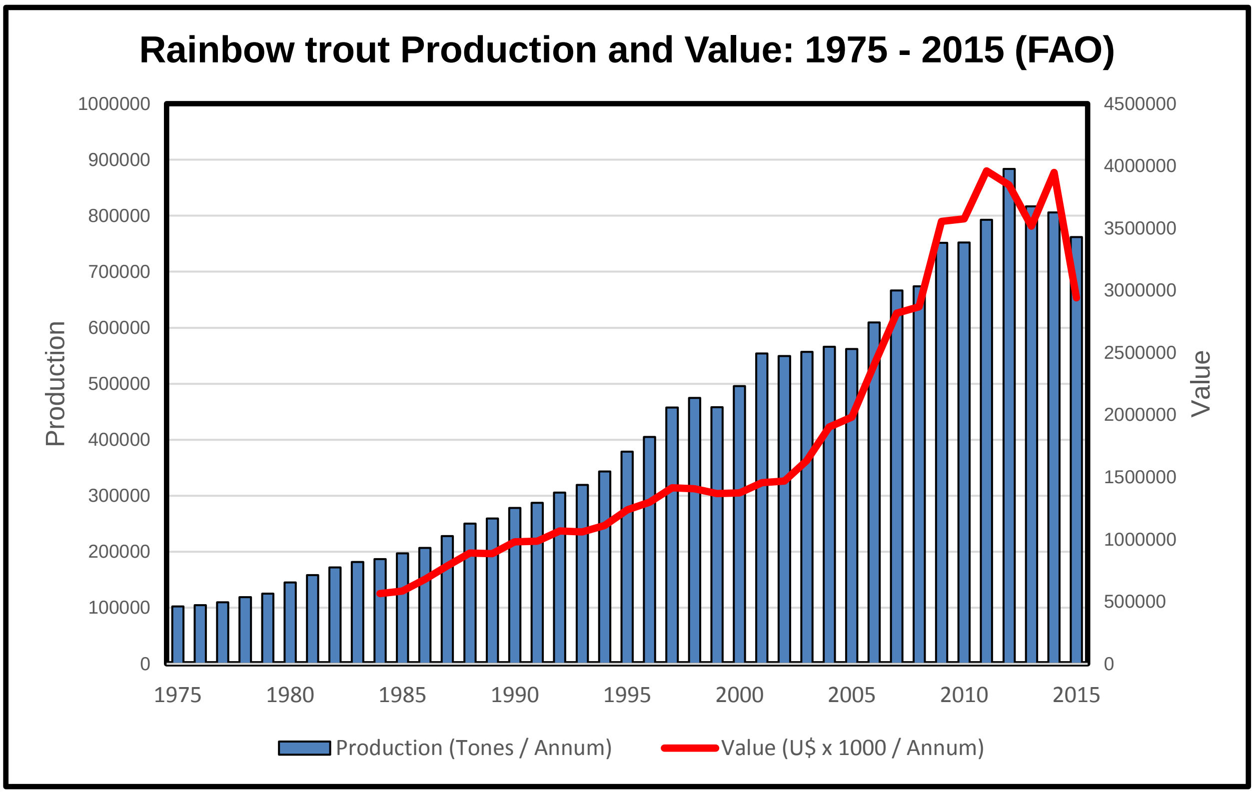

Figure 3: International production of Rainbow trout in tonnage and value between 1975 and 2016 (Source: FAO - Fisheries and Aquaculture Information and Statistics Service).

Rainbow trout was first introduced into South Africa as fertilised ova in 1897 (De Moor *et al*., 1988), after which they were domesticated and spawned in captivity. Following the establishment of several hatcheries in the Western Cape, Eastern Cape, KwaZulu Natal and later Mpumalanga, Rainbow trout were routinely spawned and stocked into rivers and dams throughout South Africa. This practice was facilitated by anglers as well as organs of state, allowing the spread of these fish to otherwise inaccessible areas (Clark & Ratcliffe, 2007). Noteworthy is that stocking of many apparently suitable waters failed to ensure the establishment of self-sustaining populations due to a range of factors that range from water quality to predation and more.

Conservation departments played a key role in the widespread introduction of these fish, through the establishment of hatcheries and stocking programmes, which then created a demand with farmers and the angling community (Cambray & Pister 2002). For example, the Pirie hatchery overseen by the then Eastern Cape Nature Conservation Department, introduced Rainbow trout into the upper reaches of the Buffalo River, threatening two endangered species, *Sandelia bainsii* and *Barbus trevelyani* (Cambray 2003).

Despite failure to establish in many stocked areas, there are currently numerous self-sustaining populations of Rainbow trout in the cooler high-altitude rivers throughout South Africa, while seasonal populations are sustained for recreational purposes by re-stocking from hatcheries (Jubb 1967, Skelton 2001, Kleynhans et al 2007, Picker & Griffiths 2011). In addition to this, fish occasionally escape from fish farms.

Rainbow trout have been recorded in the uKhahlamba Drakensberg Park World Heritage Site, albeit that no stocking has taken place in this area since 2004. (EKZN Wildlife Services, 2011).

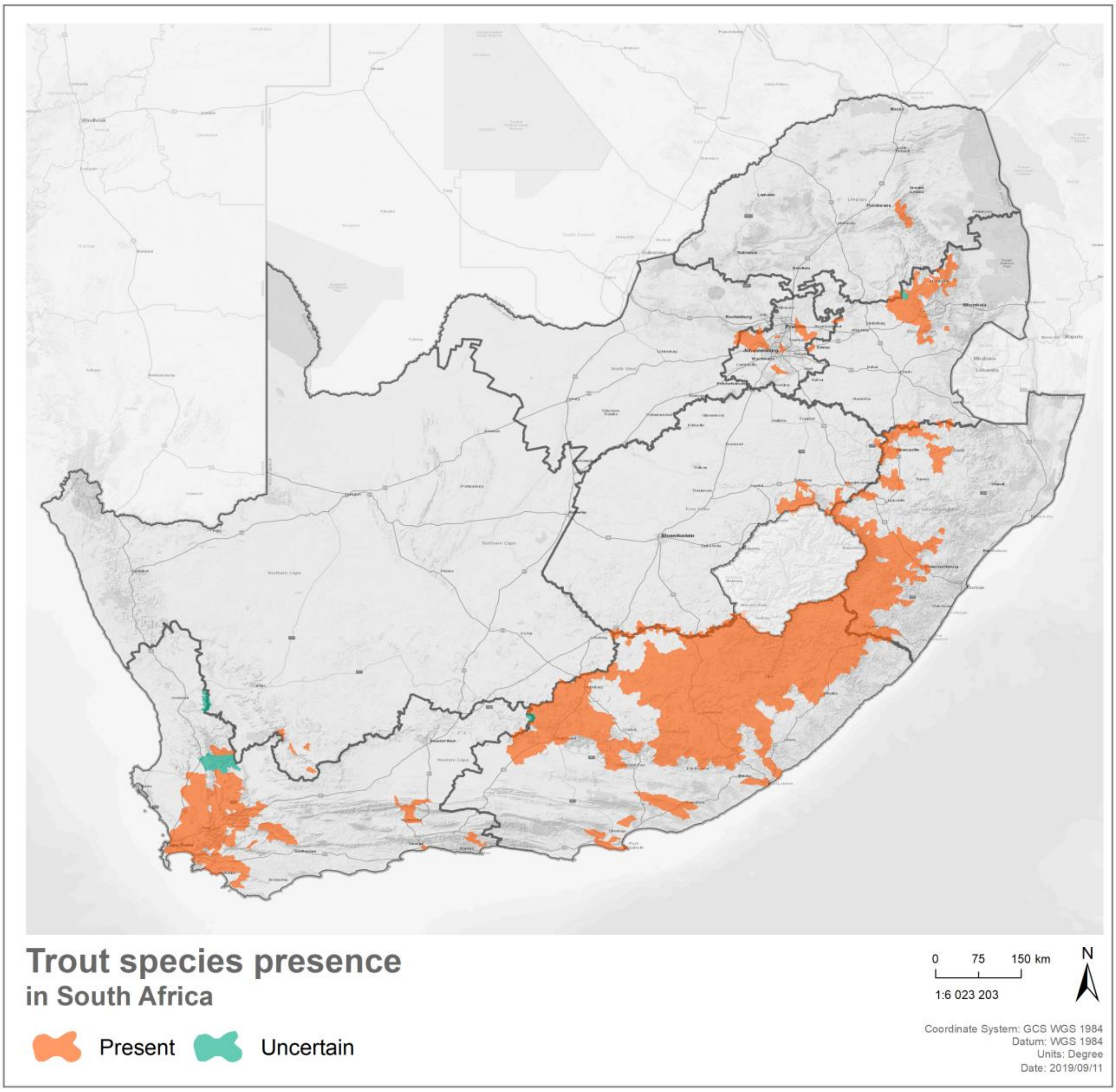

Figure 4: Collective distribution of Rainbow trout (*Oncorhynchus mykiss*) and Brown trout (*Salmo trutta*) in South Africa from a stakeholder assessment by the South African National Biodiversity Institute (Source: SANBI, 2017).

7.11. ABILITY TO CREATE ECOSYSTEM CHANGE

Rainbow trout have the ability to create ecosystem change through predation on other aquatic organisms. Predation on a range of aquatic and terrestrial invertebrates, amphibians, fish and fish eggs could cause a loss in biodiversity.

In the South African context, the ability to create ecosystem change is directly dependant on the presence of organisms that can be predated upon by Rainbow trout, as no ecosystem change is possible through hybridisation or other direct physical (abiotic) changes to the environment. In certain high streams that provide suitable habitat for year-round survival and spawning, Rainbow trout have caused local extinction of certain indigenous fish species. Although this can cause several ecological shifts, complete ecosystem dysfunction is not possible and has not been recorded.

7.12. PROBABILITY OF NATURALISATION

In South Africa, Rainbow trout has established self-sustaining populations in many areas where sufficiently cool water is present year-round. Although some of these populations depend on periodic or seasonal restocking, certain groups have become naturalised. Given the long history of this species in the country and the considerable effort that has been invested in facilitating its spread around the country, there are few areas where self-sustaining populations could become established, where they do not already exist. This is consistent with the current distribution range shown in Section 7.10.

Through the action of humans (fish farmers and anglers), these fish have an effective means of dispersal, consistent with international findings related to the facilitated spread of alien species (Courtenay et al 1992).

It can be concluded that Rainbow trout has a high probability of naturalisation only in areas where year-round temperature suits the species, where water quality meets their needs and where rivers and streams provide suitable gravel beds and flow to allow for spawning. In areas where one of these elements is absent, survival is seasonal or short-lived at best.

7.13. POSSIBLE IMPACTS ON BIODIVERSITY

As there was no biological baseline survey done in South Africa in the 19th century prior to the introduction of Rainbow trout in South Africa, it is challenging to accurately predict their impact (Bartley & Casal 1998). It is known that Rainbow trout can impact biodiversity, but that this depends on the habitat type and presence of prey species. More research is however required as knowledge gaps constrain effective management of Rainbow trout (Ellender et al, 2014a).

The potential impacts Of Rainbow trout, which can range from negligible to extensive, may include:

- Rainbow trout can impact severely on populations of prey species, including fish, amphibians, freshwater crustaceans like crabs and aquatic invertebrates. In many countries introduced Rainbow trout have been reported to have negative effects on native fish, amphibians and invertebrates (McDowall 1990, Fuller, 2000 and indicated in the IUCN Red List of Threatened Species).
- Rainbow trout can be highly fecund but are highly selective in terms of spawning habitat and conditions. Under ideal conditions this can add to the potential for these fish to establishing naturalised populations that can lead to the local extinction of certain prey species.
- Rainbow trout can prey on eggs and larvae of other fish species, leading to a potential decline in native biodiversity and species diversity.
- The introduction of Rainbow trout could cause secondary impacts to biodiversity by changing the abundance of species on which other piscivores and aquatic insectivores depend (Rivers-Moore et al, 2013).
- The potential impacts of Rainbow trout on invertebrate species are not well documented and not conclusive. These impacts are observed but are difficult to quantify accurately in a dynamic environment in which many factors affect invertebrate assemblages (Shelton et al, 2016a).

Rainbow trout are reported as being a threat to a range of South African fish species in the Red Data Book. The species affected belong mainly to the genus *Barbus* and *Pseudobarbus* (minnows), however the Eastern Cape rocky (*Sandelia bainsii*) and the Southern kneria (*Kneria auriculata*) are also affected (Skelton 1987). For example, the Treur River barb (*Barbus treurensis*) is classed as critically endangered in the IUCN Red List (as assessed by Roux and Hoffman in 2016 for the IUCN). The upper Blyde River and the Treur River are the only sites that this species is found naturally (Kleynhans 1987). However, due to predation by Rainbow trout, the population has been decimated, while a remaining stronghold for the species is protected from invasion by a waterfall barrier. Some re-introductions have been undertaken to supplement the occurrence of these fish (Engelbrecht & Bills 2007). Stocking of Rainbow trout in the upper Crocodile River, extirpated the indigenous Southern kneria (*Kneria auriculata*). However, when the alien species disappeared, these fish succeeded in re-colonising the river (Kleynhans 1988). In the Western Cape it was found that densities of Breede River redfin (*Pseudobarbus burchelli*), Cape kurper (*Sandelia capensis*) and Cape galaxias (*Galaxias zebratus*), were 89 - 97 % lower in invaded streams than in streams without trout, with several instances of apparent local extinction (Shelton et al, 2014b).

The presence of Rainbow trout has been implicated in the decline of the Natal ghost frog (*Hadromophryne natalensis*), in the uKhahlamba Drakensberg Park World Heritage Site (Karssing et al, 2010 and Karssing et al, 2012) and the Cederberg ghost frog (*Heleophryne depressa*) in the Cape Fold Ecoregion (Avidon et al, 2018), while species such as the Maluti minnow (*Pseudobarbus quathlambae*) have been impacted in the Kwazulu-Natal Drakensburg and Lesotho. In the Western Cape the extirpation of the Berg River redfin from the Eerste River has been attributed to the presence of Rainbow trout (Skelton, 2001).

Impacts on invertebrate populations have been recorded in the uKhahlamba Drakensberg Park World Heritage Site, were the comparative nature of invertebrate populations in the presence and the absence of trout was assessed, but these findings could not be attributed directly to trout, and further quantification of the results is required (Rivers-Moore et al, 2013). In other instances, aquatic invertebrate populations have been found to persist well after the introduction of trout, due to its predatory displacement of an indigenous species such a the Breede River redfin (*Pseudobarbus burchelli*), that feeds more exclusively on aquatic invertebrates as opposed to trout that may target terrestrial invertebrates (Shelton et al, 2017). Contrary to other studies, it was found that herbivorous aquatic invertebrate densities increased in the Breede River where trout was present (Shelton et al, 2014a).

In a risk assessment, consideration must be given to the potential general impacts on biodiversity, through related ecological consequences and extended tropic disturbances that may occur.

7.14. POSSIBLE IMPACTS ON OTHER NATURAL RESOURCES

The potential impacts of Rainbow trout have been illustrated in the preceding sections and have been shown to be directly linked to their predatory behaviour towards other species, which impacts the prey population and may cause competition with other predatory fish and aquatic animals that rely on the same food resources. The potential impact on other natural resources is largely limited given that Rainbow trout do not feed on other aquatic resources such as macrophytes and do not cause physical and structural damage to the environment through their habits.

7.15. RAINBOW TROUT AS A VECTOR OF OTHER ALIEN SPECIES

The uncontrolled movement of Rainbow trout from one area to another may result in the introduction of other species, if care is not taken with regards to ensuring that other species, or small fish that have few distinguishing characteristics, are excluded. This is unlikely to happen under controlled hatchery conditions where young fish of a specific species are spawned and reared.

8. THE RECEIVING ENVIRONMENT

As a national framework document, this risk assessment cannot report on the receiving environment for specific areas, and on specific Rainbow trout projects or restricted activities. Much of South Africa is seasonally within the water temperature range in which

Rainbow trout may survive, meaning that this species has the potential to survive in many South African waterways during winter, but will perish across much of this seasonal range in summer. Persistence through the summer months is restricted to cooler areas that remain below 24°C.

8.1. CLIMATE AND HABITAT MATCH

In South Africa, several habitat types are potentially suited to the naturalisation of Rainbow trout. As water temperature is a primary determinant for the survival and reproduction of Rainbow trout (Ellender et al, 2016), correlations with ambient temperatures across the 31 terrestrial ecoregions of South Africa (Kleynhans et al. 2005) was used to determine potential areas that could be suitable to naturalisation (by comparison with known tolerance ranges of the species). It was found that Rainbow trout could theoretically survive in 11 ecoregions across South Africa, but that establishment in many of these would only be possible across a very limited range and seasonally (i.e. in winter). With reference to the map that follows, these ecoregions are:

- Eastern Bankenveld (region 9)
- Northern Escarpment Mountains (region 10)
- Eastern Escarpment Mountains (region 15)
- South Eastern Uplands (region 16)
- Drought Corridor (region 18)
- Southern Folded Mountains (region 19)
- South Eastern Coastal belt (region 20)
- Great Karoo (region 21)
- Southern Coastal belt (region 22)
- Western Folded Mountains (region 23)
- South Western Coastal Belt (region 24)

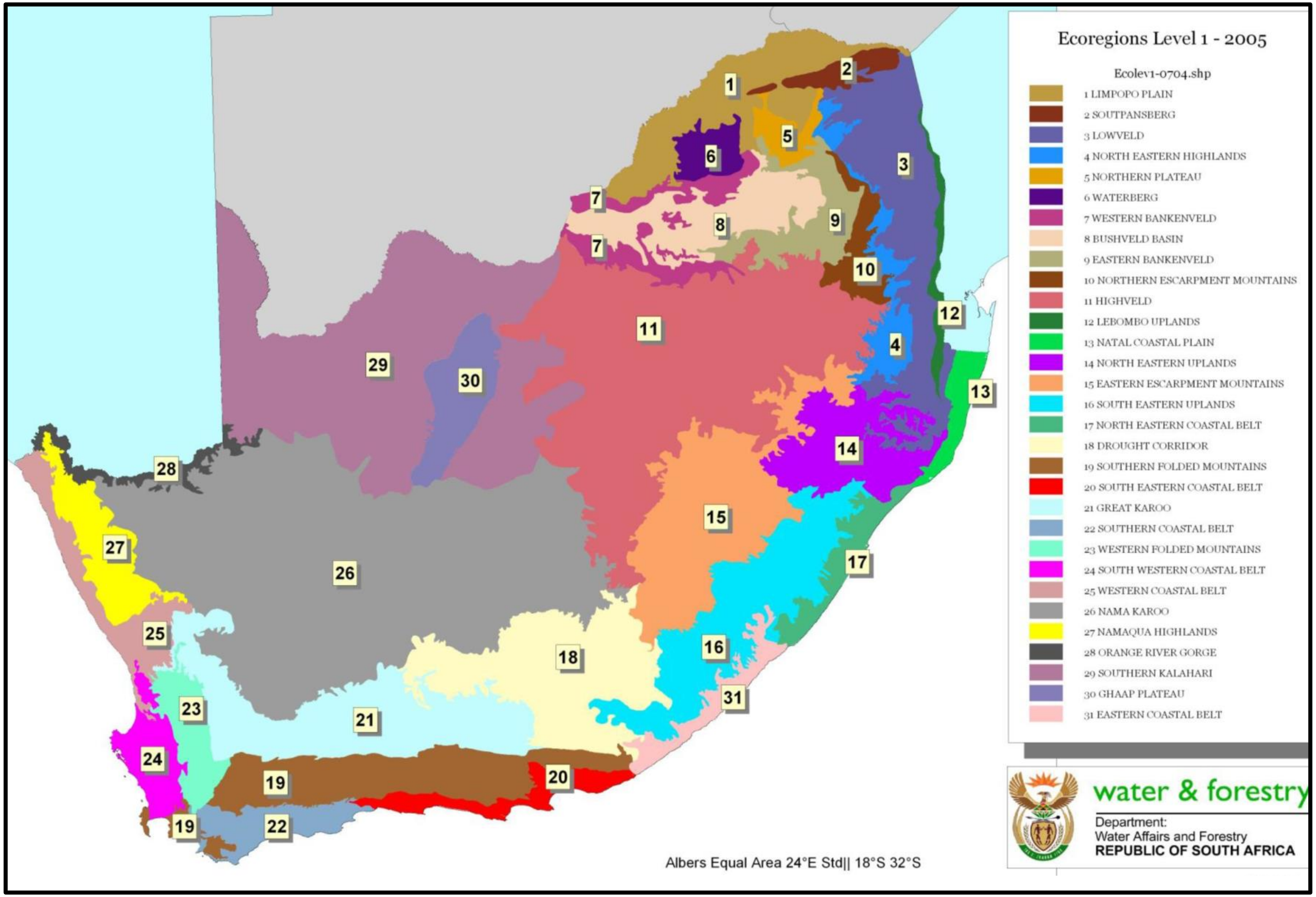

Figure 5: *Ecoregions of South Africa.*

The results above reflect a coarse analysis of areas within which these fish may survive, to which more accuracy can be added through the reported distribution in the map in Section 7.10. The probability of establishment however ranges from high in the elevated regions of the interior escapement [such as the Northern Escarpment Mountains (region 10), the Eastern Escarpment Mountains (region 15) and the South Eastern Uplands (region 16)] to low in the climatically marginal areas [such as the South Eastern Coastal belt (region 20) and the South Western Coastal Belt (region 24)]. Across these large stretches of the landscape that make out each ecoregion, the potential for establishment is not evenly distributed; to the extent that large areas within marginal zones will not be suitable for the survival of self-sustaining populations of Rainbow trout (see also Fitzpatrick et al 2009).

In this BRBA is it important to recognise that future Rainbow trout farms may increasingly be based on systems in which water temperature can be regulated. This means that Rainbow trout farming may be practised in areas outside of the environmental range in which these fish would be able to survive in open waterbodies, provided this type of farming proves economically viable. Conversely, it is likely that climate change will reduce the distribution and range of Rainbow trout in South Africa, while also impacting on indigenous species (Shelton et al, 2017).

8.2. TOOLS TO IDENTIFY SENSITIVE AREAS

Many national and provincial conservation plans, biodiversity frameworks and mapped sensitive areas can be used to determine sensitive area in which Rainbow trout may pose a biodiversity impact. These include, but are not limited to:

- The National Freshwater Ecosystem Priority Areas (NFEPA) and its implementation manual (Driver et al 2011), which geographically identifies sensitive freshwater environments, including environments in which certain fish species are identified as sensitive.
- A range of geographic mapping tools published by the South African National Biodiversity Institute (SANBI), through which proclaimed conservation areas,

critical biodiversity areas and other sensitive habitats can be identified (see also Swartz 2012).

- Apart from general information that can be accessed from the National Department of Environment, Forestry and Fisheries (DEFF), local and provincial conservation authorities, and mandated provincial biodiversity authorities can provide local information of relevance (see also Kleynhans 1999, 2005 and 2007).

9. THEORY BEHIND ECOLOGICAL RISK ASSESSMENT

Ecological Risk Assessment provides an effective tool for assessing environmental effects or actions, and aids in resource based and environmental decision making. The risk assessment approach is widely recognized and much of this document is based on internationally researched risk assessment principles (Anderson *et al.,* 2004, Covello *et al.,* 1993; EPA, 1998 and Landis, 2004.). To this end, the process is well suited to the establishment of the BRBA framework for the import, propagation and grow out of Rainbow trout, in that it provides a platform from which decisions can be made and from which risks can be identified for management and monitoring.

The European Union (2000) defines risk as the probability and severity of an adverse effect or event occurring to man or the environment from a risk source. The assessment methods for such risks are widely used in many environments and for many diverse purposes. Through determining the interplay between uncertainty and variability, a risk assessment evaluates the likelihood that adverse ecological effects may occur as a result of one or more stressors. This likelihood of occurrence can be further defined in terms of temporal structure (longevity or permanence), severity, scope (scale), uncertainty and the respective potential for mitigation and monitoring.

McVicar (2004) describes risk analysis as "*a structured approach used to identify and evaluate the likelihood and degree of risk associated with a known hazard*". This is done with due cognizance of information or outcome uncertainties, so that it is generally accepted that higher levels of uncertainty correspond to higher levels of risk. It is, however, important to realize that uncertainty and probability are different elements in risk assessment, and that these in themselves stand distinguished from factors such as extent (scope and scale), significance (severity) and permanence.

The risk analysis process is built around the concept that some aspects of the activity under consideration can lead to the release of a hazard, which in turn could lead to a change in the environment. In the case of importing, growing out and propagating Rainbow trout, an example would be the escape and survival of an alien species (the hazard) into the environment, potentially leading to impacts on indigenous biodiversity (the result or endpoint).

9.1. THE PRECAUTIONARY AND OTHER PRINCIPLES

The precautionary principle has emerged as a fundamental driver in risk assessment and has become a popular approach to deal with uncertainty in decision making (EU Commission 2000). The United Nations 1992 Conference on Environment and Development referred to the precautionary principle as an approach in which "*the lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*".

The precautionary principle was re-stated and internationally agreed in Principle 15 of the Rio Declaration of the UN Conference on Environment and Development (UNCED):

> "*In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"*.

The precautionary principle is often wrongly used as a "*trump card*" to legitimize arguments against development and environmental change. The precautionary principle is, however, a principle that removes the need for concrete scientific proof of cause and effect, and rather shifts the emphasis to responsible precaution based on logical analysis of risk and implementation of cost-effective mitigation measures.

The wide application of risk assessment also incorporates other principles, the most important of which are:

- Optimal management of risk can only occur where there is an open, transparent and inclusive process that integrates effective risk communication with hazard identification, risk assessment and risk management.
- Risk assessment is most valuable if considered together with social and economic impacts (positive and negative).
- The nature of a risk depends largely on the acceptable endpoint (acceptable level of change), which can be highly subjective.
- For risk management to be effective, acceptable endpoints should be measurable.
- Zero tolerance to environmental change is not practical in risk management.
- Specific risks should not be seen in isolation to risks associated with other activities in a common environment (risk proportionality).
- Risk assessment depends on effective and understandable communication of risk.
- Risk assessment must be consistent in the manner in which risks are determined and scaled.
- A risk does not exist if a causal pathway between the hazard and the endpoint is absent. The level of risk is however influenced by the nature of such a pathway.
- Risk assessment should lead to monitoring to improve understanding of the mechanisms leading to environmental change and the level of risk (increased or decreased).
- Risks should be identified along with the environmental change they may cause.
- Uncertainty is not a failing of risk assessment, but a characteristic which should be used in risk management.
- Cost benefit analysis should be used in risk management to logically determine the practicality, need and nature of risk mitigation measures.

9.2. METHODOLOGY IN THE RISK ASSESSMENT

In aquaculture, several risk assessment methodologies are used, each of which depicts different levels of complexity and subjectivity (Burgman 2005, Nash et al 2005, Kapuscinski et al 2007; Vose 2008, MacLeod et al 2008, FAO 2015). However, the interplay between likelihood and consequence to determine acceptability and management needs, remains at the core of most methods.

Many risk assessment methods suffer from bias and these shortcomings must be managed (Burgman, 2001). Hayes *et al.* (2007) such as to help maintain the scientific credibility of risk assessment (FAO, 2015).

Risk assessment is primarily made up of three phases, consisting of problem formulation, problem analysis and risk characterization. The problem analysis phase can be further sub-divided into two distinct sections: characterization of exposure and characterization of effect.

Risk analysis provides an objective, repeatable, and documented assessment of risks posed by a particular course of actions or hazards. This BRBA framework depicts two methods to assess risk:

1. A step-by-step process expanded and modified from the aquaculture risk assessment work by Fletcher *et al*. (different authors in 2003, 2005 and 2015), in which an inventory of potential risks is characterized and scored for probability, severity, scope, permanence, confidence, monitoring and mitigation; and
2. The European Non-Native Species Risk Analysis Scheme (ENSARS) (Copp *et al*., 2008) developed by CEFAS (UK Centre for Environment, Fisheries & Aquaculture Science). ENSARS provides a structured framework (Crown Copyright 2007-2008) for evaluating the risks of escape and introduction to, and establishment in open waters, of any non-native aquatic organism. For each species, 49 questions are answered, providing a confidence level and justification (with source listed) for each answer. Guidance was taken from the F-ISK toolkit in the compilation of this framework as it was found to be a useful risk assessment tool to evaluate invasion risk posed by aquaculture species (Marr et al, 2017). The questions and results of the assessment on Rainbow trout are found in Appendix 1.

The following steps constitute the method that has been expanded and modified from the work by Fletcher *et al*. (different authors in 2003, 2005 and 2015):

- Identification of risks and determination of endpoints (consequences). This is also referred to as problem formulation in risk assessment and determines what is at risk.
- Determination of the endpoints and the acceptability in endpoint levels (the level of acceptable change if a risk or stressor were to occur).
- Modelling of the risk pathway from hazard to endpoint (also called logical modeling).
- Assessing the risk by means of any information resources and experience. This can be divided into two distinct sections: the exposure assessment (nature of the risk / stressor) and effects assessment (nature of the endpoint or effect on the environment).
- Determination whether the risk has the potential to increase the probability of the endpoint occurring. If there is no such potential, such a risk can be eliminated from analysis.
- Describing the probability, intensity (severity) and scale (scope) of the risk to the environment (also called risk characterization).
- Determining the level of uncertainty (confidence) in risk characterization.
- Tabulating the findings according to intensity (severity or degree) of change, the geographical extent of the change (scope), and the duration or permanence of the change.
- Approximating the probability and the uncertainty.
- Addressing areas of weakness where the collated information appears incomplete or inadequate.
- Assessing the acceptability of the proposed activity through reference to the tabled analysis.
- Assessing the opportunity for risk mitigation and monitoring, and the need for additional research to reduce uncertainty.
- Effectively communicating risk in an on-going manner to all relevant stakeholders.

9.3. THE RISK PATHWAY

Before any risk can be characterised, the link between the hazard and the endpoint must be established. For any specific ecological risk to come to fruition and create an impact, a risk pathway is required. For example, in the case of Rainbow trout, the ecological risk or hazard that these fish could pose to the environment through predation on other species (example of an endpoint or impact) is directly linked to the pathway of escape from the facilities in which it is used or kept, into the surrounding water resources. The ecological endpoint is therefore facilitated and dependent on the physical pathway of escape. For this reason, each identified risk must be evaluated from its potential occurrence (the hazard), through the pathway and the resultant effects (the endpoint) thereof, as well as the mitigation measures that can be implemented to reduce the risk from occurring or minimising any negative effects.

In aquaculture of Rainbow trout, only two pathways exist through which a risk can influence or impact on an endpoint. These are the pathway of escape of the fish and the pathway that facilitates the introduction or spread of a potential disease. It is therefore logical that the potential manifestation of species related ecological impacts or endpoints of the identified risks is eliminated if the potential for escape is eliminated (apart from disease).

Some confusion is caused by the fact that both the pathway (escape in the case of aquaculture with Rainbow trout) and the endpoint can be characterised and scored for probability, severity, scope, permanence, confidence, monitoring and mitigation. It is important that characterization of the pathway be determined and presented separately, with due regard that a zero risk in occurrence of a pathway will render the risk of an endpoint invalid. However, a low risk in the pathway does not necessarily correlate with a low risk in the endpoint.

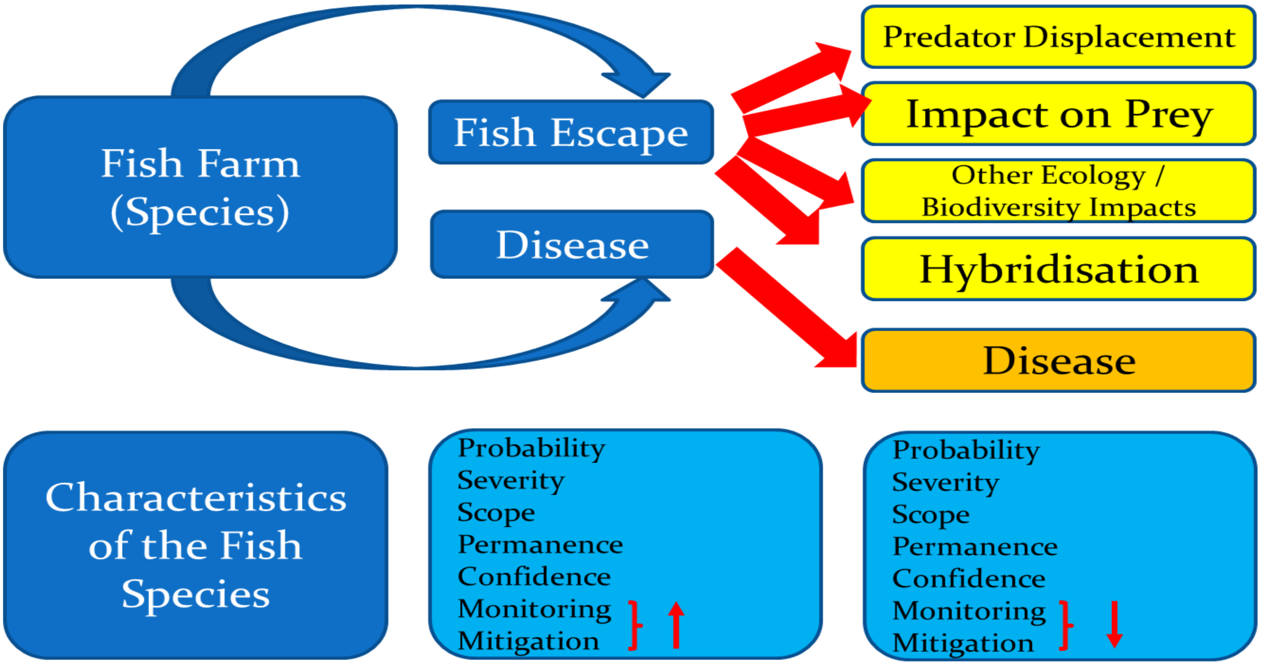

Figure 6: Schematic illustration of the risk assessment process and the dependency of endpoint risk on the pathway.

9.4. SCALES AND CATEGORISATION OF RISK

Several scaling methods are used to determine risk and the factors that contribute to risk. These scales are largely subjective but depend on professional judgement where technical experts determine a suitable scaling, bootstrapping where previous or historical examples are used, and formal analyses where theory-based procedures for modeling are used to set scales. For this risk assessment, the following scaling or categorization has been determined by using a combination of professional judgement and referencing to several international methodologies.

Table 1: Categories of risk probability: Probability of a risk or stressor occurring.

Scale	Explanation and Comments
High	The risk is very likely to occur.
Moderate	The risk is quite likely to be expressed.
Low	In most cases, the risk will not be expressed.
Extremely Low	The risk is likely to be expressed only rarely.
Negligible	The probability of the risk being expressed is so small that it can be ignored in practical terms.

Table 2: Categories of risk severity: Severity of the effects of the stressor on the endpoint.

Scale	Explanation and Comments
Catastrophic	Irreversible change to ecosystem performance or the extinction of a species or rare habitat.
High	High mortality or depletion of an affected species, or significant changes in the function of an ecosystem, to the extent that changes would not be amenable to mitigation.
Moderate	Changes in ecosystem performance or species performance at a subpopulation level, but they would not be expected to affect whole ecosystems and changes would be reversible and responsive to high levels of mitigation.
Low	Changes are expected to have a negligible effect at the regional or ecosystem level and changes would be amenable to some mitigation.
Negligible	Effects would leave all ecosystem functions in tacked without the need for mitigation.

Table 3: Categories of risk scope or scale: Scope or scale of the effects of the stressor on the endpoint (i.e. geographic extent).

Scale	Explanation and Comments
Extensive	Effects are far reaching over multiple ecosystems (or biomes) incorporating various habitat types.
Regional	The effects are manifested over a measurable distance, usually limited to one or two ecosystems.
Local	The effects are limited to a distance covering a portion of an ecosystem, such as a single water body or coastal bay.
Project Based	The effects are limited to the boundaries of the project or within a distance that can be influenced directly by remediation, without affecting other users of a common resource.
Negligible	Effects are so limited in scale that the scope is insignificant.

Table 4: Categories of permanence or longevity: Permanence or longevity of the effects of the stressor on the endpoint.

Scale	Explanation and Comments
Permanent	Change to the endpoint caused by the stressor will last for more than one century, regardless of the mitigation measures.
Long lasting	Change to the endpoint caused by the stressor will outlast the expected lifespan of the activity or project.
Moderate	Effects can be measured in years, but it is within the expected lifespan of the activity or project and where effects are measured on organisms, it is usually within the organism's expected lifespan.
Temporary	Effects are usually inside of one year in duration.
Short term	Effects can usually be measured in days.

Periodic	Effects occur more than once within the temporary or short-term classification of permanence.

Table 5: Categories of uncertainty (or certainty and confidence): Uncertainty in the analysis of risks, stressors and endpoints and the interrelationships between these.

Scale	Explanation and Comments
Doubtful	When confidence in the analysis is so low that the outcome can be near random.
Low	When confidence in the analysis is such that an alternative outcome will occur regularly, but that such an alternative in probability, severity, scope and permanence will regularly constitute a change by more than one position in the respective scales.
Moderate	When confidence in the analysis is such that an alternative outcome will occur regularly, but that such an alternative in probability, severity, scope and permanence will rarely constitute a change by more than one position in the respective scales.
High	When variability in an analysis is accurately predictable and an alternative outcome occurs only occasionally.
Very High	When confidence in the analysis is at a level at which an alternative outcome is virtually impossible and occurs rarely.

Table 6: Categories of monitoring: Monitoring of the effects of the stressor on the endpoint within reasonable time and cost.

Scale	Explanation and Comments
Zero	Where no monitoring is possible.
Low	Where limited indicators can be collected and reported about either severity, scope or the temporal nature of the effect or impact of a stressor, and where inferred changes in ecosystem functionally, habitat and species loss is mostly used.
Moderate	Where only certain indicators can be collected and reported about the severity, scope and temporal nature of the effect or impact of a stressor, and where inferred changes in ecosystem functionally, habitat and species loss is used.
High	Where sufficient information (key indicators) can be collected and reported about the severity, scope and temporal nature of the effect or impact of a stressor, to identify major changes in ecosystem functionally, habitat and species loss.
Very High	Where the full severity, scope and temporal nature of the effect or impact of a stressor may be monitored with confidence and reported within the resources of a project.

Table 7: Categories of mitigation: Mitigation of the effects of the stressor on the endpoint within reasonable time and cost.

Scale	Explanation and Comments
Irreversible	When no degree of mitigation can prevent the alteration of ecosystem functionally, habitat or species loss.

Low	When the effects of a stressor or risk can be mitigated, but where such mitigation requires additional resources and where the outcome of mitigation is doubtful, and where some ecosystem functionally, habitat or species loss may occur.
Moderate	When the effects of a stressor or risk can be mitigated, but where such mitigation requires additional resources and where the outcome of mitigation may lead to altered ecosystem functionally but not ecosystem, habitat or species loss.
High	When the effects of a stressor or risk can be mitigated within the resources of a project and when the outcome of mitigation can return the environment to a condition in which ecosystem changes and functions do not cause multi-tropic disturbances.
Very High	When the effects of a stressor or risk can be mitigated within the resources of a project and when the outcome of mitigation can return the environment to a condition near to that prior to the establishment of the activity, within a reasonable timeframe.

Using the scales above the following example of an assessment matrix for a risk and endpoint can be illustrated. This matrix has been used as the format for this risk assessment of the import, propagation and grow out of Rainbow trout in South Africa.

Table 8: Example of a matrix indicating all categories and scales of risk.

Risk / Stressor	As example: the escape of Rainbow trout				
Endpoint	As example: predation on indigenous fish species				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary (Periodic)*	Short term (Periodic)*
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

* *The addition (or submission) of "periodic" under permanence can be used to add additional information with regards to the temporal nature of the effects on the endpoints.*

One important aspect, which is not directly addressed in this multi-criteria scaling is the nature of the receiving environment. The severity of the effect is scaled, but this is only indirectly related to the nature of the receiving environment. As an example, if an activity was proposed or developed in a degraded environment, it will be necessary to adjust the severity of the impact, as opposed to the severity when the same activity was to be undertaken in a pristine environment.

It is important to continuously be mindful of the fact that the analysis, and particularly the management of risk, depends on financial, human, intellectual and other resources. The scaling of risk, and particularly the potential for monitoring and mitigation, should therefore take cognisance of the availability and practical application of financial and human resources.

The identified risks and the scaling of probability, severity, scope, permanence, confidence, mitigation and monitoring must be considered collectively, to arrive at a risk profile. As an example, if an effect on the environment has a "*high*" probability, but with "*low*" severity and "*temporary*" permanence, then the resultant risk can be seen to be acceptable.

9.5. PERCEPTION OF RISK

The nature and perception of risk differs significantly from environment to environment for the same stressors. This difference is caused by factors such as the nature of the endpoint and the surrounding environment, but also significantly by the different manner in which people perceive risk. Risk perception involves people's beliefs, education, attitudes, judgements and feelings, as well as the wider social or cultural values that people adopt towards different risks and their consequences. Factors such as income level, ethnic background, political outlook, public values, historical land use, zoning, lifestyle and psychological condition, inevitably drive the acceptance and perception of varying levels of risk, and the manner in which risk is managed.

In this case, it is important that the perception of risk remains in context to the use of Rainbow trout, the environment in which the use will occur, the use or development scale, the potential for mitigation and other factors.

9.6. RISK COMMUNICATION

A comprehensive an accurate assessment of risk is worthless if risk is not correctly communicated to planners, managers, industry experts, environmental agencies and stakeholders. In this framework assessment, the communication of risk is not being fully investigated, nonetheless, the following notes on communication of risk are important:

- Risk assessment is the first step in an on-going process in which risks must be monitored, mitigated and correctly communicated through tools such as assessments, plans, audits, meetings and more.
- The communication of risk must take cognisance of the nature of the parties to which information is given. This should incorporate consideration of factors such as education, manner in which they are being affected by the risk, social and economic character and more.
- Risk communication must be used to improve the understanding and confidence of initial risk assessment.
- Risk communication must always be clear, transparent, timely and unbiased.
- The communication of risk is the means through which information can be provided to decision making authorities to evaluate the granting of rights (authorisations, permits, concessions etc.) in terms of statutory provisions.

10. SPECIFIC FRAMEWORK ASSESSMENT FOR RAINBOW TROUT

The methodology above meets the requirements for risk assessment as per Section 14 of the AIS Regulations (GN R 598 of August 2014). However, this BRBA is a framework document that users need to populate with specific and detailed information pertaining to the receiving environment and the nature of their own proposed import, propagation and grow out of Rainbow trout.

10.1. INVENTORY OF POTENTIAL PATHWAYS AND RISKS

The ecological risks associated with the import, propagation and grow out of Rainbow trout, have been determined and generically evaluated for the entire South Africa. This information should be used as a starting point towards compiling a project specific risk assessment.

The following pathways between risks or stressors and the endpoint (i.e. the environment) have been identified:

- Escape, which could take on many forms (discussed below).
- The diverse pathways related to the movement of disease.

The following risk endpoints have been identified and make up the risk inventory for assessment:

- The potential for physical (abiotic) damage to the environment.
- The potential for predator displacement.
- The potential for competition - for food, habitat niches and other resources.
- The potential for hybridisation.
- The potential for impacts on prey species.
- The potential threat of new or novel diseases.

As indicated, the primary ecological risks in the inventory above are linked to the pathway of escape, and further, with the ability of Rainbow trout to establish a feral and self-propagating population, were it to escape. This ability is determined by the nature of the facilities in which the fish are kept, and the life history characterises of Rainbow trout as described in Section 7.

10.2. DISCUSSION OF RISK PATHWAYS

Using the risk inventory above, further information is provided for the respective risks in the sections below. It should be noted that the manifestation of any risk is directly related to the degree of mitigation, and that the severity of all risks is directly dependent on the level of mitigation.

10.2.1. THE PATHWAY OF ESCAPE

The potential for escape of all life stages must be evaluated from the proposed holding or production facilities. In this regard, consideration must be given to the following potential pathways of escape, which are discussed hereafter:

- Escape during transportation / shipment of ova, fry or fish to an aquaculture facility[4]
- Escape through the incoming water resources
- Escape by means of outflow water
- Escape caused by poor design, system malfunction or poor maintenance
- Escape by means of deliberate or accidental human actions such as theft or human error, including inadvertent actions that cause escape during grading, handling or harvesting
- Escape through predation, where fish are preyed upon and removed as live specimens to the surrounding environment in the process
- Escape due to natural disasters such as flooding

Escape during transportation / shipment

During this process, there is a risk that the containers or packaging materials could be breached, and that ova, fry or fish could be released to the environment. It is generally concluded that although a low probability of escape exists, the chances of any such event leading to the establishment of a feral population is negligible, given that escape during transport is not likely to lead to the fish landing in an aquatic environment in which they will survive. The risk of an escape event occurring during the shipment process is thus negligibly low, with a high potential for monitoring and mitigation.

[4] *This BRBA has been compiled in relation to the use of Rainbow trout for aquaculture. Due cognisance is given to the fact that Rainbow trout is extensively used and stocked for recreational angling, but this aspect is not the focus of this assessment.*

Escape through the incoming water resources

In general, escape of Rainbow trout through incoming water resources is unlikely, given that water is typically supplied to aquaculture facilities through directional flow. Nevertheless, in systems where water is supplied through passive flow with a low velocity (as is often the case with Rainbow trout farms and hatcheries) and where no other barriers to prevent fish from migrating out of a production facility are in place, escape is possible. Rainbow trout are strong swimmers with a natural ability to migrate upstream and against a strong flowing current, which means that escape through passive flow is possible.

Where Rainbow trout are farmed in cage culture systems, some level of escape is highly probably.

Escape through outflow water

Rainbow trout will move with water from a production facility and colonise the surrounding environment if:

- The physical (e.g. velocity, pressure, temperature) and chemical properties of the water through which the fish move is suitable.
- There are no physical barriers such as screens, filters, soakaway systems etc.
- The receiving environment can support survival.

In fully recirculating systems, the outflow volume can generally be controlled, and water can be released via a range of barriers, which could include the release of water into an environment that is not likely to support survival (such as irrigation to crops). However, in flow through systems and in cage culture it is probable that a pathway for escape exists.

It is important that containment for all life stages (ova, fry, fingerlings, growers and brood stock) be investigated, and the potential for escape established. In certain instances, the potential for escape for adult fish may be absent, while ova or fry may be transferred freely to the surrounding environment.

Escape through poor design, system malfunction or poor maintenance

A pathway for escape (and disease) can be facilitated by poor design, system malfunction and poor maintenance. The design of any system (even fully recirculating systems) should pay attention to the prevention of pathways that could lead to the escape of fish. Likewise, regular maintenance is required to prevent malfunction and the development of situations that could lead to escape.

The most common design and maintenance issues relate to the failure of key components such as tanks, pipes, filters etc. It is important that these critical points be identified and that the consequences of failure be anticipated through predicting a pathway of escape in the event of system failure or malfunction. Doing this will allow an opportunity for the creation of a contingency barrier against the escape of fish (such as an overflow sump or soakaway trench along the anticipated pathway of flow).

Escape by means of deliberate human actions such as theft or human error, including inadvertent actions that cause escape during grading, handling or harvesting.

Theft is a human characteristic that depends on a combination of social and economic factors. Escape through theft of live fish is generally improbable, given that the incentive for theft is mostly around fish as a means to a meal. However, measures such as security systems and access controls should be implemented to prevent theft.

Illegitimately giving or selling fish to third parties, potentially creates a greater risk than theft. Rainbow trout are widely used in South Africa for recreational angling, and although the BRBA concentrates on aquaculture, many aquaculture facilities generate an income from selling Rainbow trout for stocking into a wide array of rivers and dams. In some instances, such stocking is repeated annually in systems where Rainbow trout die off during summer due to elevated water temperature, but in other instances (cooler waters) the fish may survive and even spawn where suitable spawning habitat exists. The current distribution of Rainbow trout across South Africa is largely attributable to the stocking of fish for angling purposes. Many farmers diligently apply for stocking permits from provincial conservation authorities, while others stock without the required permitting.

Human error is an unavoidable characteristic of all human endeavour and can be directly linked to factors such as level of training, experience, awareness, employment conditions and the nature of the production facility. As with design and maintenance aspects, it is important that critical points and causes of human errors be identified and that the consequences thereof be anticipated through predicting a pathway of escape. Doing this will allow an opportunity for the creation of a contingency barrier against the escape of fish (such as an overflow sump along the anticipated pathway caused by the human error).

Escape through predation

For fish to escape through predation, a predator must gain access to the fish and prey in such a manner that allows for specimens to be transferred to an escape pathway or into the surrounding environment in a viable state. This is generally uncommon in closed or contained production systems, but can be common in cage culture, where predatory animals (e.g. crocodiles, predatory fish and predatory birds can cause structural damage that potentially leads to escape). Open ponds and open raceways systems for Rainbow trout can also pose risks around predator assisted escape, where animals such as otters are known to prey on fish.

Escape due to natural disasters such as flooding

Natural disasters such as floods and storms can lead to inundation or structural damage that facilitates the escape of fish. This risk is a function of the location of facilities, the design of such facilities and the prevalence of natural disasters. Aquaculture facilities should not be sited in low altitude areas that are prone to flooding. Rainbow trout farms are often located within the flood line of rivers and streams due to their dependency on flowing water, which makes the need for flood prevention measures important.

As with the matters above, it is important that potential weaknesses or risk prone aspects, insofar as natural disasters are concerned, be identified and that the consequences thereof be anticipated through predicting a pathway of escape. Doing this will allow an opportunity for the creation of a contingency barrier against the escape of fish (such as an overflow sump along the anticipated pathway caused by the natural disaster), albeit that contingencies against all natural disasters may be impractical and unachievable.

10.2.2. THE PATHWAY OF DISEASE

Concomitant with all species introductions, there is potential for the introduction of novel diseases (bacterial and viral pathogens, and parasites) into the recipient environment, and these could affect indigenous species and the ecology. These diseases can either originate from the introduced fish, or as a result of contaminated transport water or packaging materials.

The introduction of disease does not necessarily depend on the pathways that may exist for the escape of fish. Disease causing organisms can move from a fish farm into the surrounding environment through the transfer of water (with or without fish), but also through the disposal of dead fish, through the moving of fish farming equipment, on the hands and shoes of people that move through a fish farm and in a myriad of other ways.

The potential for the movement of disease from a fully contained recirculatory system, in which access control and biosecurity measures are strictly adhered to is low, while the potential for the movement of disease from cage farming systems, or through open ponds or raceway systems, is high. In all instances, the most effective means of control is to prevent the introduction of disease-causing organisms. The import of fish into South Africa is subject to veterinary clearance from the Directorate of Animal Health in the Department of Environment, Forestry and Fisheries (DEFF). In addition to this, the disease protocols and screening for certain notifiable diseases, in terms of the protocols of the World Organisation for Animal Health (OIE), is mandatory and should be applied.

High stocking densities commonly found in hatcheries can lead to outbreaks of parasites and diseases, if the hatchery design and management is not well maintained. Some of the parasites which affect Rainbow trout may also affect other freshwater finfish. If unknown diseases are introduced, indigenous species may not have an adequate immune system to cope with them, and as a result it can lead to their demise. The diseases that commonly affect Rainbow trout in South Africa [such as White Spot (*Ichthyophthirius multifiliis*), as well as *Aeromonas* or *Streptococci*] occur widely in all water bodies and generally do not become pathogenic under natural conditions outside of the fish farming environment. As these disease-causing organisms are already present in the environment, the farming of Rainbow trout is generally not regarded as an additional source. Nevertheless, fish farms could harbour other diseases that are novel to the surrounding environment and act as a source of infection to the environment.

10.3. DISCUSSION OF RISK ENDPOINTS

10.3.1. PHYSICAL ABIOTIC DAMAGE TO THE ENVIRONMENT

The risk of Rainbow trout causing any physical damage to the environment is highly improbable. Albeit that the male of the species can create a small depression in the environment (substrate) as a redd for spawning, their foraging, reproduction and other life history patterns does not cause physical damage to the aquatic environments in which they occur. Accordingly, this risk has been eliminated from further assessment.

10.3.2. PREDATOR DISPLACEMENT

Rainbow trout are apex predators. Their feeding habit is such that they may impact heavily on populations of prey items (as recorded in Section 6) and they have the ability to outcompete indigenous predatory fish. This supports the notion that Rainbow trout can cause predator displacement in aquatic systems where other predatory fish are present and where the environmental conditions are conducive to the survival of these fish. Few predatory fish inhabit the high-altitude cold stream waters of South Africa, but Rainbow trout can compete with indigenous predatory fish (e.g. Largemount yellowfish (*Labeobarbus kimberleyensis*) where ranges may overlap during winter months in more temperate areas. The common alien invasive species of Largemouth bass (*Micropterus salmoides*) that can inhabit temperate areas will in most instances displace Rainbow trout in the summer months.

10.3.3. COMPETITION - FOOD, HABITAT & OTHER RESOURCES

The establishment of a viable feral population of Rainbow trout can occur wherever the biotic and abiotic requirements of the species are met. In South Africa, the primary limiting factor to the survival of a viable population of Rainbow trout in any water resource, is water temperature. Where Rainbow trout escape into an environment in which the water temperature is below the lethal limits for the species, they can survive. Marginal environments, the lack of large cold-water rivers, few spawning areas, predatory pressures from birds and otters and angling pressure, mean that Rainbow trout seldom become truly invasive in South Africa, albeit that they may impact on prey species.

Rainbow trout can compete with some aquatic predators (fish, birds, crustaceans etc.) for a common prey source. High-altitude and low temperature rivers and streams in South Africa are often oligotrophic, meaning that nutrient sources are low, leading to low levels of biological productivity and associated low abundance of prey items. As Rainbow trout favour these habitat types, they can compete against other animals for food and habitat niches. Competition for food has also been found between trout and riparian predators that depend on aquatic insects, many of which originate from an aquatic larval stage (Jackson et al, 2015).

Consideration has been given in the risk assessment to the potential general impacts on biodiversity through related ecological consequences and extended tropic disturbances that arise from competition for food, habitat and other resources. Escapees from aquaculture facilities are inevitable and occur worldwide, unless appropriate mitigatory methods are applied. Due to its predatory behaviour, Rainbow trout has the potential to threaten native biodiversity across the narrow climatic and habitat range in which they can survive in South Africa.

10.3.4. HYBRIDIZATION

There are no indigenous species with which Rainbow trout can hybridise in South Africa. Given this finding, this risk endpoint has been eliminated from further assessment.

10.3.5. IMPACT ON PREY SPECIES

As indicated above, Rainbow trout are apex aquatic predators under suitable environmental conditions, and their diet includes fish, fish eggs, aquatic crustaceans, molluscs and a range of aquatic invertebrates and vertebrates such as amphibians. This has the potential to impact on populations of prey species that occur in cold waters and oligotrophic streams and rivers.

10.3.6. EFFECTS OF DISEASE

Assemblage of new stock and high stocking densities commonly found in aquaculture, can lead to disease related issues. The potential impacts of novel diseases introduced into an area through aquaculture can be wide-ranging. Nevertheless, the Rainbow trout stock that is currently used in South Africa has not been reported to carry diseases of concern; albeit that the national capacity and systems related to health management and monitoring for disease is poor. It is therefore of critical importance that specific national disease management protocols be devised and implemented.

Some of the parasites and diseases which affect Rainbow trout may also affect other freshwater finfish. If unknown diseases are introduced, indigenous species may not have an adequate immune response to cope. A summary of the symptoms of diseases and/or parasites which have been found internationally to infect Rainbow trout is provided in Table 9 below (modified from FAO, 2012). However, to date, none of these diseases has been found in South African Rainbow trout (despite regular testing of imported ova and cultured adults for Viral Haemorrhagic Septicaemia and Infectious Haemopoietic Necrosis) (DAFF 2012b).

Table 9: Symptoms of the diseases/parasites which commonly infect Rainbow trout (modified from FAO 2012).

Name of disease or parasite	Common Symptoms
Furunculosis	Inflammation of intestine; reddening of fins; boils on body; pectoral fins infected; tissues die back.
Vibriosis	Loss of appetite; fins and areas around vent and mouth become reddened; bleeding around mouth and gills; potential high mortality.
Bacterial Kidney Disease	Whitish lesions in the kidney; bleeding from kidneys and liver; some fish may lose appetite and swim close to surface; appear dark in colour.
Infective Pancreatic Necrosis	Erratic swimming, eventually to bottom of tank where death occurs.
Infective Haematopoietic Necrosis	Erratic swimming eventually floating upside down whilst breathing rapidly after which death occurs; eyes bulge; bleeding from base of fins.
Viral Haemorrhagic Septicaemia	Bulging or bleeding eyes; pale gills; swollen abdomen; lethargy.
White Spot	White patches on body; becoming lethargic; attempt to remove parasites by rubbing on side or bottom of tank.
Whirling Disease (*Myxosomiasis*)	Darkening of skin; swimming in spinning fashion; deformities around gills and tail fin; death eventually occurs.
Hexamitaisis octomitis	Lethargic, sinking to bottom of tank where death occurs; some fish make sudden random movements.
Costiasis	Blue-grey slime on skin which contains parasites.
Fluke	Parasites attached to caudal and anal fins; body and fins erode, leaving lesions that are attacked by *Saprolegnia.*
Trematode parasite	Eye lens cloudy; loss of condition.

It is important to consider the ecological risk of disease against the background of historical and current fish import practices for the aquarium and ornamental fish trade in South Africa. Very few health checks are done for the import of many fish species.

10.4. ASSESSMENT SCORING OF RISK LEVELS

With reference to the pathways and risk inventory in Section 10.1, the following sections illustrate the outcome of the assessment of risk levels. As a national risk framework, it is impossible to accurately determine the risk levels for each instance in which Rainbow trout is used, or in which it is being proposed for use in aquaculture or introduction. Moreover, it is impossible to determine the precise levels of risk based on the design of an individual aquaculture project, and the level of mitigation that will applied. For these reasons, the scoring that follows must be used as a point of departure to provide a generic framework, which will require further detailed assessment for individual projects.

10.4.1. RISK PATHWAYS

The relationship between a risk pathway and the endpoint has been illustrated in Section 9.3. It should be noted that the probably of a pathway such as escape refers specifically to the probability (chance) of escape, and not to the probability of the escape event leading to an impact or endpoint. Likewise, the severity refers to the severity (quantity) of escape, the scope to the distribution of escapees and permanence to the survival and propagation of the escapees. These aspects should not be confused with the characterisation of the endpoints or impacts.

The risks associated with the respective pathways differ greatly between the respective production systems used in aquaculture (i.e. ponds, raceways, cages, recirculatory systems etc.) For this reason, the tables hereafter depict an aggregate score for South Africa in general. Note that the risk of escape associated with the stocking of Rainbow trout as a recreational angling species is virtually impossible to quantify in a national framework, given that each waterbody that is stocked will have different characterises that contribute to the broader spread of the species into surrounding natural waters. For this reason, the application of this risk assessment methodology to aquaculture facilities, will generally not cover the risks associated with stocking Rainbow trout for recreational purposes.

a. The risk of Rainbow trout escaping during transit between hatcheries and from suppliers to farmers.

Table 10: Risk pathway characterisation related to escape during transport and transit.

Risk	Escape				
Pathway	Escape during transport or transit				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

b. The risk of Rainbow trout escaping through inflow water.

Table 11: Risk pathway characterisation related to escape through the inflow water.

Risk	Escape				
Pathway	Escape through inflow water				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

c. The risk of Rainbow trout escaping through outflow water.

Table 12: Risk pathway characterisation related to escape through the outflow water.

Risk	Escape				
Pathway	Escape through outflow water				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

d. The risk of Rainbow trout escaping through poor design, system malfunction and/or poor maintenance to aquaculture facilities.

Table 13: Risk pathway characterisation related to escape through poor design, system malfunction and/or poor maintenance.

Risk	Escape				
Pathway	Escape due to poor design, system malfunction and/or poor maintenance				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

e. The risk of Rainbow trout escaping through deliberate human actions such as theft or human error.

Table 14: Risk pathway characterisation related to escape through theft or human error.

Risk	Escape				
Pathway	Escape due to human actions such as theft or human error (excl. recreational stocking)				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

f. The risk of Rainbow trout escaping through predation, where fish are preyed upon and removed as live specimens to the surrounding environment.

Table 15: Risk pathway characterisation related to escape through predation.

Risk	Escape				
Pathway	Escape due to predation				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

g. The risk of Rainbow trout escaping through natural disasters such as flooding.

Table 16: Risk pathway characterisation related to escape through natural disasters.

Risk	Escape				
Pathway	Escape due to natural disasters				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

h. The risk of Rainbow trout serving as vector for the introduction of novel diseases and pathogens (including parasites).

Table 17: Risk pathway characterisation related to spread of novel diseases.

Risk	Spread of disease				
Pathway	Various disease pathways - water, air or direct contact				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

10.4.2. RISK ENDPOINTS/IMPACTS

It should be noted that the probably of an endpoint or an impact such as predator displacement refers specifically to the probability (chance) of impact, and not to the probability of the pathway that led to the impact or endpoint. Likewise, the severity refers to the severity (quantity) of the impact, the scope to the distribution of the impact and the permanence to the duration of the impact. These aspects should not be confused with the characterisation of the pathway.

a. The risk of Rainbow trout causing physical (abiotic) damage to the environment.

Table 18: Risk endpoint characterisation related to physical damage to the environment.

Risk	Life history characteristics of Rainbow Trout				
Endpoint / Impact	Physical (abiotic) damage to the environment				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

b. The risk of Rainbow trout competing with and/or displacing other predatory species.

Table 19: Risk endpoint characterisation related to predator competition and displacement.

Risk	Life history characteristics of Rainbow Trout				
Endpoint / Impact	Competition and displacement of predatory species				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

c. The risk of Rainbow trout causing impacts related to competition for food, habitat niches and other resources.

Table 20: Risk endpoint characterisation related to competition for food, habitat and other resources.

Risk	Life history characteristics of Rainbow Trout				
Endpoint / Impact	Competition for food, habitat niches and other resources				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

d. The risk of Rainbow trout impacting on potential prey species.

Table 21: Risk endpoint characterisation related to impacts on prey species.

Risk	Life history characteristics of Rainbow Trout				
Endpoint / Impact	Impacts on prey species				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

e. The risk of Rainbow trout acting as a vector for the introduction of disease and pathogens.

Table 22: Risk endpoint characterisation related to disease and pathogens.

Risk	Life history characteristics of pathogen				
Endpoint / Impact	Multiple disease related impacts				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

10.5. SUMMARY OF RISK PROFILE

The pathway and endpoints of the risks that have been set in the analysis above can be summarized to arrive at an overall risk profile. The characterisation of pathways and endpoints (aggregate for all production systems and environments) is summarised in the following table:

Table 23: Risk profile characterised by risk pathways and risk endpoints.

	Risk Pathways								**Risk End Point or Impacts**				
Risk	Transit	Inflow water	Outflow water	Design, malfunction or maintenance	Theft or human error	Predation	Natural disasters	Disease pathways	Physical damage	Compete or displace predators	Competition food, niches & resources	Impact prey species	Disease impacts
Probability	E Low	Low	Mod	Mod	Mod	E Low	Low	Low	Neg	Mod	Mod	High	Low
Severity	Low	Mod	Mod	Mod	Mod	Mod	Mod	Low	Neg	Mod	Mod	High	Low
Scope	Local	Local	Local	Local	Local	Local	Local	Local	Local	Local	Local	Local	Local
Permanence	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Short T	Mod	Mod	Long L	Mod
Confidence	High	Mod	Mod	Mod	Mod	High	Mod	Mod	V High	High	High	High	Mod
Monitoring	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	High	Mod	Mod	Mod	Mod
Mitigation	V High	High	High	V High	High	High	High	High	Mod	Low	Low	Low	High

Neg=Negligible, Mod=Moderate, Reg=Regional, Perm=Permanent, E Low=Extremely Low, Proj B=Project Based, Ext=Extensive, Long L=Long Lasting, Short T=Short Term, Temp=Temporary, V High=Very High, Irrev=Irreversible

Using the table above, a numeric scoring can be used to weigh and prioritise the potential risks of greatest concern. Various mathematical methods have been used for risk scoring to prioritise the importance or interrelatedness between the numerical weighting of either probability, severity, scope and/or permanence. In the methodology that has been applied to this BRBA, a selection of 4 consecutive numbers (weights) has been given to each of the five categories under probability and severity; spanning from 1 (high) to 20 (low), to correspond with high to negligible probability and very high to negligible severity, respectively. Similarly, a selection of 3 consecutive numbers, spanning from 1 (high) to 15 (low), has been used for scope and permanence, to achieve the greater relevance (weight) to probability and severity, which is sometimes achieved by applying multiplication of the scores in these categories. Given that confidence, monitoring and mitigation are based largely on judgements of value, and not on the actual nature of the impact or risk to the environment, 2 consecutive numbers, spanning from 1 (low) to 10 (high) has been used for these categories.

To illustrate this, the following numeric values are given to the respective scales:

Table 24: Numeric values associated with risk characterisation.

Probability	High	Moderate	Low	Extremely low	Negligible
	1 2 3 4	5 6 7 8	9 10 11 12	13 14 15 16	17 18 19 20
Severity	Very high	High	Moderate	Low	Negligible
	1 2 3 4	5 6 7 8	9 10 11 12	13 14 15 16	17 18 19 20
Scope	Extensive	Regional	Local	Project based	Negligible
	1 2 3	4 5 6	7 8 9	10 11 12	13 14 15
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
	1 2 3	4 5 6	7 8 9	10 11 12	13 14 15
Confidence	Doubtful	Low	Moderate	High	Very high
	1 2	3 4	5 6	7 8	9 10
Monitoring	Zero	Low	Moderate	High	Very high
	1 2	3 4	5 6	7 8	9 10
Mitigation	Irreversible	Low	Moderate	High	Very high
	1 2	3 4	5 6	7 8	9 10

Using this method, an impact or risk that is very probable, that has severe effects, a broad scope, long permanence and that is predicted with little confidence, and that is difficult to monitor and mitigate can score a theoretical low overall value/weight of 7. Alternatively, a negligible impact or risk that is unlikely to occur, with limited scope, a short lifespan and which can be predicted with confidence, and that can be monitored and mitigated, can score a theoretical high overall value of 100. Using this numeric allocation to illustrate risk is convenient in that low scoring risks pose a threat to the environment, while high scoring risks are acceptable.

The scoring of evaluated pathways and risk endpoints for Rainbow trout is as follows (table next page):

Table 25: Score allocation to the risk profile before mitigation.

	Risk Pathways								**Risk End Point or Impacts**				
Risk	Transit	Inflow water	Outflow water	Design, malfunction or maintenance	Theft or human error	Predation	Natural disasters	Disease pathways	Physical damage	Compete or displace predators	Competition food, niches & resources	Impact prey species	Disease impacts
Probability	16	12	8	8	8	13	12	10	19	6	7	4	10
Severity	14	12	11	11	11	12	12	16	20	10	10	6	16
Scope	8	8	8	8	8	8	8	8	9	8	8	8	8
Permanence	7	7	7	7	7	7	7	7	15	7	7	6	7
Confidence	8	6	6	6	6	7	6	5	9	8	8	9	5
Monitoring	6	5	5	5	6	6	6	6	8	6	6	6	6
Mitigation	10	8	8	9	8	8	8	8	5	3	3	3	8
Total Score	69	58	53	54	54	61	59	60	85	48	49	42	60

Notwithstanding all factors considered, as a general rule, scores above 50 denote acceptable levels of risk and those below 50, unacceptable. The score allocation, although subjective and debatable, has been done based on information in this BRBA.

When considering the pathways for the manifestation of risks, the scores for escape through theft or human error, poor design and malfunction or a lack of maintenance, and escape through outflow water, demonstrate that they pose the greatest threats. However, these aspects show a high potential for monitoring and mitigation, meaning that effective risk pathway management could see a lowering of the potential impact to endpoints.

With due consideration to the pathways above, the scores for the ecological endpoints or impacts related to competition for food, habitat niches and resources, as well as predator displacement, are relevant. However, of all the ecological endpoints, the risk to prey species is of greatest concern. The absolute prevention of escape is the only effective means of mitigation against this risk, which means that Rainbow trout should not be farmed in areas where they have not been introduced previously.

Note that this scoring methodology has been used to grade the potential negative risks and impacts only. The potential positive impacts of establishing a compliant Rainbow trout aquaculture sector in South Africa have not been considered (see Section 11 below). Reports abound across South Africa of unlawful distribution of Rainbow trout by unscrupulous anglers, farmers and non-abiding aquaculture facilities. It is for this very reason that the establishment of a compliant aquaculture sector is important in curbing the illegal distribution of these fish.

11. KEY ECONOMIC, SOCIAL AND SOCIETAL CONSIDERATIONS

The risk profile above is based on the potential negative environmental or ecological consequences related to the use and introduction of Rainbow trout. These risks must be considered in a balanced manner in conjunction with potential economic, social and societal considerations (Wise et al 2007).

Globally, and especially in South Africa, the demand and market for Rainbow trout have expanded rapidly, both in the food sector and as a recreational species for angling. In response to this, the interest in this species as a candidate for farming has spread across many countries, including South Africa. The historic interest in South Africa has led to the establishment of Rainbow trout farms in the Western Cape, Eastern Cape, KwaZulu Natal and Mpumalanga. In most instances these farms are operated on principles of environmental sustainability, albeit that certain farms ignore the impacts and consequences of introducing Rainbow trout into areas where they have not occurred historically. The market for Rainbow trout as a recreation species for stocking into seasonally and permanently suitable still waters and rivers could potentially lead to the introduction of these fish into areas where they have not occurred historically, or into areas where they may have occurred but have been excluded from surviving due to climate or a lack of suitable spawning grounds.

The operation and expansion of a formal and lawful Rainbow trout aquaculture sector, in specific areas and in which the risks are known and mitigated, is the most prudent response to the potential ecological impacts. This will also contribute to the furtherance and success of aquaculture in South Africa, which is a clear objective of the current policies and strategies adopted by the South African Government, particularly the Department of Environment, Forestry and Fisheries (DEFF). Rainbow trout aquaculture is one of the few species that provide inland aquaculture opportunities in South Africa and success in their farming will have several socio-economic advantages, which include:

- The creation of rare skills and the application of new technologies.
- The beneficial use of natural resources.
- The creation of economic opportunities in the broader South African context. This is especially relevant considering that these opportunities will be created in primary production.
- Direct and indirect food security.

Ultimately, the use of Rainbow trout should only be permitted in areas where the potential invasion of the species is either limited by climate, or where invasion has already occurred, Due consideration should be given to the fact that selected areas of suitable habitat may exist within conservation areas or areas of specific ecological significance. Hence, the use of Rainbow trout should not be permitted in these areas.

It is important to consider the potential socio-economic consequences that may result from the manifestation of any of the ecological impacts. Were Rainbow trout to become established across the climatic range in which they survive in South Africa, the socio-economic consequences are a loss of biodiversity caused by predation – primarily of susceptible fish species, none of which support any commercial fisheries. The establishment of Rainbow trout (regardless of the probability thereof), holds no direct threat to humans or any human livelihoods.

The Rainbow trout farming sector in South Africa produces an estimated 1500 tonnes per annum (AquaEco 2017, as reported by FAO - Fisheries and Aquaculture Information and Statistics Service 2016 and DAFF Aquaculture Yearbook 2016) which equates to a significant portion of the country's aquaculture output, creates employment opportunities, as well as economic opportunities. In addition to this, the production of Rainbow trout for the recreational angling market, as well as the production of fertilised ova that is destined for export, adds much to the economic importance of this species. The recreational angling market serves as a significant pillar of support to the trout related tourism market in certain areas of the Western Cape, the Eastern Cape, KwaZulu-Natal and Mpumalanga.

A study completed in Rhodes village, North Eastern Cape, found that the Rainbow trout angling industry in the village generates approximately R 5.66 million annually, with 39 direct jobs (for a village population of 600 persons) (Du Preez & Lee 2010). Another study, which investigated the economic impacts of trout angling in the Mhlatuze Water Management Areas, found that the recreational fishing industry in that area provides R18 000 per km of river (Anchor Environmental Consultants 2010). Towns such as Dullstroom in Mpumalanga are economically dependent on the presence of both Rainbow and Brown trout as a recreational angling species.

In 2008, there was a total of 24 trout farms in South Africa (Britz et al. 2009), and 27 farms in 2013 (DAFF Aquaculture Yearbook 2016). Rainbow trout farming in South Africa was valued at R 27.9 million in 2008 (Britz et al. 2009) and at an estimated R 51.9 million (as reported by FAO - Fisheries and Aquaculture Information and Statistics Service, 2016).

This value in primary production can conceivably be doubled through value addition to primary products to the foodservices market, is probably matched by a quarter in direct value in supply to the recreational angling market (excluding secondary value in tourism and angling related equipment etc.), and conceivably matched by another quarter in export of fertilised ova. This results in the South African Rainbow trout industry amassing an estimated primary value of R 181.7 million per annum, excluding tourism related value and the significant value in the processing and value adding of Rainbow trout imported from Lesotho and other countries.

South African trout farms in 2008 were employing 346 full time and 163 part time staff. These figures are conservative as they include only those involved in primary production and not those who work in the secondary services (such as feed manufacturers or those employed in fish processing plants) (Britz et al. 2009). It is conceivable that these numbers have increased.

Rainbow trout has been awarded green status on the World Wildlife Fund (WWF) South African Sustainable Seafood Initiative (SASSI) list. The SASSI seafood list has been compiled using an internationally accepted best practice methodology. The methodology scores a species across three categories, namely stock status, ecological impacts of the fishery in which the species is caught, and the management measures in place for that fishery. This leads to a certification of the species, rather than an individual farm. It is considered a recommended scheme which will serve to further promote the Rainbow trout aquaculture industry.

12. BALANCED COST OF ERADICATION

Given the marginal climatic and habitat conditions for Rainbow trout (especially the absence of suitable spawning grounds), there are numerous examples of areas in which Rainbow trout have been stocked and have not persisted. Seasonal restocking of recreational angling waters attests to this. Rainbow trout do however survive in cooler streams and rivers, where eradication efforts have only been through the passive means of angling and preventing restocking.

In the US partial eradication has been reported by electrofishing is small streams (Moore *et al* 1986) to improve habitat conditions for indigenous Brook trout (*Salvelinus fontinalis*). Mechanical removal (fishing and netting) has also been reported as being largely unsuccessful in the upper Krom River, a small headwater stream in the Cederberg Mountains (Shelton et al, 2016b).

The piscicide Rotenone has been used under a number of selected conditions to eradicate Rainbow trout, but it is accepted that this should not be used as a universal tool for eradication, given its toxicity to other fish.

A balanced view must be taken of the potential ecological cost of Rainbow trout invasion and the potential cost of eradicating the fish. This cannot be approached as an actual cost as an expense of this nature must be weighed up against the ecological costs and the net gain of benefits that would result from an eradication effort. Given the ecological costs, the potentially impacted species, the nature of the receiving environment, the net gains from a Rainbow trout farming industry and the limited risk towards human beings, it is suggested that the cost of actively eradicating Rainbow trout would be unwarranted in most instances. The climatic and other habitat associated control mechanisms outweigh any benefits that may accrue from the actual expenses associated with active eradication. Management through selected zones in which Rainbow trout should be excluded and the granting of permits in areas where Rainbow trout survive seasonally or in areas that have been invaded historically, would constitute a more practical approach.

Despite the balanced view above, the "*polluter pays*" principle in Section 28 of the National Environmental Management Act 107 of 1998 may apply, in terms of which the onus to cover the costs associated with environmental degradation, lies with the developer or proponent, which in this case will be the party responsible for release of Rainbow trout into an environment in which it may cause invasion.

13. RISK MONITORING

The potential for monitoring of the respective pathways and risks have been analysed as part of the assessment. Monitoring is a key aspect towards bolstering the acceptability of risk as it provides a mechanism for tracking risks through a project cycle, and it increases confidence in future assessments. Other important reasons for monitoring relate to environmental protection, research, traceability, market requirements and self-assessment of performance.

Threshold limits should be identified before allowing for the use of Rainbow trout in any specific area. The full extent of the monitoring programme should be documented in a monitoring plan so that there is clarity on what will be monitored, how, for how long and the manner in which it should be recorded and reported. Monitoring must take account of practicality, and especially the cost effectiveness in relation to the levels of identified risks.

The following preliminary monitoring requirements could be considered for inclusion in a monitoring programme associated with the use of Rainbow trout in aquaculture. It is further recommended that the monitoring regime be subjected to regular external verification by an independent specialist.

- Monitoring regime for all transit and receipt of new batches of fish to determine origin, numbers, quarantine procedures and disease status.
- Ongoing monitoring for fish health and disease.
- A monthly inspection of the sumps, screens, filters and other discharge systems through which outflow water flows.
- A monthly inspection of all maintenance, as well as integrity, functioning and contingency planning for the operation of production facilities.
- A six-monthly review of the training levels and ability of personnel, to minimise the risk of human error.
- A six-monthly review of security to prevent theft.
- A six-monthly review of fish stock records.

A site-specific Environmental Management Programme (EMPr) should be developed for each trout farm and compliance thereto should be mandatory.

14. RISK CONTROL MEASURES AND MITIGATION

Controlling the spread of an invasive species through prevention is thought to be the most cost-effective means (Leung *et al.* 2002). It was illustrated in the analysis of pathways and risks that mitigation could lead to lowered levels of severity, scope, longevity etc. Such mitigation measures should be recorded, implemented, audited and reported; both internally and, if required, externally by an independent specialist.

The following preliminary mitigation measures could be considered for inclusion as conditions related to the issuing of permits for the use of Rainbow trout in aquaculture (see also O'Sullivan 1992, Pillay 1992, Garrett et al 1997, Midlen et al 1998, Fernandes et al 2002, Hinrichsen 2007 & 2013, AU-IBAR 2016).

The prevention of escape through transit:

- Obtain fish from a single, reputable and permitted suppliers.
- Use best packaging materials and techniques, as well as reputable transit agencies.
- Keep accurate dispatch and receipt records of fish stocks.

The prevention of escape through inflow and outflow water:

- Implementation of mechanisms to prevent facilities from flooding due to overfilling or tank/pipe failure.
- The implementation of a dedicated maintenance schedule and the appointment of human resources dedicated to system maintenance.
- Use and maintenance of screens over outlet pipes (Novinger & Rahel 2003).
- All outlet and inlet pipes should have mesh screens which will prevent the escape of eggs from the hatchery and fry from the grow-out facilities.

The prevention of escape caused by design, malfunction or maintenance issues:

- The use of best technology and management to prevent poor design and malfunction, including the implementation of backup systems and contingency plans in case of system failure.

The prevention of theft of fish:

- Ensure that access is strictly controlled and that facilities remain locked when personnel are not in attendance.
- Educate personnel in their responsibility towards the maintenance of security.
- Maintain and review an accurate stock record.

For the prevention of human errors:

- The training of personnel to reduce the possibility of human error.
- The appointment of suitably qualified personnel.
- The implementation of adequate supervision systems.

The prevention of escape caused by predation:

- Keep facilities locked when personnel are not in attendance.
- Ensure that predators such as otters and birds cannot access the facilities.

Precautions against escape cause by natural disasters:

- Facilities must remain outside of the flood line where possible. Infrastructure should be built to resist the impacts of floods.
- Maintenance of facilities to prevent structural failure in storms and wind.

The prevention of risks associated with foreign disease and pathogens:

- Fish or ova may only be bought from certified disease-free suppliers and such imports should meet all further requirements that may be determined by the State Veterinarian.
- Upon receipt, all fish or ova should be subjected to quarantine. The duration of quarantine and the nature of the quarantine facilities needs to be specified in a site-specific EMPr.

- Packaging materials for every shipment must be new and destroyed after shipping.
- Water in which fish were transported must be released into the quarantine facilities or treated to ensure no parasites and /or pathogens survive.
- Limit access to the production facilities.
- Prevent use of equipment from other fish farming facilities unless properly cleaned and sterilized.
- Once in the production system, a fish health monitoring program must be applied, and records kept for a period of 2 years for inspection as required by the State Veterinarian. Animal health experts from the Department of Environment, Forestry and Fisheries (DEFF) may also be approached [South African Aquaculture Fish Monitoring and Control Programme (DAFF, 2015)].

15. BENEFIT / RISK TRADE-OFF

In all development, the use of benefit versus risk tradeoffs is common. Most such tradeoffs are done rapidly and without detailed analysis and many involve financial risks and tradeoffs between potential gains in profits against the factors that may cause financial losses. In the ecological and environmental context, the tradeoff is between viability of an aquaculture development against levels of acceptable environmental risk. This encompasses the process of precautionary decision making.

It is not possible for a proposed aquaculture activity to have no risk or impact and there is usually a trade-off between acceptable environmental risk and socio-economic benefits. This trade-off is normally defined as acceptable limits of effects.

Benefit and risk tradeoff can become a highly complicated exercise when assigning objective and comparable values to these. Although this tradeoff is not being pursued in this report, considering the risk profile indicated above in conjunction with the advantages and potential benefits from the use of Rainbow trout for aquaculture, one can arrive at an acceptable risk tradeoff in which the use of this species should be permitted in areas where it will not be able to cause invasion and in areas where invasion has already taken place.

16. RECOMMENDATIONS

Risk assessment techniques have been applied to all the major risk components related to the use of Rainbow trout for aquaculture in South Africa. This risk assessment should only serve as a framework around which the risk of any individual project and/or location can be investigated. The focus should remain on preventing the spread or deliberate introduction on Rainbow trout into new areas or river systems where they do not occur. Ongoing deliberations between conservations authorities (DEFF and provincial authorities), representatives of the Rainbow trout farming sector and scientists should formulate an approach for new projects based on the following position taken from the results of this risk assessment:

a. In areas where Rainbow trout cannot survive climatically in any season (using the distribution maps formulated by SANBI in Section 7.10), the farming and stocking of Rainbow trout should be permitted regardless.
b. In areas where Rainbow trout can survive from a climatic point of view, the establishment of a new production facility should be subjected to a project specific risk assessment that looks into the impacts and benefits (Ellender et al, 2014b), and which risk assessment must include the identification of areas into which fish may be supplied for recreational use (i.e. angling). Pending the outcome of such an assessment, new facilities should be permitted in areas where Rainbow trout already occur as self-sustaining populations, with due consideration that no new facilities should be established inside of designated protected areas or in catchments where it can be reasonably established that the introduction of Rainbow trout poses a threat to aquatic fauna.

17. CONCLUSION

This BRBA has illustrated that the primary risk related to the use of Rainbow trout in aquaculture in South Africa is its potential impact to populations of indigenous fish, many of which are endangered and vulnerable.

REFERENCES

1. Alborali L. 2006. Climate variations related to fish diseases and production. Veterinary Research Communications.
2. Alexandratos N, Bruinsma J. 2012. World agriculture towards 2030/2050: The 2012 revision. ESA Working Paper No. 12-03. Rome, FAO.
3. Allendorf FW, Leary RF, Spruell P, Wenburg JK. 2001. The problems with hybrids: Setting conservation guidelines. Trends in Ecology & Evolution.
4. Anderson MC, Adams H, Hope B, Powell M. 2004. Risk assessment for invasive species. Risk Analysis 24: 787-793.
5. AU-IBAR and SADC, 2016. Regional Framework on Environmental Management for Sustainable Aquaculture Development in Africa - Southern African Region. AU-IBAR Reports.
6. Avidon S, Shelton JM, Marr SM, Bellingan TA, Esler KJ and Weyl OLF. 2018 Preliminary evaluation of non-native rainbow trout (*Oncorhynchus mykiss*) impact on the Cederberg ghost frog (*Heleophryne depressa*) in South Africa's Cape Fold Ecoregion. African Journal of Aquatic Science 2018, 43(3): 313–318.
7. Bartley D & Casal CV. 1998. Impacts of introductions on the conservation and sustainable use of aquatic biodiversity. FAN Aquaculture Newsletter.
8. Bartley DM. 2006. Introduced species in fisheries and aquaculture: Information for responsible use and control. Rome, FAO.
9. Britz, P.J., Lee, B. & Botes, L. 2009. AISA 2009 Aquaculture Benchmarking Survey: Primary Production and Markets. AISA report produced by Enviro-Fish Africa (Pty) Ltd. 117 pp.
10. Brungs WA, Jones BR. 1977. Temperature Criteria for Freshwater Fish: Protocol and Procedures. US Environmental Protection Agency Environmental Research Laboratory, Duluth, Minn.
11. Burgman MA. 2001. Flaws in subjective assessments of ecological risks and means of correcting them. Australian Journal of Environmental Management.
12. Burgman MA. 2005. Risks and Decisions for Conservation and Environmental Management. Cambridge, UK. Cambridge University Press.
13. Cadwallader PL and Backhouse BN. 1983. A Guide to the Freshwater Fish of Victoria. Government Printer, Melbourne.
14. Cambray JA & Pister EP. 2002. The role of scientists in creating public awareness for the conservation of fish species: African and American case studies. In: MJ Collares-Pereira, IG Cowx & Coelho MM (eds) Conservation of Freshwater Fishes: Options for the Future. Oxford: Fishing News Books, Blackwell Science.
15. Cambray, J.A. 2003. Impact on indigenous species biodiversity caused by the globalization of alien recreational freshwater fisheries. Hydrobiologia 500: 217–230.
16. Cambray JA. 2003a. The global impact of alien trout species - a review; with reference to their impact in South Africa. African Journal of Aquatic Science.
17. Centre for Environment, Fisheries & Aquaculture Science (UK). 2013. Decision support tools for the identification and management of invasive non-native aquatic species.
18. Clark B & Ratcliffe G (eds). 2007. Berg River Baseline Monitoring Programme: Final Report – Volume 5: Synthesis. Publication No P WMA 19/G10/00/2107. Pretoria: Department of Water Affairs.
19. Copp GH, Britton JR, Cowx IG, Jeney G, Joly JP, Gherardi F, Gollasch S, Gozlan RE, Jones G, MacLeod A, Midtlyng PJ, Miossec L, Nunn AD, Occhipinti-Ambrogi A, Oidtmann B, Olenin S, Peeler E, Russell IC, Savini D, Tricarico E & Thrush M. 2008. Risk assessment protocols and decision-making tools for use of alien species

in aquaculture and stock enhancement. EU Co-ordination Action Project: IMPASSE Environmental impacts of alien species in aquaculture, Deliverable report 3.2.

20. Courtenay WR, Williams JD. 1992. Dispersal of exotic species from aquaculture sources, with emphasis on freshwater fishes. Dispersal of living organisms into aquatic ecosystems. Maryland Sea Grant Publication, College Park, Maryland.
21. Covello VT. Merkhofer MW. 1993. Risk Assessment Methods: Approaches for assessing health and environmental risks. Plenum Press, New York.
22. Crawford SS & Muir AM. 2008. Global introductions of salmon and trout in the genus Oncorhynchus: 1870–2007. Reviews in Fish Biology and Fisheries.
23. DAFF. Biodiversity Risk and Benefit Assessment (BRBA) of Alien Species in Aquaculture in South Africa.
24. DAFF. 2014. Aquaculture Yearbook. Department of Agriculture, Forestry and Fisheries. South Africa.
25. DEA. Risk assessment for Rainbow trout *Oncorhynchus mykiss* in South Africa. Website link: https://www.environment.gov.za/sites/default/files/docs/rainbowtrout_riskassessment.pdf.
26. De Moor IJ, Bruton MN. 1988. Atlas of alien and translocated indigenous aquatic animals in southern Africa. Pretoria: South African National Scientific Programmes Report no.144.
27. Driver A, Nel JL, Snaddon K, Murray K, Roux D, Hill L, Swartz ER, Manuel J & Funke N. 2011. Implementation Manual for Freshwater Ecosystem Priority Areas. WRC Report No. 1801/1/11. ISBN 978-1-4312-0147-1. Pretoria.
28. Du Preez M & Lee DE. 2010. The contribution of trout fly fishing to the economy of Rhodes, North Eastern Cape, South Africa. Development Southern Africa.
29. EKZN Wildlife 2011. uKhahlamba Drakensberg Park World Heritage Site: Integrated Management Plan. Version 1.0 (2011), Ezemvelo KZN Wildlife, Pietermaritzburg.
30. Ellender BR, Woodford DJ, Weyl OLF and Cowx G. 2014a. Review Paper: Managing conflicts arising from fisheries enhancements based on non-native fishes in southern Africa. Journal of Fish Biology 85.
31. Ellender BR, Weyl OLF. 2014b. A review of current knowledge, risk and ecological impacts associated with non-native freshwater fish introductions in South Africa. Aquatic Invasions Volume 9, Issue 2: 117–132.
32. Ellender BR, Rivers-Moore NA, Coppinger CR, Bellingan TA, Weyl OLF. 2016. Towards using thermal stress thresholds to predict salmonid invasion potential. Biol Invasions 18:3513 – 3525.
33. Engelbrecht J & Bills R. 2007. *Barbus treurensis*. In: IUCN 2012. IUCN Red List of Threatened Species.
34. EPA. 1998. Guidelines for Ecological Risk Assessment. US Environmental Protection Agency, Washington D.C.
35. EU Commission. 2000. Communication from the Commission on the Precautionary Principle. European Commission, Brussels.
36. Del Vecchio M. 2013. Cosmopolitan Trout: The 1883 Fisheries Exhibition and the Global Expansion of Fish Culture. Environment & Society Portal, Arcadia (2013). Rachel Carson Center for Environment and Society.
37. FAO 2010-2018. Cultured Aquatic Species Information Programme. *Oncorhynchus mykiss*. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 17 March 2017. http://www.fao.org/fishery/
38. FAO. 2016. State of World Fisheries and Aquaculture Report. FAO, Rome.
39. Fernandes TF, Eleftheriou A, Ackefors *et al*. 2002. The Management of the Environmental Impacts of Aquaculture. Scottish Executive, Aberdeen, UK.
40. FishBase, 2003. Species profile *Oncorhynchus mykiss* Rainbow trout.
41. Fitzpatrick M, Hargrove W. 2009. The projection of species distribution models and the problem of non-analog climate. Biodiversity and Conservation 18: 2255–2261.

42. Fletcher WJ, Chesson J, Fisher M, Sainsbury KJ, Hundloe T, Smith ADM, Whitworth B. 2003. National application of sustainability indicators for Australian fisheries. Final Report to Fisheries Research and Development Corporation.
43. Fletcher WJ. 2005. The application of qualitative risk assessment methodology to prioritize issues for fisheries management. ICES Journal of Marine Science
44. Fletcher WJ. 2015. Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based management framework. ICES Journal of Marine Science.
45. Froese R & Pauly D. Editors. 2017. FishBase. Electronic publication. www.fishbase.org
46. Fuller P. 2000. Nonindigenous fishes - *Oncorhynchus mykiss*. Non-indigenous Exotic Species website, US Geological Survey.
47. Gall GAE & Crandell PA. 1992. The Rainbow trout. Aquaculture.
48. Garrett E, Spencer dos Santos CL, Jahncke ML. 1997. Public, animal, and environmental health implications of aquaculture.
49. Gillespie GR. 2001. The role of introduced trout in the decline of the spotted tree frog (*Litoria spenceri*) in south-eastern Australia. Biological Conservation.
50. Global Invasive Species Database (GISD). 2018. Downloaded from http://www.iucngisd.org/gisd/search.php
51. Hayes KR, Regan HM, Burgman MA. 2007. Introduction to the concepts and methods of uncertainty analysis. Environmental Risk Assessment of Genetically Modified Organisms: Methodologies for Transgenic Fish.
52. Hinrichsen E. 2007. Generic Environmental Best Practice Guideline for Aquaculture Development and Operation in the Western Cape. Division of Aquaculture, Stellenbosch University Report. Provincial Government of the Western Cape, Department of Environmental Affairs & Development Planning, Cape Town.
53. Hinrichsen E. 2013. EIA Guideline for Aquaculture in South Africa: As gazetted in Government Notice 101 of 2013 by the Department of Environmental Affairs.
54. Hugg DO. 1996. MAPFISH georeferenced mapping database. Freshwater and estuarine fishes of North America. Life Science Software.Edgewater, Maryland, USA.
55. Integrated Taxonomic Information System (ITIS). 2015. *Oncorhynchus mykiss*. Integrated Taxonomic Information System, http://www.itis.gov.
56. IUCN. 2014. The IUCN Red List of Threatened Species.
57. Jackson MC, Woodford DJ, Bellingan TA, Weyl OLF, Potgieter MJ, Rivers-Moore NA, Ellender BR, Fourie HE, Chimimba CT. 2016. Trophic overlap between fish and riparian spiders: potential impacts of an invasive fish on terrestrial consumers. Ecology and Evolution 2016; 6(6): 1745 - 1752.
58. Jubb RA. 1967. Freshwater fishes of southern Africa. Balkema, Cape Town.
59. Kapuscinski AR, Hayes KR, Li S, Dana G (eds). 2007. Environmental Risk Assessment of Genetically Modified Organisms. Volume 3: Methodologies for Transgenic Fish. Oxfordshire, UK.
60. Karssing RJ. 2010. Influence of waterfalls on patterns of association between trout and Natal cascade frog *Hadromophryne natalensis* tadpoles in two headwater streams of the uKhahlamba Drakensberg Park World Heritage Site. MSc.Thesis, University of South Africa, Pretoria.
61. Karssing RJ, Rivers-Moore NA and Slater K. 2012. Influence of waterfalls on patterns of association between trout and Natal cascade frog *Hadromophryne natalensis* tadpoles in two headwater streams in the uKhahlamba Drakensberg Park World Heritage Site, South Africa. African Journal of Aquatic Science, 37:1, 107-112.
62. Kleynhans CJ. 1987. A preliminary study of aspects of the ecology of a rare minnow *Barbus treurensis* (Groenewald, 1958) from the Eastern Transvaal, South Africa. Journal of the Limnological Society of Southern Africa.
63. Kleynhans CJ. 1988. Aspects of the ecology of *Kneria auriculata* (Pellegrin, 1905) from the Eastern Transvaal South Africa. Journal of the Limnological Society of Southern Africa.

Kleynhans CJ. 1999. The development of a fish index to assess the biological integrity of South African rivers. Water SA 25 (3) 265-277.

64. Kleynhans CJ, Thirion C. Moolman J. 2005. A Level I River Ecoregion Classification System for South Africa, Lesotho and Swaziland. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.
65. Kleynhans CJ, Louw MD. 2007. Module A: Eco Classification and Eco Status determination in River Eco Classification: Manual for Eco Status Determination. Joint Water Research Commission and Department of Water Affairs and Forestry.
66. Kleynhans CJ, Louw MD, Moolman J. 2007. Reference frequency of occurrence of fish species in South Africa. Department of Water Affairs and Forestry (Resource Quality Services) and Water Research Commission.
67. Landis WG. 2004. Ecological risk assessment conceptual model formulation for non-indigenous species. Risk Analyses 24: 847-858.
68. Leung B., Lodge, D.M., Finnoff, D., Shogren, J.F., Lewis, M.A. & Lamberti, G. 2002. An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. Proceedings of the Royal Society of London B 269: 2407-2413.
69. Lockwood JL, Hoopes MF, Marchetti MP. 2007. Invasion Ecology. Blackwell Publishing: Oxford.
70. MacLeod G, Midtlyng A, Miossec PJ *et al*. 2008. Risk assessment protocols and decision making tools for use of alien species in aquaculture and stock enhancement. EU Co-ordination Action Project: IMPASSE Environmental impacts of alien species in aquaculture. Deliverable Report.
71. Marr SM, Ellender BR, Woodford DJ, Alexander ME, Wasserman RJ, Ivey P, et. Al. 2017. Evaluating invasion risk for freshwater fishes in South Africa. Bothalia 47(2).
72. McDowall RM 1990. New Zealand Freshwater Fishes: a natural history and guide. Auckland, Heinemann Reed.
73. McVicar AH. 2004. Management actions in relation to the controversy about salmon lice infections in fish farms as a hazard to wild salmonid populations. Aquaculture Research.
74. Midlen A, Redding T. 1998. Environmental Management for Aquaculture. Chapman & Hall, London.
75. Molony B. 2001. Environmental requirements and tolerances of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) with special references to South Australia: A Review. Fisheries Research Report Western Australia.
76. Moore SE, Larson gl, Ridley B. 1986. Population control of exotic rainbow trout in streams of a natural area park. Environmental Management Vol 10. Issue 2.
77. Nash CE, Burbridge PR, Volkman JK. 2005. Guidelines for the Ecological Risk Assessment of Marine Aquaculture. NOAA Technical Memorandum.
78. Novinger, D.C. & Rahel, F.J. 2003. Isolation management with artificial barriers as a conservation strategy for cutthroat trout in headwater streams. Conservation Biology 17: 1–11.
79. O'Sullivan AJ. 1992. Aquaculture and user conflicts. Aquaculture and the environment.
80. Picker MD, Griffiths CL. 2011. Alien and Invasive Animals - A South African Perspective. Randomhouse/Struik, Cape Town, South Africa.
81. Pillay TVR. 1992. Aquaculture and the environment. Fishing New Books, Oxford.
82. Rivers-Moore NA, Fowles B & Karssing RJ. 2013. Impacts of trout on aquatic macroinvertebrates in three Drakensberg rivers in KwaZulu-Natal, South Africa. African Journal of Aquatic Science, 38:1, 93-99.
83. Robins CR and Ray GC Ray. 1986. A field guide to Atlantic coast fishes of North America. Houghton Mifflin Company, Boston, MA.
84. Rowe DK. and Chisnall BL. 1995. Effects of oxygen, temperature and light gradients on the vertical distribution of Rainbow trout, *Oncorhynchus mykiss*, in two North Island, New Zealand, lakes differing in trophic status. New Zealand Journal of Marine and Freshwater Research.

85. Shelton JM, Samways MJ, Day JA. 2015. Biological Invasions 17(1): 365-379.
86. Shelton JM, Samways MJ, Day JA. 2014a. Non-native rainbow trout change the structure of benthic communities in headwater streams of the Cape Floristic Region, South Africa. Springer International Publishing Switzerland.
87. Shelton JM, Samways MJ, Day JA. 2014b. Predatory impact of non-native rainbow trout on endemic fish populations in headwater streams in the Cape Floristic Region of South Africa. Springer International Publishing Switzerland.
88. Shelton JM, Samways MJ, Day JA, Woodford DJ. 2016a. Are native cyprinids or introduced salmonids stronger regulators of benthic invertebrates in South African headwater streams? Austral Ecology (2016) 41, 633 - 643.
89. Shelton JM, Weyl OLF, Van der Walt J, Marr S, Impson D, Maciejewski K, Tye D, Dallas H, Esler K. 2016b. Effect of an intensive mechanical removal effort on a population of non-native rainbow trout *Oncorhynchus mykiss* in a South African headwater stream. Aquatic Conserv: Mar Freshw Ecosyst. 27: 1051 - 1055.
90. Shelton JM, Bird MS, Samways MJ, Day JA. 2017. Non-native rainbow trout (*Oncorhynchus mykiss*) occupy a different trophic niche to native Breede River redfin (*Pseudobarbus burchelli*) which they replace in South African headwater streams. Ecol. Freshw Fish. 26: 484 – 496.
91. Shelton JM, Weyl OLF, Chakona A, Ellender BR, Esler KJ, Impson ND, Jordaan MS, Marr SM, Ngobela T, Paxton BR, Van der Walt J, Dallas HF. 2017. Vulnerability of Cape Fold Ecoregion freshwater fishes to climate change and other human impacts. Aquatic Conserv: Mar Freshw. Ecosyst. 28:68 - 77.
92. Skelton P. 2001. A complete guide to the freshwater fishes of Southern Africa. Struik Publishers, Cape Town.
93. Smith MM, Heemstra PC. 2003 (eds). Smiths' Sea Fishes. Struik, Cape Town.
94. Stander H. 2009. Trout Farming in South Africa: Expanding Local Markets with Ecotourism. Global Aquaculture Advocate.
95. Swartz E. 2012. Summary of the mapping process for alien invasive fishes for NEM:BA. Prepared for the South African National Biodiversity Institute.
96. Vandeputte M, Storset A, Kause A & Henryon M. 2008. A review on breeding and reproduction of European aquaculture species: Rainbow trout (*Oncorhynchus mykiss*).
97. Vose D. 2008. Risk Analysis: A Quantitative Guide. 3rd ed. West Sussex, England: John Wiley & Sons.
98. Wise RM, Van Wilgen BW, Hill MP, Schulthess F, Tweedle D, Chabi-Olay A and Zimmerman HG. 2007. The economic impact and appropriate management of selected invasive alien species on the African continent. Final Report prepared for the Global Invasive Species Programme. CSIR Report.
99. Welcomme RL. 1988. International introductions of inland aquatic species. FAO Fisheries Technical Paper.
100. Woodford DJ & Impson ND. 2004. A preliminary assessment of the impact of alien rainbow trout (*Oncorhynchus mykiss*) on indigenous fishes of the Upper Berg River, Western Cape Province, South Africa. African Journal of Aquatic Science.

APPENDIX 1. Risk scoring methodology for Rainbow trout and guidance supplied by the F-ISK toolkit (Copp *et al.* 2008)

(For the following South African Ecoregions: Limpopo Plain; Soutpansberg; Lowveld; North Eastern Highlands; Northern Plateau; Waterberg; Western Bankenveld; Bushveld Basin; Lebombo Uplands; Natal Coastal Plain; North Eastern Uplands; North Eastern Coastal Belt; Western Coastal Belt; Nama Karoo; Namaqua Highlands; Orange River Gorge; Southern Kalahari; Ghaap Plateau; and Eastern Coastal Belt).

Question	Risk query: Biogeography/historical	Reply	Comments & References	Certainty
1	**Is the species highly domesticated or cultivated for commercial, angling or ornamental purposes?** *Guidance*: This taxon must have been grown deliberately and subjected to substantial human selection for at least 20 generations or is known to be easily reared in captivity (e.g. fish farms, aquaria or garden ponds).	Y	Cambray 2003; FAO 2012; ISSG 2012	4
2	**Has the species become naturalised where introduced?** *Guidance*: The taxon must be known to have successfully established self-sustaining populations in at least one habitat other than its usual habitat (e.g. lotic vs lentic) and persisted for at least 50 years (response modifies the effect of Q1).	Y	Picker & Griffiths 2011; Cambray 2003	4
3	**Does the species have invasive races/varieties/sub-species?** *Guidance*: This question emphasizes the invasiveness of domesticated, in particular ornamental, species (modifies the effect of Q1).	Y	ISSG 2012	4
4	**Is species reproductive tolerance suited to climates in the risk assessment area (1-low, 2-intermediate, 3-high)?** *Guidance*: Climate matching is based on an approved system such as GARP or Climatch. If not available, then assign the maximum score (2).	1	Kleynhans et al. 2005; FAO 2012; Molony 2001; Rowe & Chisnal 1995	4
5	**What is the quality of the climate match data (1-low; 2-intermediate; 3-high)?** *Guidance*: The quality is an estimate of how complete are the data used to generate the climate analysis. If not available, then the minimum score (0) should be assigned.	2	Kleynhans et al. 2005; FAO 2012	3
6	**Does the species have broad climate suitability (environmental versatility)?** *Guidance*: Output from climate matching can help answer this, combined with the known versatility of the taxon as regards climate region distribution. Otherwise the response should be based on natural occurrence in 3 or more distinct climate categories, as defined by Koppen or Walter (or based on knowledge of existing presence in areas of similar climate).	N	Molony 2001; FAO 2012	4
7	**Is the species native to, or naturalised in, regions with equable climates to the risk assessment area?**	N	FAO 2012	4

	Guidance: Output from climate matching will help answer this, but in absence of this, the known climate distribution (e.g. a tropical, semi-tropical, south temperate, north temperate) of the taxon's native range and the 'risk area' (country/region/area for which the FISK is being run) can be used as a surrogate means of estimating.			
8	**Does the species have a history of introductions outside its natural range?** *Guidance*: Should be relatively well documented, with evidence of translocation and introduction.	Y	Wellcome 1988	4
9	**Has the species naturalised (established viable populations) beyond its native range?** *Guidance*: If the native range is not well defined (i.e. uncertainty about it exists), or the current distribution of the organism is poorly documented, then the answer is "Don't know".	Y	Cambray 2003	4
10	**In the species' naturalised range, are there impacts to wild stocks of angling or commercial species?** *Guidance:* Where possible, this should be assessed using documented evidence of real impacts (i.e. decline of native species, disease introduction or transmission), not just circumstantial or opinion- based judgments.	Y	Campton & Utter 1985	3
11	**In the species' naturalised range, are there impacts to aquacultural, aquarium or ornamental species?** *Guidance*: Aquaculture incurs a cost from control of the species or productivity losses. This carries more weight than Q10. If the types of species is uncertain, then the yes response should be placed here for more major species, particularly if the distribution is widespread.	Y	Campton & Utter 1985	3
12	**In the species' naturalised range, are there impacts to rivers, lakes or amenity values?** *Guidance*: Documented evidence that the species has altered the structure or function of natural ecosystems.	Y	Eutrophication from farming	3
13	**Does the species have invasive congeners?** *Guidance*: One or more species within the genus are known to be serious pests.	Y	*Salmo trutta, Salmo salar* (ISSG 2012)	4
14	**Is the species poisonous, or poses other risks to human health?** *Guidance*: Applicable if the taxon's presence is known, for any reason, to cause discomfort or pain to animals.	N	Jonsson 2006	4
15	**Does the species out-compete with native species?** *Guidance:* Known to suppress the growth of native species, or displace from the microhabitat, of native species.	Y	Cambray 2003; Skelton 1987	4
16	**Is the species parasitic of other species?**	N	No record of this	3

	Guidance: Needs at least some documentation of being a parasite of other species (e.g. scale or fin nipping such as known for topmouth gudgeon, blood- sucking such as some lampreys).			
17	**Is the species unpalatable to, or lacking, natural predators?** *Guidance*: This should be considered with respect to where the taxon is likely to be present and with respect to the likely level of ambient natural or human predation, if any.	N	No reference	4
18	**Does species prey on a native species (e.g. previously subjected to low (or no) predation)?** *Guidance*: There should be some evidence that the taxon is likely to establish in a hydrosystem that is normally devoid of predatory fish (e.g. amphibian ponds) or in river catchments in which predatory fish have never been present.	Y	Cambray 2003; Skelton 1987	4
19	**Does the species host, and/or is it a vector, for recognised pests and pathogens, especially non-native?** *Guidance*: The main concerns are non-native pathogens and parasites, with the host being the original introduction vector of the disease or as a host of the disease brought in by another taxon.	Y	FAO 2012	4
20	**Does the species achieve a large ultimate body size (i.e. > 10 cm FL) (more likely to be abandoned)?** *Guidance*: Although small-bodied fish may be abandoned, large-bodied fish are the major concern, as they soon outgrow their aquarium or garden pond.	Y	Skelton 2001	4
21	**Does the species have a wide salinity tolerance or is euryhaline at some stage of its life cycle?** Guidance: Presence in low salinity water bodies (e.g. Baltic Sea) does not constitute euryhaline, so minimum salinity level should be about 15%.	Y	FAO 2012	4
22	**Is the species desiccation tolerant at some stage of its life cycle?** *Guidance*: Should be able to withstand being out of water for extended periods (e.g. minimum of one or more hours).	N	No air-breathing organ	3
23	**Is the species tolerant of a range of water velocity conditions (e.g. versatile in habitat use)?** *Guidance*: Species that are known to persist in a wide variety of habitats, including areas of standing and flowing waters (over a wide range of velocities: 0 to 0.7 m per sec).	N	Prefers fast flowing water (Picker & Griffiths 2011)	4
24	**Does feeding or other behaviours of the species reduce habitat quality for native species?** *Guidance*: There should be evidence that the foraging results in an increase in suspended solids, reducing water clarity (e.g. as demonstrated for common carp).	?	No record of this	2

25	**Does the species require minimum population size to maintain a viable population?** *Guidance*: If evidence of a population crash or extirpation due to low numbers (e.g. overexploitation, pollution, etc.), then response should be 'yes'.	Y	Need certain number to prevent inbreeding (no reference)	3
26	**Is the species a piscivorous or voracious predator (e.g. of native species not adapted to a top predator)?** *Guidance*: Obligate piscivores are most likely to score here, but some facultative species may become voracious when confronted with naïve prey.	Y	Picker & Griffiths 2011	4
27	**Is the species omnivorous?** *Guidance*: Evidence exists of foraging on a wide range of prey items, including incidental piscivory.	Y	Skelton 2001	4
28	**Is the species planktivorous?** *Guidance*: Should be an obligate planktivore to score here.	Y	Doergeloh 1994	4
29	**Is the species benthivorous?** *Guidance*: Should be an obligate benthivore to score here.	Y	Molineri 2008	4
30	**Does it exhibit parental care and/or is it known to reduce age-at-maturity in response to environment?** *Guidance*: Needs at least some documentation of expressing parental care.	N	Skelton 2001	3
31	**Does the species produce viable gametes?** *Guidance*: If the taxon is a sub-species, then it must be indisputably sterile.	Y	FAO 2012	4
32	**Does the species hybridize naturally with native species (or uses males of native species to activate eggs)?** *Guidance:* Documented evidence exists of interspecific hybrids occurring, without assistance under natural conditions.	N	No native congeners in S. Africa	4
33	**Is the species hermaphroditic?** *Guidance:* Needs at least some documentation of hermaphroditism.	N	FAO 2012	4
34	**Is the species dependent on presence of another species (or specific habitat features) to complete its life cycle?** Guidance: Some species may require specialist incubators (e.g. unionid mussels used by bitterling) or specific habitat features (e.g. fast flowing water, particular species of plant or types of substrata) in order to reproduce successfully.	N	FAO 2012	4
35	**Is the species highly fecund (>10,000 eggs/kg), iteropatric or have an extended spawning season?** Guidance: Normally observed in medium-to-longer lived species.	N	FAO 2012	4
36	**What is the species' known minimum generation time (in years)?** *Guidance*: Time from hatching to full maturity (i.e. active reproduction, not just presence of gonads). Please specify the number of years.	1	For males (Skelton 2001)	4
37	**Are life stages likely to be dispersed unintentionally?**	Y	No reference	3

	Guidance: Unintentional dispersal resulting from human activity.			
38	**Are life stages likely to be dispersed intentionally by humans (and suitable habitats abundant nearby)?** *Guidance*: the taxon has properties that make it attractive or desirable (e.g. as an angling amenity, for ornament or unusual appearance).	Y	Cambray 2003	3
39	**Are life stages likely to be dispersed as a contaminant of commodities?** *Guidance*: Taxon is associated with organisms likely to be sold commercially.	?	Depends on management practices	2
40	**Does natural dispersal occur as a function of egg dispersal?** *Guidance*: There should be documented evidence that eggs are taken by water currents or displaced by other organisms either intentionally or not.	N	Winckler-Sosinski et al. 2005	3
41	**Does natural dispersal occur as a function of dispersal of larvae (along linear and/or 'stepping stone' habitats)?** *Guidance*: There should be documented evidence that larvae enter, or are taken by, water currents, or can move between water bodies via connections.	N	Winckler-Sosinski et al. 2005	3
42	**Are juveniles or adults of the species known to migrate (spawning, smolting, feeding)?** *Guidance*: There should be documented evidence of migratory behaviour, even at a small scale (tens or hundreds of meters).	Y	Froese & Pauly 2011	4
43	**Are eggs of the species known to be dispersed by other animals (externally)?** *Guidance*: For example, are they moved by birds accidentally when the water fowl move from one water body to another?	N	Could happen but unlikely	3
44	**Is dispersal of the species density dependent?** *Guidance*: There should be documented evidence of the taxon spreading out or dispersing when its population density increases.	?	No record of this	2
45	**Any life stages likely to survive out of water transport?** *Guidance:* There should be documented evidence of the taxon being able to survive for an extended period (e.g. an hour or more) out of water. *(Note that this is similar to question 22. this is an error with the FISK toolkit and the creators will be alerted. for the purposes of this study, the answer has been repeated*).	N	No record of this	3
46	**Does the species tolerate a wide range of water quality conditions, especially oxygen depletion & high temperature?** *Guidance:* This is to identify taxa that can persist in cases of low oxygen and elevated levels of naturally occurring chemicals (e.g. ammonia).	N	Rowe & Chisnall 1995	4
47	**Is the species susceptible to piscicides?** *Guidance*: There should be documented evidence of susceptibility of the taxon to chemical control agents.	Y	Moore et al. 2008	4

48	**Does the species tolerate or benefit from environmental disturbance?** *Guidance:* The growth and spread of some taxa may be enhanced by disruptions or unusual events (floods, spates, dessication), especially human impacts.	N	FAO 2012	4
49	**Are there effective natural enemies of the species present in the risk assessment area?** *Guidance:* A known effective natural enemy of the taxon may or may not be present in the Risk Assessment area. The answer is 'Don't know' unless a specific enemy/enemies is known.	?	No record of this	2