Assessing the risk of Tilapia from proposed aquaculture ponds establishing and becoming invasive in coastal marine ecosystems at Port Resolution (Tanna Island), Vanuatu

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Coasts | Climate | Oceans

Report to the Secretariat of the Pacific Regional Environment Programme (SPREP) under the Pacific Ecosystem-based Adaptation to Climate Change (PEBACC) project

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1. Executive summary

The Secretariat of the Pacific Regional Environment Programme (SPREP) is implementing the Pacific Ecosystem-based Adaptation to Climate Change (PEBACC) project. The PEBACC project promotes the use of an Ecosystem-based Adaptation (EbA) approach to reducing vulnerability and building resilience in the face of climate change and associated impacts, and in Vanuatu has sites in Port Vila and on Tanna Island. In Tanna the project is facilitating the establishment of a community-based Marine Community Conservation Area (CCA) in Port Resolution which includes support for associated livelihood activities required to ensure sustainability. The initiative to conserve and place tabu's in the regular coastal fishing grounds will reduce the options available to the communities of Port Resolution, who have historically relied much on coastal fisheries for protein. The Port Resolution CCA committee, as representatives of the local communities, has identified four livelihood projects to assist them in the sustainable management of their marine CCA. One of these projects is Tilapia fish farming.

However, Tilapia species are considered to be an invasive species in many parts of the world and therefore, an environmental safeguards assessment is required to assess the risk of Tilapia escaping into coastal waters and posing a threat to coastal marine ecosystems. The Mozambique Tilapia, *Oreochromis mossambicus*, has existed in Lake Eweya in Port Resolution for approximately 50 years and is one of the least preferred Tilapia species for aquaculture due to their relatively slow growth rates. The species proposed to be introduced for aquaculture in the region is the Nile Tilapia, *Oreochromis niloticus* (GIFT strain), a genetically modified strain that has very fast growth rates.

To assess the threat that this introduction may present to the Port Resolution coastal marine ecosystems I conducted a standard risk assessment approach. Some of the key considerations in determining the risk factors for this assessment were: the high capacity for both species to outcompete native species; the moderate tendency for each species to alter habitats; the high salinity tolerance of *O. mossambicus*; the low salinity tolerance of *O. niloticus* (GIFT); the current impacted state of Lake Eweya and its ecological importance; the potential introduction of new diseases or pathogens; and, the high likelihood that the two Tilapia species will hybridise with the potential to confer greater fitness of these hybrids. Implicit to the assessment was the assumption that the likelihood of introduced Nile Tilapia translocating to the wild was high. Further, the interpretation for this assessment is that the "threat" is based on *whether Tilapia will maintain a presence in coastal marine environments AND that they will adversely impact ecosystem processes and components*. The marine area assessed under the risk assessment is Resolution Bay since it is assumed to have the highest local risk of Tilapia establishment due to its direct connectivity with Lake Eweya and suitable environmental conditions.

Therefore, the key risk factors assessed were:

- the chances that fish translocate (HIGH),
- the extent translocated fish will compete with wild fish for prey, space, and mates or predate on them (ecological impacts),
- the extent translocated fish will affect habitats,
- the likelihood that translocated fish will establish a self-sustaining population,
- the likelihood of transmission of infections/disease/pathogens,
- the potential impact of *O. niloticus* (GIFT) forming hybrids with *O. mossambicus*.

Risk was assessed for: 1. the species already present in Lake Eweya (*O. mossambicus*), 2. for the GIFT strain of *O. niloticus* which may be introduced for aquaculture, and 3. for a potential hybrid of the two species. Further, these risk factors are assessed separately for Resolution Bay and Lake

Eweya. The assessment also examines the risk that fish will impact on the coastal marine ecosystem even though they may not establish self-sustaining populations there.

Overall, the level of risk that *O. mossambicus* would be a threat to coastal marine areas was medium-high; the level of risk for *O. niloticus* was generally moderate-low, although there were two high risks identified; and the level of risk for the hybrid between the two species was generally high. This is due primarily to the combination of the two species having the potential to have a high salinity tolerance, high growth rates and a greater ability reach a large size. This means a hybrid may have the capacity dominate the lake environment and present a higher risk to either establishing itself in marine waters or at least moving into Resolution Bay and having an impact.

Based on the outcomes of this assessment several key recommendations are provided. The key recommendation is <u>not</u> to introduce the Nile Tilapia to Port Resolution for aquaculture. Other recommendations include: explore the introduction of small-scale aquaculture trials using the species already in existence at Port Resolution, the Mozambique Tilapia, potentially using grow out cages in Lake Eweya to maximise growth rates; continue to harvest the current stock of Mozambique Tilapia in Lake Eweya; consider an assessment of this stock, their impact on the lake, and the establishment of a simple community harvest strategy; for the local community to monitor for the presence of Tilapia in coastal marine waters, especially in Resolution Bay, and for signs of disease or pathogens in local Tilapia and/or other species; for appropriate education and awareness with local communities to be conducted about the outcomes of this assessment and relevant actions, in particular education and awareness about the GIFT strain and its potential impacts on the local ecosystems; and, for this report be shared with relevant staff of the Vanuatu Fisheries Department and the Vanuatu Department of Environmental Protection and Conservation.

2. Introduction

Background

The Secretariat of the Pacific Regional Environment Programme (SPREP) is implementing the Pacific Ecosystem-based Adaptation to Climate Change (PEBACC) project. PEBACC is a sub-regional project designed to explore and promote the uptake of ecosystem-based management approaches in planning for climate change adaptation in the Pacific Island Region. The 5-year project forms part of the International Climate Initiative (IKI) supported by the German Federal Ministry of Environment. It is implemented by SPREP in collaboration with the Governments of Fiji, Vanuatu and Solomon Islands and in partnership with a number of conservation and community development NGOs. In Vanuatu, the project operates in Port Vila and in Tanna.

The Pacific Islands Region is extremely vulnerable to the impacts of global warming, sea level rise and climate change. Recognising that healthy ecosystems contribute positively to the resilience of pacific island communities, societies and biodiversity, the PEBACC project promotes the use of an Ecosystem-based Adaptation (EbA) approach to reducing vulnerability and building resilience in the face of climate change and associated impacts. It is further recognized that the drivers of ecosystem degradation are often non-climate change related; often being related to unsustainable human activities. Therefore, restoring ecosystem health requires an understanding of how human activities are impacting on ecosystems and ensuring that interventions are targeted at addressing the root causes while at the same time investing in restoration activities.

The project began in 2014 and is due for completion in July 2020. It is structured over four phases with phase one having been the implementation of an ecosystem and socio-economic resilience analysis and mapping (ESRAM) for the city of Port Vila and for Tanna island as a basis for identifying climate change threats and EbA adaptation options to address them. Phase two involved the formulation of EbA options assessment reports and EbA implementation plans for selected EbA demonstration projects. The project is currently in phase three – Implementation of EbA demonstration projects. Phase four which will commence in 2020 involves compilation and dissemination of lessons learned.

On Tanna Island the project is facilitating the establishment of a community-based Marine Community Conservation Area (CCA) in Port Resolution which includes support for associated livelihood activities required to ensure sustainability. The initiative to conserve and place tabu's in the regular coastal fishing grounds will reduce the options available to the communities of Port Resolution, who have historically relied much on coastal fisheries for protein. The Port Resolution CCA committee, as representatives of the communities, has identified four livelihood projects to assist them in the sustainable management of their marine CCA. One of these projects is Tilapia fish farming.

Relevant government technicians have been contacted and are ready to assist with the establishment of ponds as well as conducting the specific trainings in the identified communities. However, specific for the tilapia fish farming, an environmental safeguards assessment is required to assess the risk of Tilapia escaping into coastal waters and posing a threat to coastal marine ecosystems. This is important because haphazard or untested introductions of exotic species to new habitats can produce devastating consequences to local ecosystems (Lobel, 1980). The Tilapia strain that would be introduced for household farming will be the one currently promoted by the Vanuatu Fisheries Department, which is the Nile Tilapia, *Oreochromis niloticus* (as opposed to the Mozambique Tilapia, *Oreochromis mossambicus,* which currently exists in the Port Resolution lake and elsewhere in Vanuatu).

Therefore, the objectives of this report are to:

1. Assess the risk of proposed Tilapia fish cultivation at Port Resolution on Tanna Island resulting in Tilapia escaping from confined ponds and posing a threat to the coastal marine ecosystem, and
2. Provide options for ameliorating any risks identified.

3. Analysis of Risk

Approach

I used a standard risk assessment approach to assess the risk that escaped Tilapia would be a threat to the coastal marine ecosystem of Port Resolution. A risk assessment is used to determine the likelihood that an undesired event will occur and the consequences of such an event so that we can make informed decisions about ways to best avoid them (Arthur et al., 2009).

There are four main steps involved in a risk assessment:

i) Establishing the context – this is about identifying what can occur and therefore, what are the risks.
ii) Determining the likelihood of the risk occurring and the magnitude of its consequences (i.e. impacts).
iii) Assessing and ranking each risk by evaluating the interaction of likelihood and consequence.

iv) Managing the risks by identifying potential mitigation strategies and recommendations to minimise or avoid the adverse impacts from occurring.

There are also several types of risk analysis approaches that can be undertaken ranging from qualitative to quantitative, generally dictated by the extent and quality of available data, the time available for the assessment and by the intended audience (Fletcher et al., 2004). For the purposes of this report, a semi-quantitative approach was conducted given that the assessment is to inform non-specialist stakeholders, the rapid nature of this assessment and the uncertainty in some of the knowledge that informs the assessment.

Analysis scope and risk components

The scope of the current risk assessment is pre-determined in that it is confined to the area of Port Resolution on Tanna Island. Also, there are two adverse impact components under question: i) escapement and ii) Tilapia posing a threat to coastal marine areas. For Tilapia to be a threat to local coastal marine ecosystems, they must first escape, or more accurately, translocate from domestic farm ponds. I use the preferred term of translocation throughout this report as it is a more accurate descriptor since fish can move from ponds to the wild by non-intentional ways (e.g. escaping or transference) or intentional ways (e.g. direct release into the wild by humans). Assessing the likelihood of translocation is limited since the introduction of farms to the area has not yet occurred and the extent of the training provided is unclear (e.g. education about the risks associated with releasing Tilapia into the wild). Therefore, the determination of the likelihood of translocation is limited to drawing on experiences from similar situations elsewhere. Further, the determination of the *consequences* of translocation is dependent on the 2nd adverse impact under question: the risk of Tilapia posing a threat to the coastal marine ecosystem. On this basis, this report evaluates the likelihood of translocation using documented examples, and assesses the risk of Tilapia populations posing a threat to the coastal marine ecosystem should they translocate using a formal risk assessment framework.

When assessing the risk of translocated Tilapia posing a threat to the coastal marine ecosystem of Port Resolution, the interpretation for this assessment is that the "threat" is based on *whether Tilapia will maintain a presence in coastal marine environments AND that they will adversely impact ecosystem processes and components* (e.g. predation, competition or habitat modification). Further, the marine area assessed under the risk assessment is Resolution Bay since it is assumed to have the highest local risk of Tilapia establishment due to: direct accessibility from/to Lake Eweya, calm conditions more suited to Tilapia, and habitat more suited to Tilapia.

Finally, the temporal scale for this assessment is for a 15-year time horizon. This is based on existing knowledge from a study that demonstrated consistent generational increases in harvest weight in the GIFT strain of *O. niloticus* that occurred over 10 generations (Hamzah et al., 2014). Further, the study authors concluded that there still exists abundant genetic variation which provides scope for further enhancement in performance of this genetic strain.

Risk context

Determining the risk context involves identifying the key risk factors that influence whether Tilapia would survive and/or thrive in marine environments of Port Resolution, and the factors that affect their likelihood and consequences. This section therefore provides a summary of knowledge about relevant Tilapia species and of the local environmental characteristics that influence Tilapia survival. This information also helps to inform the identification of the key risk factors to be assessed.

Translocation

As mentioned above, the overall threat from translocation of Tilapia from aquaculture ponds is dependent on the risk of them surviving and becoming established in adjacent natural ecosystems; that is, the consequence of translocation. This will be determined in the risk analysis below. Even though Tilapia has not been introduced to Port Resolution, it is worth drawing on experiences from similar areas where Tilapia farming has been introduced to infer the likelihood that they may translocate.

Translocation of fish from ponds to the natural ecosystem can occur in a number of ways generally influenced by human intervention. For fish to become established in the marine environment, they may be translocated directly to marine coastal waters, or indirectly into adjacent waterways which connect to the sea, such as rivers, lakes and swamps. Some of the ways this can occur include:

1. Accidental – accidental escape from the ponds, e.g. from overflow of ponds during flooding.
2. Deliberate release – where an animal is transferred into the wild on purpose.
3. Transference – whereby fertilised eggs and/or early juveniles are accidentally transferred into natural water bodies, e.g. water transfer or disposal of the carcass of a brooding female.

In Mississippi, Tilapia populations have been observed in coastal canals following accidental releases by farmers evaluating Tilapia (Nugon, 2003). Tilapia have been intentionally stocked into lakes, reservoirs, and rivers of Texas, Alabama and Florida as prey for game fish or as sportfish and have persisted where temperature allows (Hargreaves, 2000). In Florida released Tilapia have become so prevalent the state has established the first capture fishery for Tilapia in the United States (Costa-Pierce and Riedel, 2000). Tilapia are currently found in at least eighteen counties in Florida and have become established in many of the environments (e.g. lakes, rivers, canals) they have had access to (Courtenay et al., 1984), becoming the most common exotic fish encountered in Florida (Costa-Pierce and Riedel, 2000).

In earthen ponds in Fiji, juvenile Nile Tilapia were able to escape during flooding events into nearby water ways (Nandlal and Foscarini, 1990). In Australia, Tilapia are found in numerous waterways of tropical and sub-tropical Queensland and Western Australia after first arriving as an ornamental fish for the aquarium trade and being deliberately released into the wild, sometimes for sport fishing opportunities (Russell et al, 2010).

In Vanuatu, the introduction of Nile Tilapia (GIFT) to communities for small-scale domestic farming, and associated training has been conducted in approximately 200 locations (includes prawn farming. This training is based on the SPC manual specific to Tilapia farming in the Pacific (Nandlal and Pickering, 2004). Although the manual does not include a section on education and awareness about the risks Tilapia may present to natural ecosystems if allowed to be released into the wild, some basic training in Vanuatu is provided. Since the establishment of these farms no monitoring has been conducted to assess if fish find their way into natural local waterways. However, there is at least one reported incidence of Nile Tilapia being found in natural waterways near a farm (Rocky Kaku, Vanuatu Fisheries Department, pers. comm.; 04/06/2020).

Globally, wherever Tilapia have been introduced they have ended up in the local natural waterways. In fact, the CABI Invasive Species Compendium describes the translocation of tilapia to the wild when introduced to new aquaculture ventures as "inevitable" and that the likelihood of them being intentionally and/or illegally moved from areas where they have been introduced is high (https://www.cabi.org/isc/datasheet/72086).

Tilapia biology and ecology

Tilapia tolerate a broad range of habitat types, from full freshwater to hypersaline conditions. In Australia they have been recorded in diverse habitats including waterholes in ephemeral rivers, reservoirs, lakes, ponds, farm dams, rivers, creeks, drains, swamps, salt lakes and tidal areas. There are few habitats that they will not inhabit. Tilapia also have broad dietary tolerances and are extremely adaptable; thus, there is potential for them to compete with native species where their diets and habitats overlap. Although primarily feeding on detritus, algae, macrophytes and other organic matter, Tilapia have been known to shift their diet to invertebrates and other fish according to food availability. They can range from complete herbivory, to omnivory and total carnivory, even reverting to cannibalism as well as preying on native fish eggs and larvae (Greiner and Gregg, 2008).

Therefore, there are numerous potential impacts from the introduction of Tilapia to new areas including:

- impacts on native fish and other biota,
- reduction in water quality, including potable water supplies, through:
    - increase of blue-green algal blooms (through resuspension of sediments and nutrients), and
    - undermining river banks due to destruction of river plants and nesting behaviour.

Currently there are two species of Tilapia known to be present in Vanuatu. The introduction of the Mozambique Tilapia to Pacific Island countries is documented to have first occurred during the 1950's. The same report documented the introduction of Tilapia during a similar period to Lake Siwi, adjacent to Mt Yasur on Tanna Island and not far from Port Resolution (Devambez, 1964). While they did not report the species, it is highly likely to be *O. mossambicus* given its introduction to neighbouring countries during the same period, and the presence today of what is believed to be Mozambique Tilapia in nearby Lake Eweya. This was reported to be introduced to the lake as early as the 1960's (Werry Narua, pers. comm.). Today they are very common in Lake Eweya and their population size is reported to vary markedly depending on saltwater ingress and when the lake is seasonally closed to the sea it is reported that tilapia populations "explode". They are harvested regularly, along with everything else that lives in the lake, and their status and impacts have not been assessed (Welch et al., 2019).

The second species is the GIFT strain of the Nile Tilapia, *O. niloticus*. This strain has been introduced to Vanuatu as part of the national government aquaculture program with training in the construction of ponds, fish husbandry and the supply of fish being carried out in communities at various locations by the Vanuatu Fisheries Department. This is the species that is under consideration for introduction to Port Resolution for domestic farming.

Nile Tilapia (GIFT)

The Nile Tilapia, *Oreochromis niloticus*, is native to Africa and the south-western Middle East with a tropical/sub-tropical range. During a project that spanned from 1988 to 1997, Worldfish, along with a number of partner organisations, used selective breeding techniques to develop a faster growing strain of the Nile Tilapia. This strain is known as the GIFT strain (Genetically Improved Farmed Tilapia) and grew up to 85% faster than the fish used at the beginning of the breeding program (Ponzoni et al., 2011). Since then, research has proven that, under the right conditions, this strain is capable of continuing to improve its growth rates over many generations (Hamzah et al., 2014). It is now used extensively in aquaculture ventures across the world, particularly in Asia.

Characteristics

Habitat preference - Their preferred habitat is shallow well-vegetated waters that are generally still with little flow. They prefer brackish water but will live in freshwater, although their growth is slower. They can tolerate high turbidity, allowing it to live in silty lagoons or degraded waterways often found in association with urban areas (Arthington & Milton, 1986). Ultimately, they have a preference for estuaries and brackish inshore waters that contain vegetative littoral habitats with low water current (Lobel, 1980; Costa-Pierce and Riedel, 2000; Hargreaves, 2000).

Temperature tolerance - The optimal temperature range of Nile tilapia for growth is 27–31 °C at which growth can be up to 3x faster than at 22 °C (Popma and Masser, 1999). The species can, however, survive at temperatures between 15 and 42 °C and mortality occurs at temperatures below about 11 °C (Popma and Masser, 1999). However, salinity appears to influence survival at temperature extremes with optimum survival in brackish water (El-Sayed, 2006). In temperatures above 22 °C they are capable of continuous growth and year-round reproduction (Xia, 2018).

Salinity tolerance – A critical consideration for the purpose of the current assessment is the salinity tolerance of the two Tilapia species concerned. Salinity is a measure of the amount of salt in the water. This is measured as the number of grams of salts per kilogram of water and is expressed as parts per thousand (ppt). As a general guide to assist the reader, freshwater is generally regarded as being 0 ppt and average seawater is ~35 ppt (Figure 1).

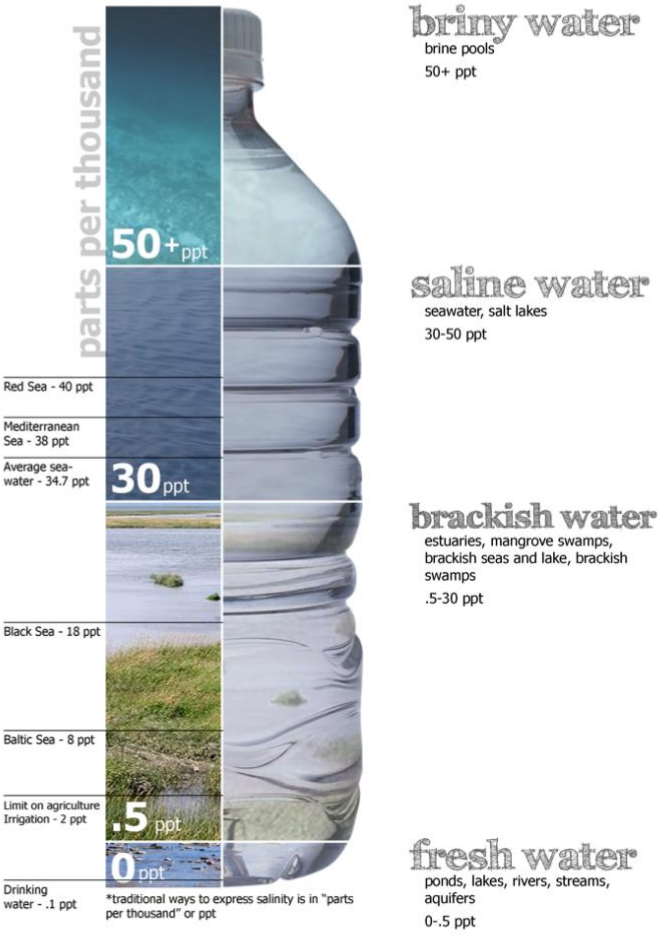

Figure 1. Explanatory diagram showing approximate salinity levels of different types of water bodies. Source: Wikipedia.

Nile Tilapia are the least saline tolerant of the commercially important Tilapia species. Early studies in Hawaii found Nile tilapia at 20 ppt were able to grow and reproduce (Brock and Takata, 1955). These findings were confirmed by Al Asgah (1984) reporting reproduction in salinities up to 20 ppt and survival at 20-25 ppt (Watanabe et al., 1985). Reproduction is reported to stop completely at salinities above 30 ppt (El-Sayed, 2006). However, juveniles have a lower tolerance to high salinity water. Nugon (2003) used an experimental study and found juvenile *O. niloticus* to have 100 % survival at up to 10 ppt salinity water, however at 20 ppt this dropped to 81 % survival and 0 % survival at 35 ppt (seawater) salinity. Another experimental study found that early juveniles reared in salinities up to 7 ppt had 100 % survival while at 9 and 10 ppt there was 0 % survival (Lawson and Anetekhai, 2010). Others report a lower tolerance with harmful effects at >10 ppt for adults and at >5 ppt for eggs and early life history stages (https://www.cabi.org/isc/datasheet/72086). While there are differences in these studies, which may be due to different temperature regimes which alter salinity tolerances, they suggest that *O. niloticus* are not capable of surviving in a marine environment where salinities of 35 ppt are expected (Figure 1).

pH tolerance - They are reported to tolerate a pH range of 5-10 for all life history stages (https://www.cabi.org/isc/datasheet/72086).

Growth and longevity - The maximum published size is 60 cm SL and a weight of 4.3 kg, and individuals can live for up to 9 years (www.fishBase.se). The GIFT strain of *O. niloticus* has shown enhanced growth characteristics compared to the original pure strain, and it has been demonstrated that these gains have the potential to increase by as much as 10 % or more per generation, giving the GIFT strain an enormous capacity to further increase productivity (Hamzah et al., 2014). Growth is faster in brackish water compared to fresh water.

Maturity - Age at sexual maturity for Nile Tilapia is highly variable and depends on environmental conditions (e.g. temperature) and density-dependent factors. They can reach sexual maturity anywhere from as young as 3 months and at around 100 grams in size, up to 12 months and 500 grams in size (Popma and Masser, 1999; Xia, 2018).

Reproduction - Nile tilapia are maternal mouthbrooders. The female lays eggs in a depression in the substrate prepared by the male, the male fertilizes the eggs and then the female picks the eggs up in her mouth where she incubates them. Even after eggs hatch, fry will remain in the mother's mouth, and once free-swimming they will return to her mouth for protection. Females can produce several hundred to several thousand young per spawn (https://www.cabi.org/isc/datasheet/72086). Optimum spawning temperatures are reported to be between 25 and 33 °C (https://www.cabi.org/isc/datasheet/72086) and at temperatures above 22 °C they can spawn all year round every 4-6 weeks (Nandlal and Pickering, 2004).

Diet - Nile Tilapia are omnivores and will eat algae, plant matter, plankton, organic particles, detritus, small invertebrates and sometimes fish, especially fish larvae (Popma and Masser, 1999).

Behaviour - They are usually solitary, but may form schools (www.fishBase.se). Males require large territories and defend them against each intruder with aggressive behaviour (Sterba, 1966).

Mozambique Tilapia

The Mozambique Tilapia, *Oreochromis mossambicus*, is native to Africa with a tropical range between approximately 13 °S and 35 °S. They are now widely established in tropical and sub-tropical areas across the world having been introduced for various reasons including aquaculture, insect control and sports fishing.

Characteristics

Habitat preference - Their preferred habitat is essentially the same as for *O. niloticus* preferring shallow, generally well-vegetated and calm or slow-moving waters that are brackish. They will live in freshwater however their growth is slower. They can also tolerate high turbidity and a wide range of conditions allowing them to live in silty lagoons or degraded waterways (Arthington & Milton, 1986).

Temperature tolerance - The optimal temperature range of Mozambique tilapia for growth and reproduction is 22–30°C. The species can, however, survive at temperatures between 16 and 39°C. However, salinity appears to influence survival at temperature extremes with optimum survival in brackish water (El-Sayed, 2006).

Salinity tolerance - *O. mossambicus* is regarded as one of the most salt tolerant Tilapia species. One study found they could survive in seawater (35 ppt; Lobel, 1980), and another early study cited that the salinity range they can tolerate is from 0-120 ppt (Allanson et al., 1971). In Western Australia fish have been found living in small isolated pools with salinities of 95 ppt (Morgan et al., 2004). Studies have also shown that they can grow normally and reproduce at water salinity of up to 49 ppt, and their fry are capable of surviving at up to 69 ppt (Popper and Lichatowich, 1975; Whitefield and Blaber, 1979). Other studies suggest 36 ppt as an upper limit for *O. mossambicus* to grow and reproduce, however noting that their optimum is closer to 19 ppt (Mjoun et al., 2010). Despite the variability among studies, it is clear that *O. mossambicus* is capable of living and potentially successfully breeding in salinities found in coastal marine waters. However, Hargreaves (2000) noted that there is little evidence available to suggest that they have become established in these environments even when introduced to an isolated oceanic atoll in the central Pacific Ocean where they preferentially reside in the shallow brackish water areas (Lobel, 1980).

pH tolerance - They are reported to tolerate a pH range of 4-11 (Arthington, 1986).

Growth and longevity - The maximum published size is 39 cm SL or 1.13 kg, and individuals can live for up to 11 years (www.fishBase.se), while other reports suggest they live as long as 13 years, up to 46 cm and 2 kg (Russell et al., 2010). Growth is faster in brackish water compared to fresh water.

Maturity - *O. mossambicus* demonstrate plasticity in their life history depending on environmental conditions. For example, in stable environments males and females have been found to reach sexual maturity at around three years of age at an average length of 38 cm. In disturbed environments they are capable of reaching sexual maturity as young as one year of age at lengths as small as 7–10 cm (Australian Centre Tropical Freshwater Research, 2007). Others report maturity can be attained as young as 2-3 months old and as small as only 7 cm (Popma and Masser, 1999; Russell et al., 2010). Under similar conditions, *O. mossambicus* tend to reach maturity at smaller sizes and younger ages than *O. niloticus* (Popma and Masser, 1999).

Reproduction - Males excavate a shallow, basin-shaped depression in the substrate where eggs are laid and are fertilised by males. The eggs are then picked up by the female and fry hatch in her mouth after 3-5 days. Fry are protected (in the mouth of females) for around three weeks (Clarke et al., 2000). Males often mate with several females over a short period of time (Arthington & Cadwallader, 1996). Water temperatures above 23°C are required to induce spawning (Clarke et al., 2000). New broods can be produced every 4-6 weeks (Arthington & Milton, 1986). Different studies estimate that females can produce between approximately 400 and 600 eggs per 100 g for each spawning (Arthington, 1986; Arthington and Milton, 1986). Females aggressively defend their young and therefore early life history survival is very high.

Diet - Mozambique tilapia are opportunistic omnivores and will eat algae, plant matter, organic particles, small invertebrates and fish (Australian Centre Tropical Freshwater Research, 2007).

Behaviour - They are usually solitary, but may form schools (www.fishBase.se). Males require large territories and defend them against each intruder with aggressive behaviour (Sterba, 1966). They are also reported to have the ability to bury themselves in the moist upper layers of sediment in sandy streams (up to 3 m deep) as a drought survival mechanism (Arthington & Blühdorn, 1995; Clarke et al., 2000)

Hybridisation in Tilapia

O. niloticus and *O. mossambicus* are both known to readily hybridise with many other *Oreochromis* species (www.fishbase.se), including each other (Pickering, 2009). Both species are very similar in their biology and ecology, each capable of outcompeting native species by their tolerance for a range of conditions, especially modified waterways. There are two key differences among them however:

- *O. mossambicus* has a much higher salinity tolerance and it feasible that they may be able to establish themselves in a marine environment. The opposite is observed for *O. niloticus*, which has one of the lowest salinity tolerances of all Tilapia species.
- *O. niloticus* (GIFT) has a much higher growth rate and grows to a much larger size than *O. mossambicus*.

During the 1970s and 80s both species were introduced into Sri Lankan reservoirs and there is evidence that the two species hybridised resulting in an imbalance in sex ratios. They postulated that despite early increases in yield because hybrids grow faster, recruitment over time might be reduced because hybrids are less fecund (Amarasinghe and de Silva, 1996). In an experimental study lasting 392 days, researchers found that *O. mossambicus* and *O. niloticus* hybrids had higher survival, higher yield and higher growth rates than pure strains of each species (Siddiqui and Al-Harbi, 1995). Another experimental study found that *O. niloticus* x *O. mossambicus* hybrids had an optimum of 15 ppt salinity and "failed to adapt" at 35 ppt (El-Sayed, 2006). Despite this, other studies suggest that with gradual acclimation hybrids have the capacity to tolerate higher salinities. In similar circumstances to Port Resolution, both *O. mossambicus* and *O. niloticus* have been introduced to Lake Satoalepai in Samoa. The small lake opens to the sea and is adjacent to two local villages who regularly harvest the Tilapia. The project found evidence that both species had maintained their populations in the lake over many years, and that there was also evidence that the two species had hybridised. The relative success and impacts of each species and/or the hybrid were not investigated under the project, and environmental conditions in the lake were not reported to inform the current assessment (Nandlal et al., 2007).

These studies have shown positive impacts in terms of salinity tolerance and growth with the use of the *O. mossambicus* x *O. niloticus* hybrids (de Verdal et al., 2014). El-Sayed (2006) generalised that Tilapia hybrids descended from salt-tolerant parents are highly salt-tolerant. Wan-qi et al. (2004) also found evidence that Tilapia hybrids are able to be more resistant to disease.

These traits, when combined in a hybrid between the two species, have the potential to produce a Tilapia strain that has enhanced capacity to establish in coastal marine waters, as well as enhanced productivity.

Local environmental characteristics

The aquatic habitats of Port Resolution are varied. On the south-eastern coastline there are sandy beaches and rocky headlands exposed to prevailing winds and high wave action, with clear water and coral reef flat and reef slope environments. The northern part of the Port Resolution area is dominated by the sheltered turbid waters of Resolution Bay which is a large, almost teardrop shaped bay characterised by a benthic sediment substrate, influenced by run-off over the years (Le Bas, 2017; Welch et al. 2019). Resolution Bay is a natural harbour, sheltered by a large peninsula from the prevailing south-easterly trade winds (Figure 2). The bay supports seagrass beds although the presence and condition of this habitat appears to vary considerably over time. Seagrass are naturally ephemeral, however, there appears to have been significant diebacks of seagrass at different stages likely from local runoff events and/or from the Siwi River in the next bay to the north. Seagrass meadows are known to be important nursery areas for a range of coral reef fish and invertebrate species. Small areas of the bay support rock and coral habitat and these are mostly located to the seaward edges of the bay (Le Bas, 2017). The bay has a sandy/muddy shoreline with very little vegetation except for fallen trees due to shoreline erosion (Welch et al., 2019).

Adjacent to Resolution Bay is Lake Eweya; a small freshwater influenced lake and wetland area that connects to Resolution Bay (Figure 2). It comprises an area of floodplain that is also an area of significant subterranean thermal springs, which leads to at least one main tributary into the lake. The total habitat area, excluding the extensive floodplain currently used for grazing cattle, is approximately 0.28 km^2. The lake is seasonally connected to the sea in Resolution Bay via a mangrove-lined river channel. Lake Eweya is a significant nursery area for local reef fish species (e.g. snappers, trevallies, butterfly fishes, emperors, Moorish idols, mullets) (Welch et al., 2019), although their survival is unknown given that the lake is seasonally cut off from the sea during which time salinity is likely to decline.

Port Resolution also supports the only tracts of mangrove habitat found on Tanna Island (Ceccarelli et al. 2018). This habitat is found around the entire shoreline of Lake Eweya, although this has been modified and cleared around some parts for human access and possibly from grazing by cows. The densest mangrove growth occurs in the eastern section of the lake and continues along the banks of the short river connecting the lake to the sea in Resolution Bay (approx. 0.5 km in length) (Figure 2). This habitat supports a variety of crab species, including mud crabs (*Scylla* spp.), as well as numerous juvenile reef fish species (Welch et al., 2019). The Lake Eweya conditions are perfectly suited to Tilapia species.

Subterranean thermal springs are present in the region, mainly in the area immediately to the south and west of Lake Eweya, but also in the southwestern corner of Resolution Bay on the shoreline. These thermal springs occur due to heat from the magma beneath the adjacent active volcano, Mt Yasur, radiating through the bedrock and heating the spring water deep beneath the island, before it percolates upwards to ground level. It is not known if any of these springs erupt directly into Lake Eweya, however at least two erupt on the southwestern shoreline of Resolution Bay. These discharge near boiling temperature water (93-97 °C) that are characterised as alkali chloride waters high in sulfates (a salt of sulfuric acid) (Bloomberg and Leodoro, 2016). This is not unusual for thermal springs with a volcanic origin (Thorp and Covich, 2015).

Figure 2. Map of the Port Resolution area shown on the right-hand side of the image. Resolution Bay (RB) and Lake Eweya (*) are each marked. The nearby active volcano, Mt Yasur, can be seen on the far left of the map image. Source: Google Earth.

Water quality parameters of Resolution Bay and Lake Eweya are not readily available however it is reasonable to describe the salinity in the bay to be at or approaching full seawater salinity of 35 ppt, while Lake Eweya is a brackish water environment with salinity varying throughout the year as the lake is periodically opened and closed to the sea due to seasonal rainfall patterns (Welch et al., 2019). Water chemistry is likely to be high in mineral content and sulfates although this may be localised to areas around thermal springs. These springs have been shown to produce acidic waters in Port Resolution, but again their influence may be localised. Seasonal sea water temperatures around Port Resolution are in the range of 22- 28 °C, ideal for Tilapia species.

Impacts of Tilapia

Globally, Tilapia are well known as a highly effective invasive pest species, as it has established itself in the wild in many countries where adverse ecological impacts have been reported. Competition with local species for resources is one perceived impact mechanism (www.fishBase.se). In Hawaii, Tilapia are suspected of reducing the population of *Mugil cephalus*, an important local species (Randall, 1987). Populations of cultured mullet, bonefish and milkfish in brackish water ponds are reported to have decreased after Tilapia were introduced to Kiribati (Eldredge, 1994). A similar impact was observed on milkfish in Nauru (Nelson & Eldredge, 1991; Eldredge, 1994). The introduction of Tilapia has even been blamed for the extinction of two duck species (*Anas superciliosa* and *A. gibberifrons*) in the Solomon Islands (Nelson & Eldredge 1991; Eldredge 1994). Despite the many studies citing these impacts, the evidence is mainly circumstantial.

A global review of the impacts of Tilapia introductions by Canonico et al. (2005) found correlative evidence for the decline of native fish in many countries. For example, in the Philippines, where both *O. niloticus* and *O. mossambicus* were introduced to enhance fisheries, native fish declines were observed in lakes Lanao and Buhi. Also, *O. mossambicus* was found to become the dominant species in Lake Chichincanab in Mexico where it competed with a native fish for habitat resulting in its decline and threatening extinction.

Indirect impacts can also occur. The GIFT strain has been implicated in serious resuspension of solids causing excessive turbidity in clear waters that impacts all photosynthesising organisms. GIFT apparently also discharges high nutrient excreta which causes severe water pollution that are hazardous for native species (Ghosh and Patra, 2017). There is also the potential for Tilapia to introduce new diseases or pathogens into the wild. This is possible when Tilapia are held in ponds at very high densities which promotes the spread of these diseases and pathogens, which can then be transferred to local fish populations if translocation occurs.

Key risk factors

Risk Identification is about identifying the sources of risk with the potential to contribute to the occurrence of an undesirable event. On the basis of global experiences, it is assumed that the likelihood of Tilapia translocation into the wild, that have been introduced to Port Resolution for grow-out in enclosed ponds, is HIGH. In the context of this report, the other key risk factors can be defined as the sources of risk that determine whether Tilapia will become a threat to coastal marine ecosystems.

Therefore, the processes that determines the risk of this occurring are:

- the chances that fish translocate (HIGH),
- the extent translocated fish will compete with wild fish for prey, space, and mates or predate on them (ecological impacts),
- the extent translocated fish will affect habitats,
- the likelihood that translocated fish will establish a self-sustaining population,
- the likelihood of transmission of infections/disease/pathogens,
- the potential impact of *O. niloticus* (GIFT) forming hybrids with *O. mossambicus*.

These risk factors are examined in the assessment framework to determine the risk that Tilapia will become a threat to Port Resolution coastal marine ecosystems. Risk is assessed for: 1. the species already present in Lake Eweya (*O. mossambicus*), 2. for the GIFT strain of *O. niloticus* which may be introduced for aquaculture, and 3. for a potential hybrid of the two species. To examine this further, these risk factors are assessed for Resolution Bay and Lake Eweya, which replicate direct and indirect means of Tilapia becoming established in the marine waters, and each with different environmental conditions relevant to the different Tilapia species being assessed. The assessment also examines the risk that fish will impact on the coastal marine ecosystem even though they may not establish self-sustaining populations. That is, they will move between the lake and the sea having an impact on marine ecological communities and habitats. Given that *O. mossambicus* has been established in Lake Eweya for many years, the scoring necessarily uses this history as a basis. Further, it allows the risk determined for *O. mossambicus* to be used as a baseline to compare to the risk from the potential introduction of *O. niloticus* or from hybrids occurring.

Risk assessment

The definitions for scoring likelihood and consequence for each risk factor are provided in Tables 1 and 2 and are modified from Fletcher et al. (2004). When scoring for likelihood and consequence a precautionary approach was taken whereby, under uncertainty due to a lack of data and/or knowledge, the higher score was taken. For example, if it was deemed a likelihood of 2 or 3 was appropriate but there was uncertainty, the score of 3 would be given.

Table 1. Definitions of Likelihood used for each of the risks occurring. Modified from: Fletcher et al. (2004).

Score	Definition	Likelihood of occurrence
1	Rare	May occur in exceptional circumstances
2	Unlikely	Uncommon, but has been known to occur elsewhere
3	Possible	Some evidence to suggest this is possible here
4	Likely	The event will probably occur in most circumstances
5	Almost certain	Expected to occur

Table 2. Definitions of Consequence used for each of the risks occurring. Modified from: Fletcher et al. (2004).

Score	Definition	Likelihood of occurrence
1	Negligible	Very insignificant impacts. Unlikely to be even measurable at the scale of the stock/ecosystem against natural background variability
2	Minor	Possibly detectable but minimal impact on structure/function or dynamics
3	Moderate	Will result in wider and longer-term impacts
4	Severe	Very serious impacts occurring with relatively long-time frames likely to be needed to restore to an acceptable level
5	Catastrophic	Widespread and permanent/irreversible damage or loss will occur – unlikely to ever be fixed (e.g. causing local extinctions)

Based on the combination of likelihood and consequence, a ranking for each risk can be determined based on the multiplication of the two scores (likelihood score x consequence score). These risk rankings are described as different levels of risk: Negligible, Low, Moderate, High, Extreme, and each risk level can then guide responses to mitigate the different risks (see Tables 3 and 4).

Several assumptions are made in carrying out each risk assessment:

- the continuation of the periodic pattern of the lake being open and closed to the sea based on rainfall, and
- the risk of translocation established in Section 3 (High) is constant.

Table 3. Different levels of risk determined from the risk assessment based on likelihood and consequence scores, and indicative responses to mitigate the risk for each level. Modified from: Fletcher et al. (2004).

Risk ranking	Score	Response
Low	1-6	No major concern so no response required
Moderate	7-14	Action may be needed; consideration should be made for further research and/or alternative options
High	>= 15	Requires affirmative action that either significantly reduces the risk level or changes to a lower risk alternative

Table 4. Risk rankings matrix indicating the risk levels for each combination of likelihood and consequence scores.

LIKELIHOOD	CONSEQUENCE				
	Negligible 1	**Minor 2**	**Moderate 3**	**Severe 4**	**Catastrophic 5**
Rare 1	**1**	**2**	**3**	**4**	**5**
Unlikely 2	**2**	**4**	**6**	**8**	**10**
Possible 3	**3**	**6**	**9**	**12**	**15**
Likely 4	**4**	**8**	**12**	**16**	**20**
Almost certain 5	**5**	**10**	**15**	**20**	**25**

Table 5. Risks identified for *O. mossambicus* and their evaluation using the likelihood and consequence scores from Tables 1 and 2. N.B. Current impacts in Lake Eweya that inform the assessment are anecdotal and includes stripping of aquatic plants, while impacts on other species is confounded by very high levels of fishing effort on all lake species.

#	Risk description	Likelihood	Consequence	Risk Ranking
1	Risk of impacts to ecological communities in marine waters from *O. mossambicus* establishing a self-sustaining population	2	4	8
2	Risk of impacts to habitats in marine waters from *O. mossambicus* establishing a self-sustaining population	2	4	8
3	Risk of impacts to ecological communities in Lake Eweya from *O. mossambicus* establishing a self-sustaining population	5	3	15
4	Risk of impacts to habitats in Lake Eweya from *O. mossambicus* establishing a self-sustaining population	5	3	15
5	Risk of *O. mossambicus* moving from Lake Eweya to Resolution Bay and impacting ecological communities	3	4	12
6	Risk of *O. mossambicus* moving from Lake Eweya to Resolution Bay and impacting habitats	3	4	12
7	Risk of *O. mossambicus* releasing infections, disease and/or pathogens in *either* Lake Eweya or Resolution Bay	2	4	8

Table 6. Risks identified for *O. niloticus* (GIFT strain) and their evaluation using the likelihood and consequence scores from Tables 1 and 2.

#	Risk description	Likelihood	Consequence	Risk Ranking
1	Risk of GIFT translocating into marine waters and establishing a self-sustaining population that impacts ecological communities	1	4	4
2	Risk of GIFT translocating into marine waters and establishing a self-sustaining population that impacts habitats	1	4	4
3	Risk of GIFT translocating into Lake Eweya and establishing a self-sustaining population that impacts ecological communities	5	4	20
4	Risk of GIFT translocating into Lake Eweya and establishing a self-sustaining population that impacts habitats	5	3	15
5	Risk of GIFT moving from Lake Eweya to Resolution Bay and impacting ecological communities	1	4	4
6	Risk of GIFT moving from Lake Eweya to Resolution Bay and impacting habitats	1	3	3
7	Risk of translocated GIFT releasing infections disease/pathogens in *either* Lake Eweya or Resolution Bay	3	3	9

Table 7. Risks identified for *O. mossambicus/O. niloticus* (GIFT strain) HYBRID and their evaluation using the likelihood and consequence scores from Tables 1 and 2.

#	Risk description	Likelihood	Consequence	Risk Ranking
1	Risk of GIFT that had translocated into Lake Eweya cross-breeding with *O. mossambicus* to form hybrids	4	5	20
2	Risk of impacts to ecological communities in marine waters from hybrids establishing a self-sustaining population	3	5	15
3	Risk of impacts to habitats in marine waters from hybrids establishing a self-sustaining population	3	4	12
4	Risk of impacts to ecological communities in Lake Eweya from hybrids establishing a self-sustaining population	4	5	20
5	Risk of impacts to habitats in Lake Eweya from hybrids establishing a self-sustaining population	4	4	16
6	Risk of hybrids moving from Lake Eweya to Resolution Bay and impacting ecological communities	4	5	20
7	Risk of hybrids moving from Lake Eweya to Resolution Bay and impacting habitats	4	4	16

4. Risk mitigation

Mozambique Tilapia, *O. mossambicus*

Responding to the outcomes of the risk assessment process is guided by pre-determined levels of action (see Table 3). The risk assessment for the species already present in Lake Eweya at Port Resolution, *O. mossambicus*, determined an overall medium-high level of risk that they would be a threat to coastal marine areas (Table 5). This is due primarily to the high salinity tolerance of this species, coupled with their continual access to the sea from the lake. Therefore, despite having a presence in the lake for approximately 50 years and not the adjacent bay area, this remains a possibility.

The two high risks identified were related to the impacts from their establishment in the lake as a self-sustaining population. Despite their long-term establishment, any impacts of *O. mossambicus* on Lake Eweya's ecosystem are poorly known as the relevant research has not been undertaken. Although there are impacts evident (e.g. low cover of aquatic plants, low number of fish and invertebrates), these observations are largely observational and anecdotal, and the fishing pressure is very high on all species in the lake (Welch et al., 2019). Therefore, an accurate assessment of the impacts due to Tilapia is likely to be confounded by the effects of fishing. The recommended actions to mitigate the high risks are for local communities to continue to harvest the Tilapia resource in the Lake as a food resource, however consideration should be made to control harvest to ensure continued supply and in doing so minimise potential impacts on the lake ecosystem (Table 8). This is consistent with recommendations made by Welch et al. (2019).

Most of the risks received a moderate risk ranking and are related to the potential for *O. mossambicus* to impact the marine coastal areas. Given their ongoing lake presence, it is recommended that any distributional shifts from the lake to Resolution Bay are carefully monitored. Actions recommended above for the high ranked risks will help mitigate these risks also (Table 8). There is a high level of uncertainty in the occurrence of disease/pathogens from the introduction of *O. mossambicus* due to a lack of data.

Nile Tilapia, *O. niloticus* (GIFT strain)

Overall the level of risk that *O. niloticus* would be a threat to coastal marine areas was generally moderate-low, however there were two high risks identified. These were related to impacts caused to the lake ecosystem from their establishment as a self-sustaining population. This is because the lake represents their natural habitat with suitable environmental conditions, but also because of their superior growth rates and large size which would make them potentially formidable competitors for native species and even for *O. mossambicus*. Given that the likelihood of them translocating to the lake from aquaculture ponds is deemed to be high, their establishment likelihood in the lake is deemed to be 'almost certain' (Table 6). Therefore, the only way to mitigate this risk is not to introduce them to the Port Resolution area for aquaculture (Table 8). Instead, it is recommended that the existing *O. mossambicus* species is used for aquaculture grow-out pond establishment. An advantage of this is the continual supply of brood stock from the local lake.

O. niloticus (GIFT) x *O. mossambicus* hybrid

The potential impacts from a hybrid between *O. niloticus* and *O. mossambicus* is obviously more hypothetical than for each species separately, however, there is considerable experience documented in the literature to inform this scenario. Hybridisation appears to readily occur between Tilapia species so the risk of hybridisation occurring is high. The risk assessment for the hybrids determined an overall high level of risk that they would be a threat to coastal marine areas (Table 7). This is due primarily to the combination of the two species having the potential to have a high salinity tolerance, high growth rates and the ability reach a large size. This means a hybrid may have the capacity dominate the lake environment and present a higher risk to either establishing itself in marine waters or at least moving into Resolution Bay and having an impact.

The only way to mitigate this risk is not to introduce *O. niloticus* (GIFT) to the Port Resolution area for aquaculture (Table 8). Instead, it is recommended that the existing *O. mossambicus* species is used for aquaculture grow-out pond establishment.

Table 8. Summary of assessed risks, their risk ranking and justification, along with recommended responses to mitigate and/or minimise the risk they pose.

Risk	Risk ranking	Justification of ranking	Recommendations
Oreochromis mossambicus			
1. Risk of impacts to ecological communities in marine waters from *O. mossambicus* establishing a self-sustaining population	Moderate	- High tolerance for marine water salinity - Competitive advantage over other species	- Distributional shifts from the lake to Resolution Bay are carefully monitored - Establish a community harvest strategy for Tilapia in the lake
2. Risk of impacts to habitats in marine waters from *O. mossambicus* establishing a self-sustaining population	Moderate	- High tolerance for marine water salinity - Behaviour of disturbing habitats	
3. Risk of impacts to ecological communities in Lake Eweya from *O. mossambicus* establishing a self-sustaining population	High	- Optimal environmental conditions - Competitive advantage over other species	- Establish a community harvest strategy for Tilapia in the lake
4. Risk of impacts to habitats in Lake Eweya from *O. mossambicus* establishing a self-sustaining population	High	- Optimal environmental conditions - Behaviour of disturbing habitats	
5. Risk of *O. mossambicus* moving from Lake Eweya to Resolution Bay and impacting ecological communities	Moderate	- Ready accessibility between the lake and sea - High tolerance for marine water salinity - Competitive advantage over other species	- Distributional shifts from the lake to Resolution Bay are carefully monitored - Establish a community harvest strategy for Tilapia in the lake
6. Risk of *O. mossambicus* moving from Lake Eweya to Resolution Bay and impacting habitats	Moderate	- Ready accessibility between the lake and sea - High tolerance for marine water salinity - Behaviour of disturbing habitats	
7. Risk of *O. mossambicus* releasing infections, disease and/or pathogens in *either* Lake Eweya or Resolution Bay	Moderate	- Non-native species - Time since first introduction	- Monitor health and/or impacts of native species

Risk	Risk ranking	Justification of ranking	Recommendations
***Oreochromis niloticus* (GIFT)**			
1. Risk of GIFT translocating into marine waters and establishing a self-sustaining population that impacts ecological communities	Low	- Low tolerance for marine water salinity	- No actions required
2. Risk of GIFT translocating into marine waters and establishing a self-sustaining population that impacts habitats	Low		
3. Risk of GIFT translocating into Lake Eweya and establishing a self-sustaining population that impacts ecological communities	High	- Optimal environmental conditions - Significant competitive advantage over other species	- Do not introduce *O. niloticus* (GIFT) to the Port Resolution area for aquaculture - Utilise the existing *O. mossambicus* in the lake to stock domestic aquaculture ponds
4. Risk of GIFT translocating into Lake Eweya and establishing a self-sustaining population that impacts habitats	High	- Optimal environmental conditions - Behaviour of disturbing habitats	
5. Risk of GIFT moving from Lake Eweya to Resolution Bay and impacting ecological communities	Low	- Low tolerance for marine water salinity	- No actions required
6. Risk of GIFT moving from Lake Eweya to Resolution Bay and impacting habitats	Low		
7. Risk of translocated GIFT releasing infections disease/pathogens in *either* Lake Eweya or Resolution Bay	Moderate	- Non-native species - New introduction to the area	- Monitor health and/or impacts of native species

Risk	Risk ranking	Justification of ranking	Recommendations
***O. niloticus* (GIFT) x *O. mossambicus* hybrid**			
1. Risk of GIFT that had translocated into Lake Eweya cross-breeding with *O. mossambicus* to form hybrids	High	- Strong evidence that hybrids readily occur between these two species	- Do not introduce *O. niloticus* (GIFT) to the Port Resolution area for aquaculture - Utilise the existing *O. mossambicus* in the lake to stock domestic aquaculture ponds
2. Risk of impacts to ecological communities in marine waters from hybrids establishing a self-sustaining population	High	- High tolerance for marine water salinity - Significant competitive advantage over other species	
3. Risk of impacts to habitats in marine waters from hybrids establishing a self-sustaining population	Moderate	- High tolerance for marine water salinity - Behaviour of disturbing habitats	
4. Risk of impacts to ecological communities in Lake Eweya from hybrids establishing a self-sustaining population	High	- Optimal environmental conditions - Significant competitive advantage over other species	
5. Risk of impacts to habitats in Lake Eweya from hybrids establishing a self-sustaining population	High	- Optimal environmental conditions - Behaviour of disturbing habitats	
6. Risk of hybrids moving from Lake Eweya to Resolution Bay and impacting ecological communities	High	- Ready accessibility between the lake and sea - High tolerance for marine water salinity - Significant competitive advantage over other species	
7. Risk of hybrids moving from Lake Eweya to Resolution Bay and impacting habitats	High	- Ready accessibility between the lake and sea - High tolerance for marine water salinity - Behaviour of disturbing habitats	

5. Recommendations

Based on the outcomes of this risk assessment, the level of risk that proposed Tilapia fish (*O. niloticus*, GIFT) cultivation at Port Resolution on Tanna Island will result in Tilapia escaping from confined ponds and posing a threat to the coastal marine ecosystem is deemed to be unacceptably high. The high level of risk is not directly from the introduction of *O. niloticus* (GIFT), but due to the high potential that they would hybridise with the local Tilapia species in the lake and the superior fitness likely from a hybrid of the two species. Further, the key threats that Tilapia present in the lake is principally the negative impact on the nursery characteristics for many marine reef species (ecological impacts) (Welch et al., 2019).

The key recommendations from this assessment are given below as mitigation strategies identified as appropriate to reduce this risk. One of the key recommendations is for small-scale trials using the species already in existence at Port Resolution, the Mozambique Tilapia, *O. mossambicus*. If this approach were to be taken, expert guidance would be needed since the strain of this species thought to be introduced in the Pacific has little genetic variation which may restrict their long-term fitness and viability and ultimately limit their potential population size (Smith and Chesser, 1981). Further, it should be acknowledged that this species is not recommended for aquaculture in the Pacific due to their slower growth rate compared to the Nile Tilapia (Pickering, 2009). However, when examined in the context of risk to the coastal marine ecosystem in Port Resolution, directly and indirectly, this assessment advises against the introduction of a new Tilapia species to the region. This recommendation is partly due to the already impacted state of coastal marine resources in the region, but also due to the potential for even greater impacts from Tilapia introductions. Also, the lower productivity of Mozambique Tilapia is less of an issue given that the proposed nature of aquaculture in Port Resolution is for small-scale domestic operations. One approach that may better optimise growth in the local Mozambique Tilapia is the installation of grow-out cages within the lake itself, since Tilapia grow faster in brackish water compared to freshwater.

In the interim, an immediate recommendation, as per Welch et al. (2019), is to continue to harvest the local 'wild' *O. mossambicus* population in the lake, both as a source of food for the local community but also to alleviate pressure on depleted coastal marine resources. Part of this recommendation is for the development of simple harvest strategies to ensure sustainability of catches. This would require some expert guidance and perhaps the establishment of a community committee as recommended for a similar scenario in Samoa (Nandlal et al., 2007).

Additional complementary recommendations are also provided.

Key Recommendations

- That *O. niloticus* (GIFT strain) Tilapia are <u>not</u> introduced to the Port Resolution area for aquaculture purposes.
- That the Tilapia species currently existing in Lake Eweya, *O. mossambicus*, is considered as brood stock for local domestic aquaculture. To maximise growth rates the use of grow-out cages within Lake Eweya may present the best option for this to occur.

- That appropriate training and assistance is provided to local communities to facilitate the development of any local aquaculture.
- That the community continue to harvest wild Tilapia from Lake Eweya, and that consideration is made to assisting them in developing a simple harvest strategy that ensures continued supply.
- That the local community monitor for the presence of Tilapia in coastal marine waters, especially in Resolution Bay.
- That the local community monitor for signs of disease or pathogens in local Tilapia and/or other species.
- That appropriate education and awareness with local communities are conducted about the outcomes of this assessment and relevant actions, in particular education and awareness should be about the GIFT strain and its potential impacts on the local ecosystems.
- That consideration is given to an assessment being conducted by a qualified expert on the status of the Tilapia population in Lake Eweya and its impacts on the lake ecosystem.
- That this report be shared with relevant staff of the Vanuatu Fisheries Department and the Vanuatu Department of Environmental Protection and Conservation.

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