MOTHAE DIAMONDS PTY (LTD)
SPECIALIST FISH IMPACT ASSESSMENT
(2017 Revision)

Prepared for Mothae Diamonds Pty (Ltd) by:
Bruce Paxton
31 Glenalpine Rd.
Welcome Glen
Cape Town, South Africa
7975
Cell: +27786426179
email: bruce.r.paxton@gmail.com

August 2017

EXECUTIVE SUMMARY

Introduction and background—The primary aim of this study was to assess *inter alia* the extent, magnitude and significance of the potential impacts of the proposed mining activities undertaken by Mothae Diamonds (Pty) Ltd on freshwater fish species inhabiting the mainstem and tributaries of the Mothae River, Lesotho. Special consideration is given to the Maloti redfin *Pseudobarbus quathlambae* because of its threatened status and the fact that it is flagship species for conservation in Lesotho.

Baseline Fish Survey—A Baseline Fish Survey was conducted between 12-15 April 2011 and focused on a reach of the Mothae River between 4.6 and 8.7 km from its source and ending 3 km upstream of its confluence with the Matsoku River. Continuous backpack electrofishing was conducted along the shoreline and thalweg of the Mothae River. The study recorded a previously undocumented population of *P. quathlambae* in the Mothae River. The presence of a waterfall barrier appears to limit fish passage beyond the downstream end of Site Mot-2B (upstream of the mine confluence) to the source of the Mothae. Similarly, although Maloti redfin were collected from the mine tributary, the upper limit of their distribution was constrained by a waterfall barrier 450 m upstream of the confluence of this tributary with the Mothae River. In all, a total of 107 Maloti redfin were collected during the course of the survey. Mean number of fish and CPUE for all sites was 12.4 (±SD 8.0) and 0.002 fish/hour (±SD 0.001) respectively. The presence of Maloti redfin in this river has important national and international implications for their future conservation and management. The relative abundances of fish in the river were relatively low (max. 0.004 fish/hr). However, the survey was conducted late in the season (mid-April) when temperatures start declining and fish become less susceptible to being caught. The presence of all size and age classes in the river and the absence of invasive species such as trout, however, suggests that the population is healthy and recruiting. This was confirmed by the growth model confirming the presence of relatively high abundances of age 1+ fish. Although similar relative abundances of adults were caught at the Control and Impact sites (reaches Mot-2 and Mot-3 respectively), the greater numbers of small fish in the Impact site (downstream of the mine tributary), suggest that these reaches are important for recruitment processes in the Mothae River

Assessment of potential impacts—Potential future sources of risk to Maloti redfin populations as a result of the proposed mining activities by Mothae Diamonds were identified and grouped into the following four categories:

1. Increase sediment supply (Total Suspended Sediment (TSS), turbidity and sedimentation)
2. Wastewater pollutants;
3. Water abstraction, impoundments and flow modification and
4. Facilitating the translocation of invasive species.

A detailed description of each current and future impact and the corresponding response of fish populations is explained. Mitigation measures are recommended for each impact. **Note**: only **Alternative D** outlined in the Conceptual Study was assessed here. The table below provides a summary of the activity and potential impacts and their significance with and without mitigation

Summary Table describing the significance of potential impacts		
Activity and potential impacts	**Significance of impacts**	
	Without mitigation	**With mitigation**
Increased TSS and turbidity from fine tailings	Major (negative)	Minor (negative)
Increased TSS and turbidity from non-point sources runoff	Moderate (negative)	Minor (negative)
Accidental discharge of wastewater or poor performance of WWTW	Major (negative)	Moderate (negative)
Increased wastewater contaminants from non-point pollution sources	Moderate (negative)	Minor (negative)
Water abstraction and use (dam in Mothae River)	Major (negative)	Negligible
Water abstraction and use (dams in tributaries within mining lease area)	Major (negative)	Moderate (negative)
Translocation and invasion by introduced fish species	Major (negative)	Moderate (negative)

Monitoring Plan—The rationale, objectives and methodology of a programme to monitor Maloti redfin populations and habitat downstream of the Mothae Diamond Mine in order to assess the effectiveness of environmental management practices and the recommendations contained is presented. This plan includes a description of the key indicators used to assess the status of fish populations, outlines equipment and personnel requirements, describes assessment methodologies and the approach used to derive the Thresholds of Potential Concern (TPCs). It also identifies high risk points where habitat monitoring needs to take place and where automated monitoring devices must be situated.

Thresholds of Potential Concern—TPCs for Maloti redfin populations were estimated from the baseline monitoring survey reported in Chapter 2. These are preliminary figures obtained from a survey conducted during the least favourable time of the year for sampling (April). These TPCs will need to be revised once information from the first monitoring survey at a more suitable time of the year (Nov-Mar) becomes available. No long term baseline data exist for the hydrology or water quality conditions of the Mothae River. For turbidity it is suggested that a minimum TPC of 500 mg/*l* for a period > 20 days be set. However, this figure be revised once one full year's monitoring has been completed. No baseline data exists for the Mothae River on physical habitat. Reference conditions and TPCs for these conditions can be set only after the first monitoring survey has been completed.

Concluding remarks—The Maloti redfin is a high profile and irreplaceable species. The Mothae River is one of the few rivers still supporting a relatively pristine population. This represents a unique opportunity for Mothae Diamonds to consider environmental factors early in the design and implementation of fully-scale mining in the Matsoku River catchment and to enforce best practice when it comes to environmental management within and beyond the boundaries of its lease area.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

1. INTRODUCTION

1.1 Background

In June 2006, Motapa Exploration Ltd (“Motapa”) was awarded a two year Prospecting Licence to investigate the economic feasibility of mining diamonds from a kimberlite deposit in the Mokhotlong district, Lesotho. Following an initial geological investigation, Motapa entered into an agreement with Lucara Diamond Corp. ("Lucara") to implement bulk sampling. A subsidiary company – Mothae Diamonds (Pty) Ltd ("Mothae") – was formed by Lucara in partnership with the Government of Lesotho and this company was subsequently granted a lease to begin pre-production/trial mining in September 2009. The purposes of this pre-production phase was to commence bulk sampling in order to assess the grade of the surface kimberlite in the Mothae pipe, to determine the value of the diamonds and to generate model of kimberlite pipe and estimate its tonnage potential.

Prior to bulk sampling, Mothae appointed Amathemba Environmental Management Consulting CC ("Amathemba") to conduct a baseline environmental assessment of the mining site (Davey et al. 2007a). This assessment was completed in February 2007 and included an aquatic ecosystem and botanical survey. Drawing on the findings of the baseline study, Amathemba went on to prepare an Environmental Management Plan (EMP) that would mitigate the potential negative effects of the prospecting and trial mining operation – particularly with regards to mine tailings management, water quality impacts and rehabilitation – on affected ecosystems (Davey et al. 2007b).

A Conceptual Study for full scale commercial production was completed in June 2009. This would entail expanding the current footprint of the mine into a neighbouring catchment, re-locating and upgrading the current infrastructure to accommodate the expanded mine pit and constructing additional processing and storage facilities, together with tailings and water supply dams.

In order to proceed with full scale mining, Mothae Diamonds (Pty) Ltd is required to undertake an Environmental Impact Assessment (EIA) process in terms of Lesotho’s Environment Act, 2008 (Act 10 of 2008). Amathemba has been appointed as the Lead EIA consultant for this EIA. In the aquatic assessment, the need for a fish survey was identified and Dr. Bruce Paxton was appointed to undertake the Fish Specialist Study.

1.2 Terms of Reference

The primary aim of this study as outlined in the initial ToR for the Fish Specialist Study was to assess the significance of the potential impacts of the proposed mining activities on freshwater fish – particularly the Maloti redfin *Psuedobarbus quathlambae* – in the Mothae River and potentially affected tributaries. The following objectives were outlined:

- Collate all relevant information and data on freshwater fish in rivers of the North-eastern Highlands of Lesotho that is available.

- Conduct fish surveys to determine whether Maloti redfin are present or likely to be present in any of the streams that could be affected by the proposed mining activities.

- Conduct fish surveys to determine what fish are present or likely to be present in the reaches of the Mothae River that could be affected by the proposed mining activities and in potentially affected tributaries of the Mothae River.

- Identify and explain the potential impacts of all the proposed mining activities on freshwater fish in the study area.

- Assess the significance of the potential impacts of the proposed mining project on freshwater fish, using the prescribed assessment method (see Standard Terms of Reference for Specialists).

- Recommend mitigation measures to reduce the significance of potentially negative impacts on freshwater fish and provide recommended monitoring actions to assess the success of the proposed mitigation measures.

2. BASELINE FISH SURVEY OF THE MOTHAE RIVER, LESOTHO

2.1 Introduction

In this section, the fishes of the Lesotho Highlands are introduced, the approach and methodologies used in the Mothae River Fish Survey described and the results of the survey presented. Special consideration is given to the Maloti redfin *Pseudobarbus quathlambae* because of its threatened status and the fact that it is flagship species for conservation in Lesotho.

2.1.1 Fishes of the Lesotho Highlands

The headwater and foothill reaches of the Orange River are to be found in Lesotho (where it is known as the Senqu) and these waters drain south and westward into South Africa's Orange-Vaal River system. As a consequence Lesotho shares much of its freshwater fish fauna with the Orange-Vaal, the exception being the Maloti redfin which is no longer found beyond the borders of Lesotho. Nine out of the approximately 15 fish species found in Lesotho are therefore indigenous to the Orange/Senqu-Vaal, the remainder are introduced exotics (Table 2.1) (Tilquin and Lechela 1995). Figure 3.1 shows the distribution of Orange-Vaal freshwater fish fauna that are expected to be found in the highlands of Lesotho (records of the South Africa Institute of Aquatic Biodiversity, SAIAB). From these figures it is apparent that among the indigenous species, smallmouth yellowfish, Orange River mudfish, and rock catfish can be expected in low-order headwater tributaries, whereas among the exotic species, rainbow trout and brown trout can more commonly be expected in these reaches.

Table 2.1 Fish species expected in Lesotho and their conservation status.

Common Name	Scientific name	Conservation status
Rock catfish	*Austroglanis sclateri*	Indigenous, Least concern
Chubbyhead barb	*Barbus anoplus*	Indigenous, unknown
Straigthfin barb	*Barbus paludinosis*	Indigenous
Smallmouth yellowfish	*Labeobarbus aeneus*	Indigenous, Least concern
Largemouth yellowfish	*Labeobarbus kimberleyensis*	Indigenous, Near threatened
Orange River mudfish	*Labeo capensis*	Indigenous, Least concern
Moggel	*Labeo umbratus*	Indigenous, Least concern
Maloti redfin	*Pseudobarbus quathlambe*	Indigenous, Endangered
Sharptooth catfish	*Clarias gariepinus*	Indigenous, not-listed
Rainbow trout	*Onchorynchus mykiss*	Exotic, introduced
Brown trout	*Salmo trutta*	Exotic, introduced
Largemouth bass	*Micropterus dolomeiu*	Exotic, introduced
Bluegill sunfish	*Lepomis machrochirus*	Exotic, introduced
Common carp	*Cyprinius carpio*	Exotic, introduced

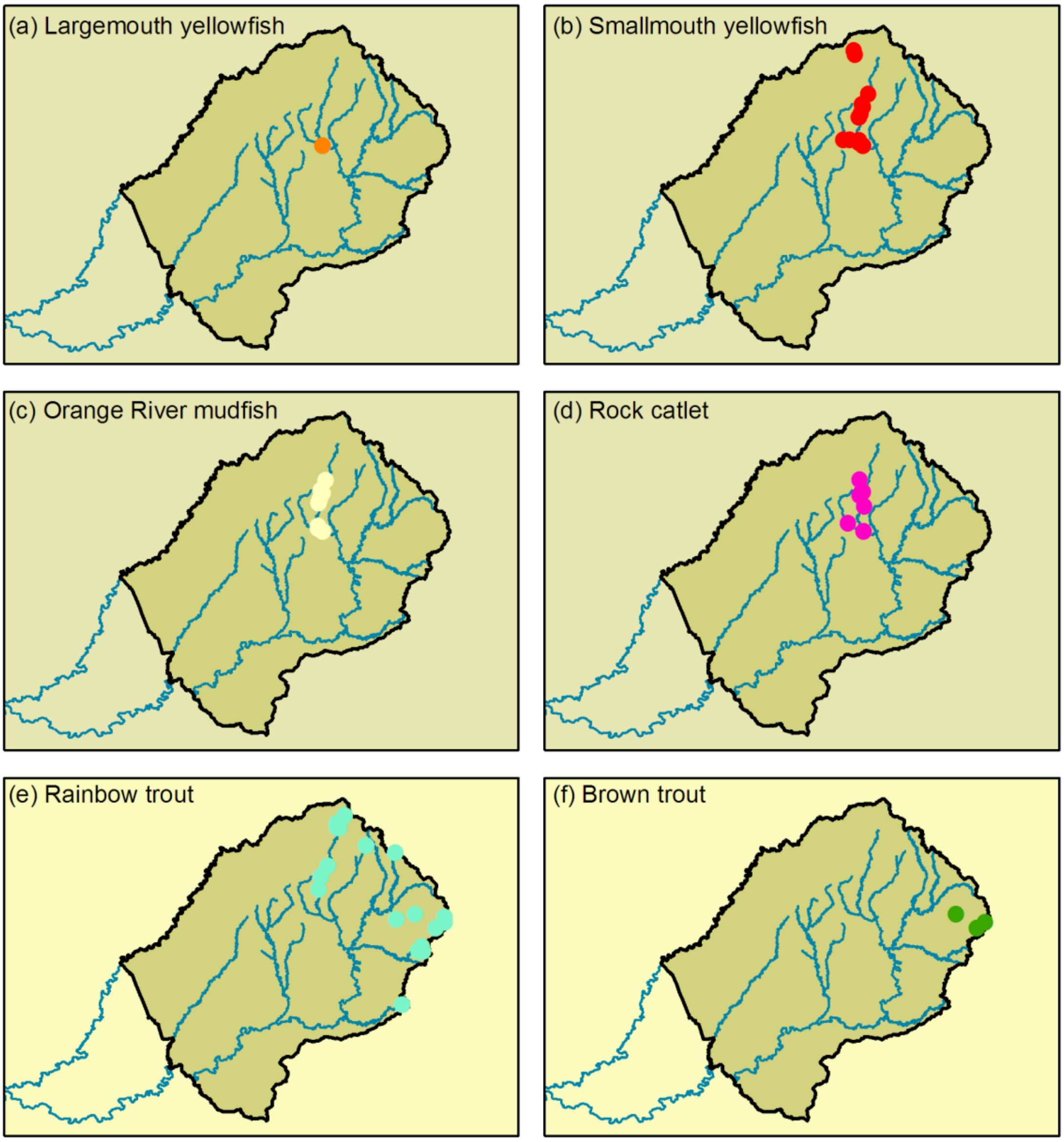


Figure 2.1 Distribution records for indigenous (a-d) and exotic (e-f) fish species in the Northeastern Lesotho Highlands (SAIAB records).

2.1.2 The Maloti redfin (Pseudobarbus quathlambae)

Taxonomy and distribution—The Maloti redfin *Pseudobarbus quathlambae* (Endangered B2ab(ii,iii,v)) (IUCN 2010), is a small minnow native to the headwater streams of the Senqu River and its tributaries and the only vertebrate endemic to Lesotho (Plate 2.1). The species was first described from the Umkomazana River in Kwazulu-Natal, South Africa by Barnard (1938), from whence it has subsequently become extinct as a result of predation and competition from trout (Skelton 2000, Swartz 2005). Prior to its rediscovery in Lesotho, Greenwood and Jubb (1967) assigned it to its own genus, '*Oreodaimon*', meaning 'spirit of the mountains' since it was at the time thought extinct. A Lesotho population was then discovered in the 1970s by Pike and Tedder (1973) who collected specimens from the Tsoelikane River.

Plate 2.1 The Maloti redfin *Pseudobarbus quathlambae* (P. Skelton).

Populations have subsequently been discovered in the Senqu and Moremoholo Rivers (Rondorf 1976), the Senqunyani catchment (Cambray and Meyer 1988), as well as the Sani (Skelton 2000) and Matsoku Rivers (SAIAB 61857, Swartz 2005). Skelton (1988) recognised that the species had strong affinities with the *Psuedobarbus* (redfin) lineage of the Cape Floristic Region (CFR), South Africa. This relationship has since been reinforced by genetic studies and the species is now assigned to the *Psuedobarbus* genus (Swartz 2005). Its restricted distribution in high altitude rivers flowing through the Drakensberg Alpine Floral Centre in Lesotho (> 2000 m) and its genetic divergence from other CFR species is, however, anomalous for this group (Swartz 2005). Swartz (2005) identified three divergent lineages within the broader Lesotho Highlands distribution. Two of these are considered Evolutionary Significant Units (ESUs), i.e. historically isolated and sufficiently divergent from one another to warrant special conservation attention. They are: (1) the Mohale ESU and (2) the Eastern ESU (Figure 2.2). The Mohale ESU is restricted to the Senqunyane drainage basin, whereas the Eastern ESU consists of five populations that include the Matsoku, Senqu-Moremoholo, Linaheng (Sani) and Tsoelikane Rivers. Together with the Mohale ESU, each of these populations should be considered separate conservation units and managed accordingly (Swartz 2005).

Ecology, habitat and breeding—Maloti redfin occur in the high altitude (>2000 m) headwater tributaries of the Senqu River where temperatures in winter can fall below 0° C and where rivers can freeze over in winter. They are physiologically and anatomically specialised for these conditions, possessing enlarged pectoral fins, small scales and a high vertebral count – characteristics of fishes that are adapted for benthic habitat, cool temperatures and swiftly flowing water (Gephard 1978, Cambray and Meyer 1988, Skelton 1980). The Maloti redfin is an invertivore and feeds on a wide variety of freshwater invertebrates including the larval phases of Ephemeroptera, Diptera and Trichoptera (Rall 1999).

Rall (1999) described the habitat preferences of Maloti redfin. They select shallower water (0.1-0.4 m) with few fish occurring in water deeper than 0.4 m and highest numbers occurring in the 0.3-0.4 m depth range. Abundances are negatively correlated with the deposition of fines (silt and clay), suggesting their limited tolerance for these conditions. Adults school in open water during summer, whereas in winter they select hydraulic and aerial cover in the form of boulders or bedrock overhangs in slow-flowing areas at the foot or tail of pools and runs. Larvae are found in slow-flowing backwaters, whereas juveniles select a wide range of habitats in riffles, runs and rapids over a variety of substratum types (Rall 1999, Arthington et al. 1999). They breed during the summer months (October to March) in clear, flowing water at temperatures ranging between 14 - 22 °C (Arthington et al. 1999).

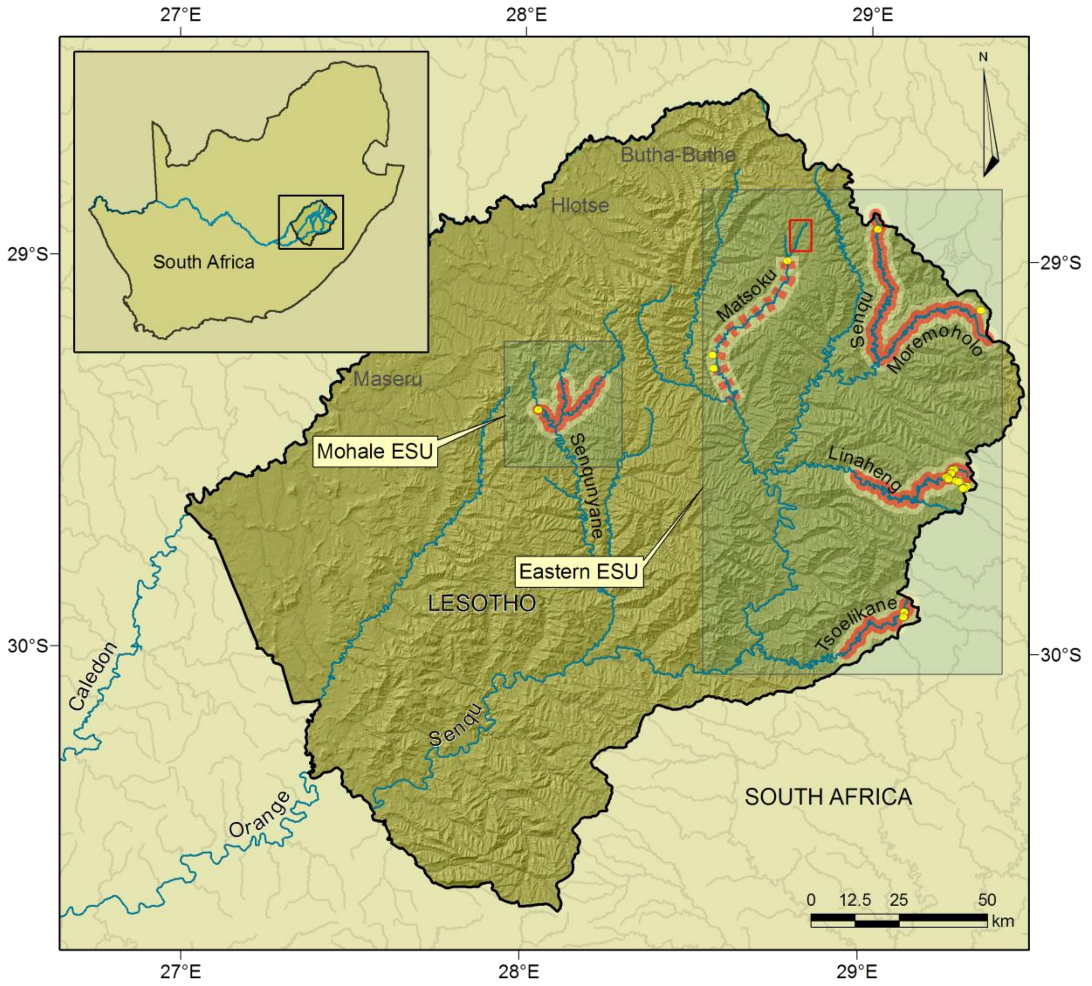


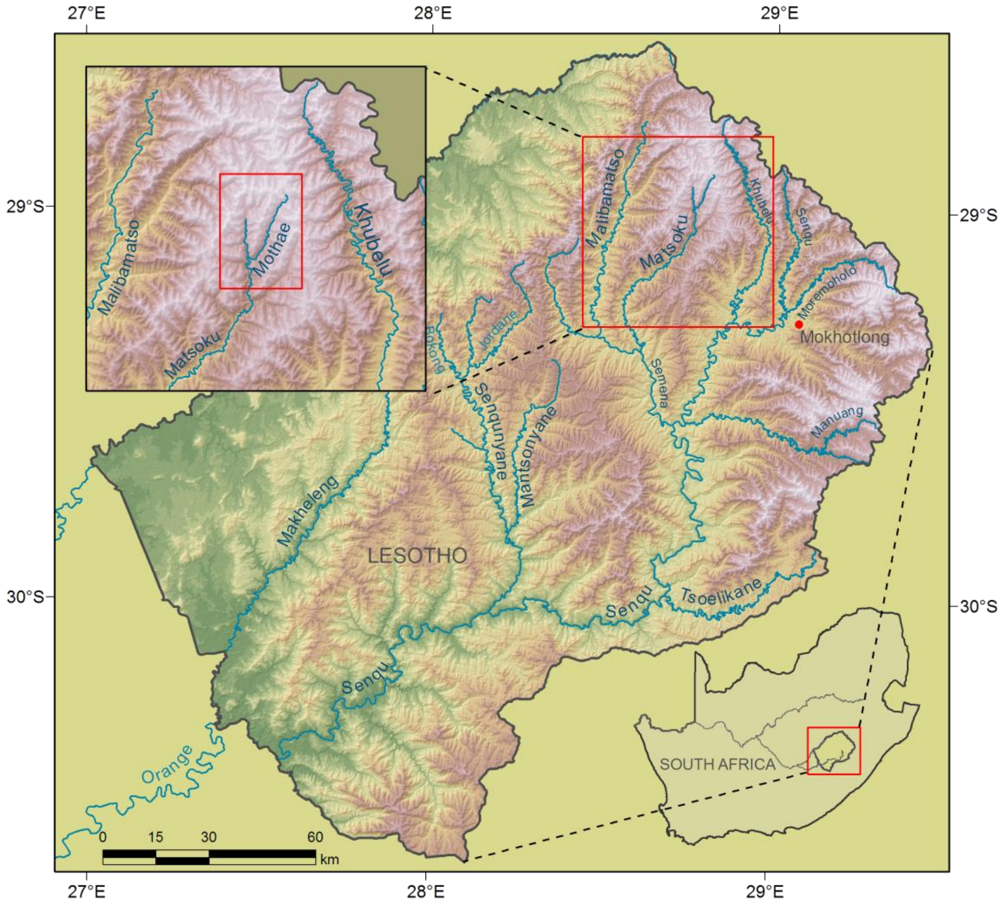
Figure 2.2 Distribution of the Maloti redfin *P. quathlambae* in the Lesotho Highlands. *Red Square*—The study area relevant to this study (the Mothae River). *Broken red line*—former distribution in the Matsoku River (SAIAB records, Swartz 2005).

Maloti redfin are considered serial, non-guarding, open substratum benthic spawners, depositing eggs in course sediments at depths between 0.2-0.4 m and velocities of ~0.5-0.6 m s^{-1} (Rondorf 1976, Gephard 1978, Cambray and Meyer 1988, Arthington et al. 1999). Eggs and larvae have been found to be acutely sensitive to silt (Rondorf 1976). They have an extended breeding season (October to March) and are able to quickly take advantage of an increase in flow conditions and favourable temperatures (14-22℃).

Threats—The primary threats facing the Maloti redfin are predation and competition from exotic and translocated fish species together with water resource development and impaired habitat and water quality conditions that result from overgrazing and human settlements (Swartz 2005, Rall 1999, Skelton 2000, Gephard 1978). The Lesotho Highlands Water Project (LHWP) has facilitated invasion by trout which have colonised river reaches from which they were previously excluded through routes provided by the LHWP water infrastructure. For instance, trout have been able to move from the Mohale Dam to the Katse Dam via a tunnel linking the two dams (Swartz 2005). The smallmouth yellowfish which have invaded redfin habitat also pose significant threat to Maloti redfin habitat. This is the case in the Matsoku River where smallmouth yellowfish were introduced through the Matsoku Diversion. As a consequence, it is now believed that the Matsoku River populations are extinct – as suggested by the broken line in Figure 2.1 – as a result of invasion and/or competition from both trout and yellowfish (Rall and Sephaka unpublished).

2.2 Study Area

The Mothae River has it source in the northeastern Highlands of Lesotho at an altitude of 3150 m. It is a 13 km[1] long second-order tributary of the Matsoku River which it joins very near to the source of that river and 76 km from the confluence of the Matsoku with the Semena River which then flows into the Senqu (Figure 2.3). The focus of this study was on a 3.3 km segment of the Mothae River centered at 28°47′7″ E and 28°58′9″S and at an altitude of ~2860 *amsl*. The Mothae River and its tributaries flow over basaltic lava of the Drakensberg Group. Water in the river is typically clear (3.2 NTU), with low Electrical Conductivity (EC) (<10 mS/m) and neutral pH (Ollis 2009). River widths vary between ~2-10 m with maximum pool depths reaching ~1.5 m. Physical habitat is characterized by typical pool-riffle-pool sequences with bedrock and boulder-cobble substrata exhibiting low particle embeddedness. In lower-energy pools and slow-flowing runs, sand and gravel predominates. There is no hydrological information available for the Mothae River. The wet season corresponds to October and March with peak flows in January and February.



---

[1] River distances as measured by km along the river channel.

Figure 2.3 Location of the Study Area showing the Mothae and Matsoku Rivers in the northeastern Lesotho Highlands.

2.3 Methods

Fish surveys were conducted between 12-15 April 2011 and focused on a reach of the Mothae River between 4.6 and 8.7 km from its source and ending 3 km upstream of its confluence with the Matsoku River (Figure 2.4). This 4.1 km reach (30 % of the length of the Mothae River) was selected because it encompassed reaches both upstream and downstream of the river potentially impacted by diamond mining activities.

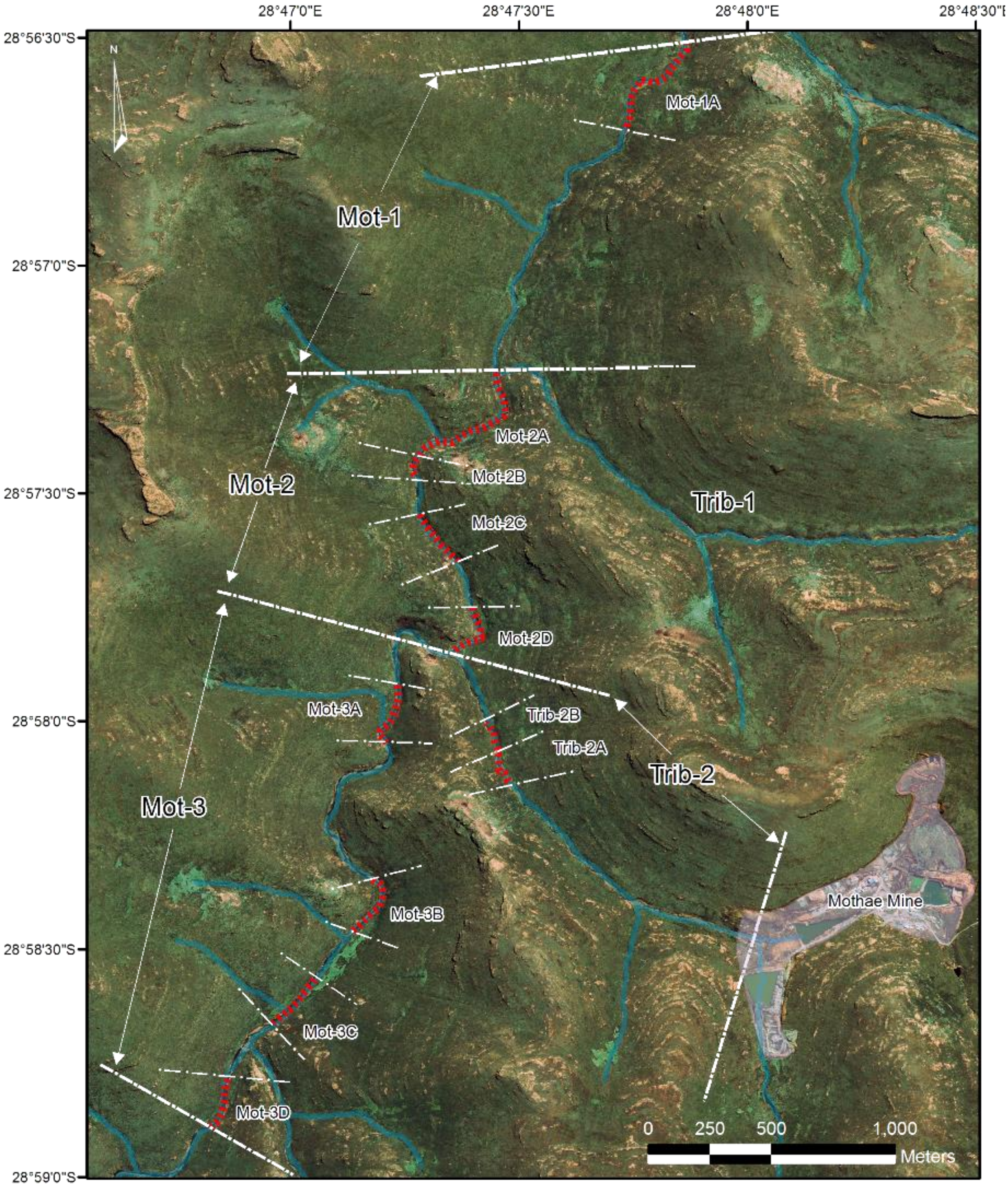


Figure 2.4 Reaches (Mot-1 – Mot-4) and sites (Mot-1A – Trib-4B) selected for the Mothae River Baseline Fish Survey. Broken red lines indicate electrofishing paths, the shaded area indicates the current footprint of the Mothae mine.

An additional 600 m segment was selected on a tributary of the Mothae River directly impacted by the Mothae mine (Trib -2) – henceforth referred to as the 'mine tributary'. Both the mainstem and tributary reaches were categorized into four sub-reaches between one and two kilometers long: Mot-1, Mot-2, Mot-3 and Trib-2 (Figure 2.4). Mot-1 was the most upstream reach and extended from the river crossing on road B804, 3.6 km north of the Mothae mine, to the left bank tributary immediately upstream of the mine (Trib-1). Mot-2 was located between the two left bank tributaries (Trib-1 and Trib-2) and Mot-3 downstream of Trib-2 to within 3 km of the Matsoku River confluence. Trib-1 wasn't sampled since it was early found to be upstream of the uppermost limit of fish distribution. Mot-1 and Mot-2 included five sites upstream of the mine tributary (Control sites), Mot-3 and Trib-2 included six sites potentially impacted by mining activities (Impact sites). Within each of these sub-reaches eleven electrofishing sites varying between ~150 and 500 m in length were then selected: Mota-1A, Mot-2A-C, Mot-3A-D and Trib-2A and B (Table 2.2).

Table 2.2 River reaches and electrofishing segments selected for the Mothae River fish Survey reporting the site length, start and end times and the total time taken to electrofish the site.

Reach	Site	River Length (m)	Time Start	Time End	Duration (min)
Mot-1	Mot-1A	470	14:50	15:20	30:00
Mot-2	Mot-2A	532	10:50	11:50	60:00
	Mot-2B	100	13:09	13:17	8:00
	Mot-2C	240	12:26	13:03	37:00
	Mot-2D	270	10:37	11:33	56:00
Mot-3	Mot-3A	270	15:30	16:34	64:00
	Mot-3B	280	15:04	15:40	36:00
	Mot-3C	250	13:26	14:13	47:00
	Mot-3D	224	11:08	12:00	52:00
Trib-1	Trib-2A	134	09:47	09:59	12:00
	Trib-2B	154	09:00	09:19	19:00

At each of these sites, continuous backpack electrofishing was conducted along the shoreline and thalweg of the Mothae River using a pulsed-DC current delivered from a SAMUS725G portable electrofisher with a maximum output power of 650 watts, a maximum output voltage of 1000 V and an output frequency of between 5-100 Hz. The electrofishing team began at the most downstream end of the reach and moved in an upstream direction recording the time that each fish was caught. The beginning and end of each site was marked with a handheld GPS unit and the track for that site containing the coordinates with a date-time stamp was saved. Sites were electrofished continuously for the entire length of the site (broken red lines Figure 2.4). Since most of the river was wadeable, riffles, pools and runs were sampled in the same manner. At the end of each electrofishing site, the fish collected were counted, measured (mm Total Length, TL and Fork Length, FL) and returned to the river. Relative abundance estimates were used as an index of overall abundance in the form of Catch Per Unit Effort (CPUE, fish/hr) which was calculated as the number of fish collected per hour of electrofishing. Genetic samples (finclips) were taken from a selected number of fish and lodged at SAIAB. Size classes were represented as length frequency histograms.

2.4 Results

P. quathlambae were collected from the mainstem of the Mothae River between Mot-1A and Mot-3D. No fish were caught upstream of Mot-2C. Further investigation revealed the presence of a waterfall barrier that appears to limit fish passage beyond the downstream end of Mot-2B (28°47'16.7"E, 28°57'28.2" S) to the source of the Mothae (Plate 2.2c). The fishless zone of the Mothae River is therefore considered to begin at Mot-2B. Similarly, although fish were collected from the mine tributary (Trib-2), the upper limit of their distribution was constrained by a waterfall barrier 450 m upstream of the confluence of this tributary with the Mothae River. All statistics reported here therefore relate to sites within the fish zone, i.e. downstream of Mot-2B including the mine tributary (Trib-2).

Abundance and CPUE—A total of 107 *P. quathlambae* were collected during the course of the survey (8 of which were caught on the first day and not included in the calculation of CPUE per reach). Mean number of fish and CPUE for all sites was 12.4 (±SD 8.0) and 14.1 fish/hour (±SD 8.8) respectively. The highest relative abundances of *P.quathlambae* were collected from the most upstream site (Mot-2C) and the lowest from Mot-3C (Figure 2.5). As previously indicated, no fish were caught upstream of Mot-2C and Trib-2B suggesting that these reaches represented the uppermost limit of fish distribution in the system.

Plate 2.2 (a) Typical pool-riffle-pool sequence with bedrock-boulder substratum on the Mothae River at Mot-3A (upstream); (b) view of the Mothae River facing downstream at Mot-3A and (c) barrier waterfall on the

Mothae River at the downstream end of Mot-2B that prevents fish passage upstream and marks the upstream limit of the fish zone.

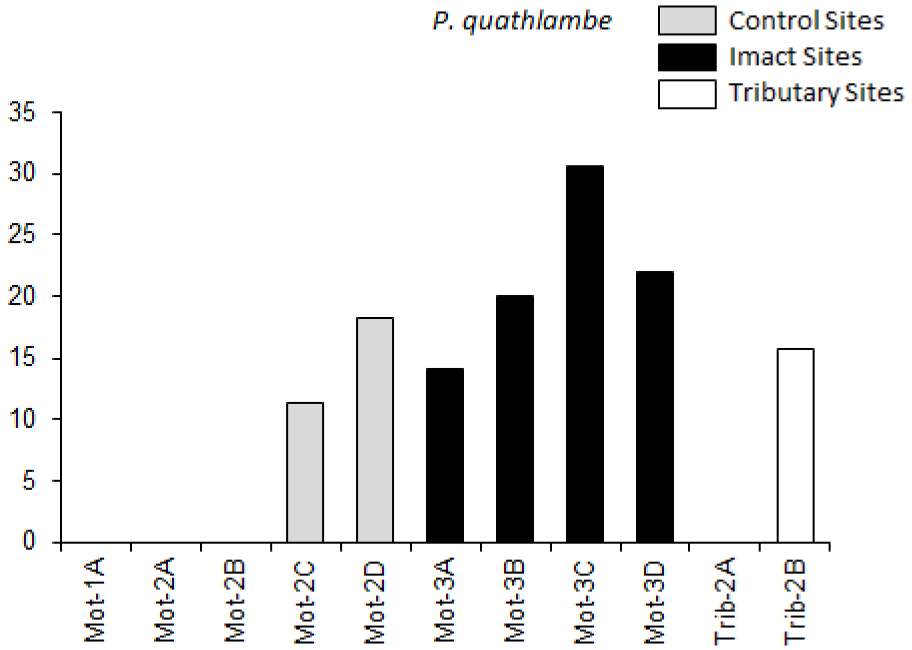


Figure 2.5 Relative abundance (CPUE, fish/hr) of *P. quathlambae* collected from the mainstem and tributaries of the Mothae River. The grey bars represent fish caught upstream of the mine tributary (Control sites), the black bars sites downstream of the mine tributary (Impact sites) and open bars sites in the mine tributary.

Fish size classes—the mean size of *P. quathlambae* caught on the Mothae River was 89.6 (±SD 21.5) mm TL and 82.7 (±SD 20.5) mm FL respectively and the maximum length was 122 mm TL and 115 mm FL respectively. A length frequency histogram of age classes for all sites and reaches is shown in Figure 2.6 and for the Control (Mot-2) and Impact (Mot-3) reaches in Figure 2.7. Fewer and larger fish were caught upstream of the mine tributary (Mot-2) than downstream. Most young fish were caught in the Impact reach (Mot-3).

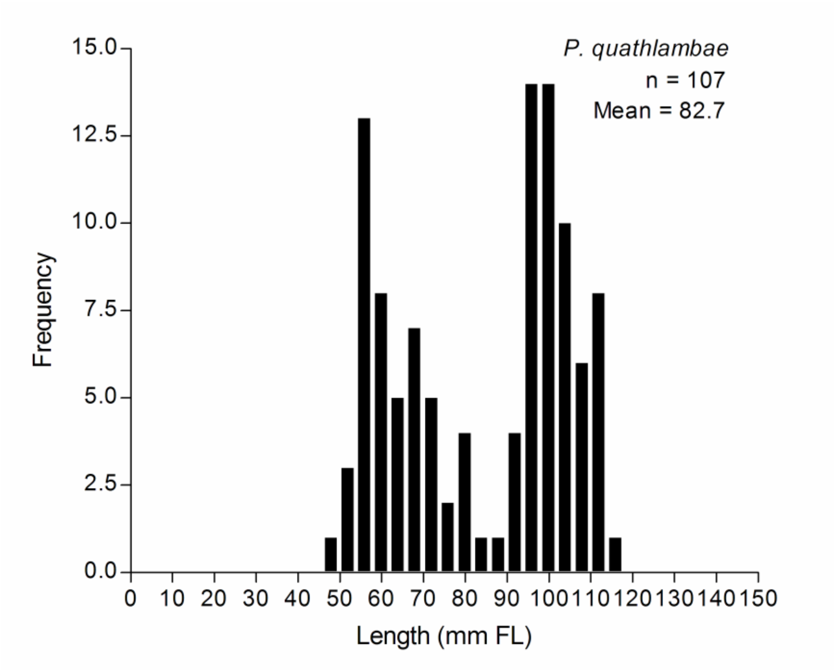


Figure 2.6 Frequency histogram of *P. quathlambae* size classes (mm FL).

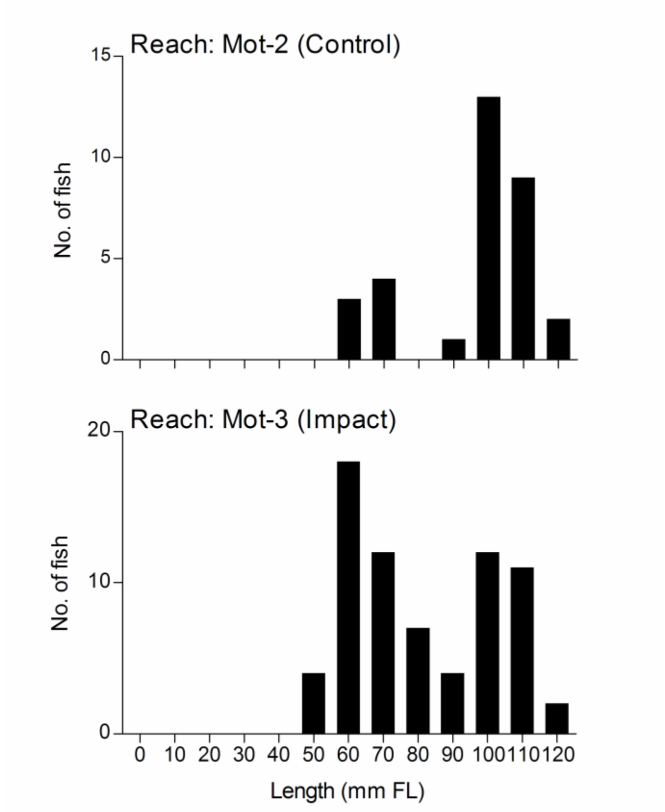


Figure 2.7 Length classes of *P. quathlambae* for the Control (Mot-2) and Impact (Mot-3) sites.

A von Bertolanffy growth curve developed by Rall (1999) for the Bokong River population (Figure 2.8) was used to estimate the age classes of *P. quathlambae* caught in the Mothae River (Figure 2.9).

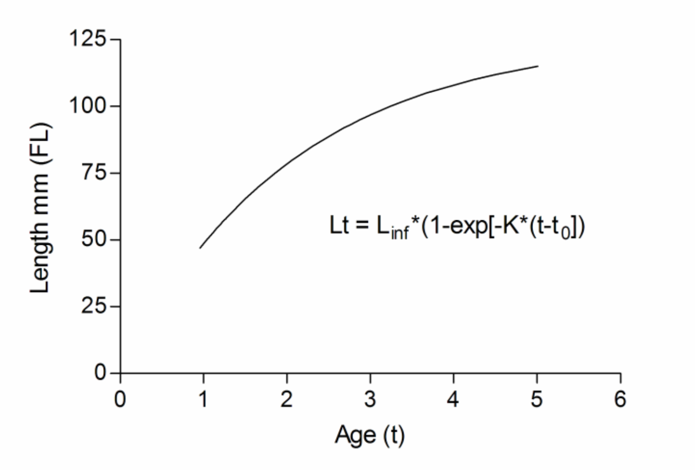


Figure 2.8 Von Bertolanffy growth curve developed from *P. quathlambae* populations in the Bokong River by (Rall 1999) and used in this study to establish age-classes for the Mothae River population: Lt = length at time ‘t’, L_{inf} = 126 (asymptotic length), K = 0.487 (rate at which maximum size is reached), t = age in years.

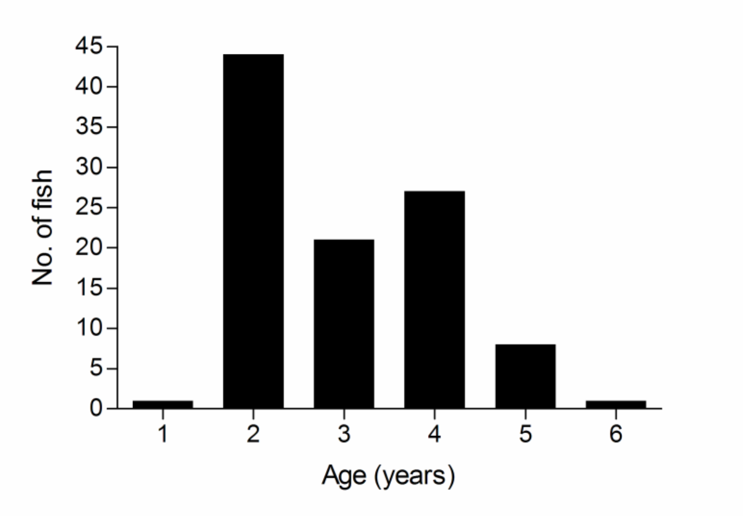


Figure 2.9 Age classes of fish population in the Mothae River from Rall’s (1999) growth model developed for populations in the Bokong River.

The Bokong River growth model was selected since it was considered the most similar in terms of habitat conditions (shorter, faster, steeper and shallower) to the Mothae River than the models developed by Rall (1999) for populations in the Jordane and Senqunyane Rivers (Rall, *pers. comm.*). The Bokong model suggests a maximum age of 6 years for the Mothae River population with a bimodal distribution at 2 and 4 years. It should be noted, however, that genetic divergence between the Bokong and Mothae River populations means that these estimates may require revision and should therefore be regarded as preliminary.

2.5 Conclusions

As the only endemic vertebrate in Lesotho and an IUCN-listed species, the Maloti minnow has an iconic conservation status in that country. The declining trend of populations throughout its range as a result of invasion by exotic fish species and water resource development, as well as its early disappearance from rivers in South Africa, emphasizes the importance of conserving the few remaining populations that have thus far evaded these threats.

This study has recorded the presence of a previously undocumented population of *P. quathlambae* in the Mothae River, Lesotho. Their presence in this river has therefore important national and international implications for their future conservation and management. Reports of the decline and possible localized extinction of the populations in the Matsoku River, into which the Mothae River feeds, means that the Mothae population is more than likely all that remains of this population making the need for effective management all the more pressing. The vulnerability of Mothae *P. quathlambae* in the Mothae River is highlighted by the fact that their upstream passage is limited by a waterfall which restricts their distribution to within 6.6 km of the Matsoku confluence, of which ~ 900 m is upstream of the Mothae Mine tributary. The downstream limit of their distribution is currently not known, but it is suggested that this be established in future surveys.

The relative abundances of fish in the river were relatively low (max. 0.004 fish/hr). However, the survey was conducted late in the season (mid-April) when temperatures start declining and fish become less susceptible to being caught. The presence of all size and age classes in the river and the absence of invasive species such as trout, however, suggests that the population is healthy and recruiting. This was confirmed by the growth model confirming the presence of relatively high abundances of age 1+ fish. Although similar relative abundances of adults were caught at the Control and Impact sites (reaches Mot-2 and Mot-3 respectively), the greater numbers of small fish in the Impact site (downstream of the mine tributary), suggest that these reaches are important for recruitment processes in the Mothae River.

3. ASSESSMENT OF POTENTIAL IMPACTS ON FISH POPULATIONS

Potential future sources of risk to Maloti redfin populations as a result of the proposed mining activities by Mothae Diamonds have been identified and grouped into the following four categories:

5. Increase sediment supply (Total Suspended Sediment (TSS), turbidity and sedimentation)
6. Wastewater pollutants;
7. Water abstraction, impoundments and flow modification and
8. Facilitating the translocation of invasive species.

A detailed description of each current and future impact and the corresponding response of fish populations is explained in the ensuing sections. Each section contains assessment tables that relate to the factors considered in that section and which lists the impacts in terms of their extent, duration, magnitude, significance and confidence in the predictions. Mitigation measures are recommended for each impact. **Note**: only **Alternative D** outlined in the Conceptual Study was assessed here.

3.1 Increased sediment supply (Total Suspended Sediment (TSS), turbidity and sedimentation)

TSS and Turbidity—TSS refers to the concentration (mg/*l*) of fine sediments that remain in suspension in the water column. It is also measured as turbidity (nephelometric units, NTUs) – a property of sediments that causes light to scatter in water and reduce its penetration. The quantity of TSS and the size of the particles is a function of supply from the upstream catchment and flow rate. Higher flow rates are able to transport more and larger particles. Once flow rates decline – either in pools or over low flow periods – sediments precipitate out of suspension and become deposited on the river bed.

Increased concentrations of TSS in rivers can result in histological damage to fish gills, causing clogging, excessive mucous production and respiratory impairment. Sutherland and Meyer (2007), for example, reported significant impairment to gill condition of an upland minnow exposed to 500 mg/*l* for 21 days together with a 15-fold decrease in growth rates. Prolonged exposure can also reduce resistance to disease and result in abnormal development of eggs and larvae (Bergstedt and Bergersen 1997). In this regard, Rivier and Seguier (1985) reported a 75 % mortality of brown trout eggs after exposure to 20-100 mg/*l* for 20 days. An increase in TSS also disrupts feeding which affects the nutrition, health and growth of individual fish. Turbidity reduces forage efficiency resulting in reduced prey capture rates. The Maloti redfin depends on visual detection of invertebrate prey and reaction time is reduced in turbid conditions. Prey availability may also decline as a result of TSS effects on benthic invertebrate communities. The severity of the impact depends not only on the concentration of TSS, but also on the frequency, duration and timing of exposure (Bergstedt and Bergersen 1997). Figure 3.1 summarises the principal impacts to fish arising from exposure to a range of turbidity values at consecutively longer exposure intervals. From this schematic, it is clear that a distinction should be made between chronic (long term) and episodic (e.g. rainfall dependent) increases in suspended sediment. Maloti redfin populations in the Mothae River are able to persist despite current elevated TSS values that result from overgrazing and erosion. However, these events are likely sporadic and rainfall dependent. It is expected that prolonged exposure to higher than normal TSS levels in the Mothae River would have a detrimental impact on fish populations.

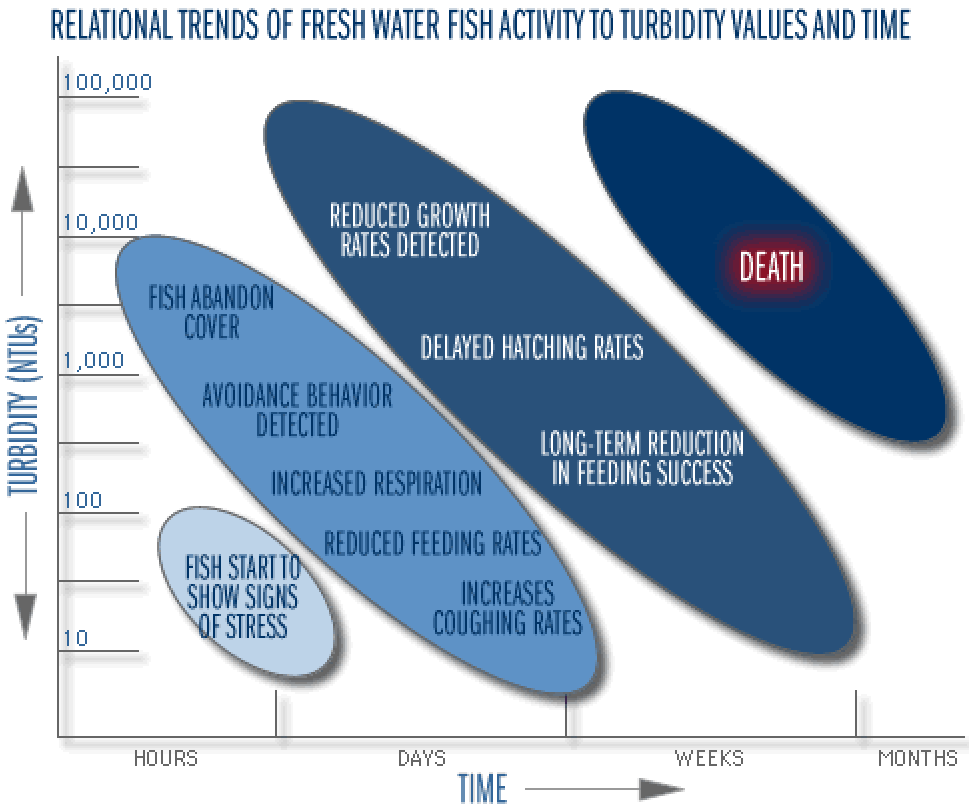


Figure 3.1 Schematic of the relationship between turbidity and fish population responses (Munson et al. 2008).

Sedimentation and physical habitat integrity—Sedimentation is the process whereby sediment carried in the suspended load settles out of suspension and onto the river bed. The degree of sedimentation will depend on the size of the particles and flow rate. At low flows, or along slow-flowing channel margins and in pools, more sediment will settle out of suspension than at high flows or in faster flowing riffles or rapids.

Deposited material accumulates among substratum particles covering structural elements of the river bed, thereby reducing instream habitat diversity and complexity and therefore its suitability to support river fish populations (Mol and Ouboter 2004). Interstitial spaces between larger bed particles (boulders, cobbles and gravels) provide important hydraulic and predation cover for adults and juveniles, as well as breeding areas for fish such as the Maloti redfin that tend to spawn in rocky crevices. Increased fines in and on the bed of the river reduces the size and abundance of interstitial spaces, subsurface flow rates decline, and the reduced exchange of gases around eggs and developing larvae leads to increased mortality. For example, Wyatt et al. (2010) found that a sediment covering of >1 mm for a period of six days significantly reduced the survival of rainbow smelt embryos. Diminished availability of interstitial habitat also impacts food availability for invertivorous fish because of its concomitant effects on benthic invertebrate communities. Table 3.1 summarises the potential impacts of an increase in TSS, turbidity and sedimentation from fine tailings and Table 3.2 the impacts arising from non-point sediment sources at the Mothae mine.

Table 3.1 Summary table of the impacts of increased TSS, turbidity and sedimentation from fine tailings on indigenous fish species.

ASPECT: Indigenous Fish **POTENTIAL IMPACT: Increased TSS and turbidity from fine tailings**		
Impact description:		**Source**: Failure or poor performance of tailings storage facilities – slimes dams and dumps – due to seepage, overtopping and/or failure during storm events **Maloti redfin response**: stress response, avoidance behaviour, respiratory impairment, reduced growth rates, egg and larval mortality, reduced foraging efficiency, reduced habitat integrity and reduced complexity, recruitment failure.
Proposed mitigation:		• No slimes dams should be constructed in the catchment to the north of the ore body (Option D) • Proper design and implementation of a tailings management system • Implement water quality monitoring at high risk points and continuous automated monitoring in the Mothae River • Design and implement an adaptive management strategy to review environmental performance and mitigate unforeseen impacts • Interpretative signage and education campaign for mine staff and visitors to highlight the conservation importance of the Maloti redfin and the importance of sound environmental management practices
Nature of impact:	without mitigation	Negative (Direct)
	with mitigation	Negative (Direct)
Extent of impact:	without mitigation	National, International
	with mitigation	National, International
Duration of impact:	without mitigation	Long term
	with mitigation	Long term
Magnitude (intensity) of impact:	without mitigation	Medium
	with mitigation	Low
Consequence of impact:	without mitigation	High
	with mitigation	High
Probability of occurrence:	without mitigation	Probable
	with mitigation	Unlikely
Significance rating:	without mitigation	Major
	with mitigation (residual impact)	Minor
Confidence rating:		Medium
Irreplaceable loss of resources:		Possibly YES (without mitigation). If TSS or turbidity levels in the Mothae River increased to levels that led to the loss of the Maloti redfin, this would represent an irreplaceable loss of an important population of an endangered fish species.

Table 3.2 Summary table of the impacts of increased TSS and turbidity from non-point source runoff on indigenous fish species.

ASPECT: Indigenous Fish **POTENTIAL IMPACT: Increased TSS and turbidity from non-point sources runoff**		
Impact description:		**Source**: non-point source runoff from (1) construction phase activities, i.e. roads, tailings dams, mine camp, blasting; (2) mining-related storage and transport infrastructure: roads, overburden and tailings dump, site offices. **Maloti redfin response**: stress response, avoidance behaviour, respiratory impairment, reduced growth rates, egg and larval mortality, reduced foraging efficiency, degraded habitat integrity and reduced complexity, recruitment failure.
Proposed mitigation:		• Minimise and contain runoff from construction phase activities, i.e roads, tailings dams, mine camps, blasting sites; • Channel runoff from disturbed, non-vegetated areas into slimes dams; • Take special precautions at excavation sites to route drainage into slimes dams • Implement water quality monitoring at high risk points and continuous automated monitoring in the Mothae River • Design and implement an adaptive management strategy to review environmental performance and mitigate unforeseen impacts • Interpretative signage and education campaign for mine staff and visitors to highlight the conservation importance of the Maloti redfin and the importance of sound environmental management practices
Nature of impact:	without mitigation	Negative (Direct)
	with mitigation	Negative (Direct)
Extent of impact:	without mitigation	National, International
	with mitigation	National, International
Duration of impact:	without mitigation	Long term
	with mitigation	Long term
Magnitude (intensity) of impact:	without mitigation	Medium
	with mitigation	Low
Consequence of impact:	without mitigation	High
	with mitigation	High
Probability of occurrence:	without mitigation	Probable
	with mitigation	Probable
Significance rating:	without mitigation	Moderate
	with mitigation (residual impact)	Minor
Confidence rating:		Medium
Irreplaceable loss of resources:		Possibly YES (without mitigation). If TSS/turbidity in the Mothae River increased to levels that led to the loss of the Maloti redfin, this would represent an irreplaceable loss of an important population of an endangered fish species.

3.2 Wastewater pollutants

The constituents of effluent from Wastewater Treatment Plants and its effect on receiving ecosystems is varied and depends on the sources of the wastewater and treatment processes (Tsai 1978). In general, wastewater may contain chlorine, detergents, ammonia and industrial wastes, all of which are toxic to aquatic organisms. In addition to toxic substances, both treated and untreated wastewater contains organic pollutants including nitrates and phosphates that increase primary productivity in the receiving water body. If these can be assimilated by the ecosystem, they can be beneficial, but if they can’t, then oxygen concentrations decline and algal blooms could proliferate in the receiving water bodies. Apart from being direct causes of mortality in freshwater fishes, toxic substances in wastewater are known suppressants of immune system responses, resulting in increased parasite loads, increased susceptibility to bacterial infections and reduced fish condition (Bernet et al. 2000, Poulin 1992). Developing embryos and larval fish are particularly sensitive to these environmental stressors (McKim 1977). Table 3.3 summarises the impacts of an accidental discharge of wastewater or poor performance of the WWTW on the indigenous fish population and Table 3.4 summarises the impacts of potential non-point sources of contamination.

Table 3.3 Summary table of the impacts of accidental discharge of untreated wastewater, or poor performance of WWTW on indigenous fish species.

ASPECT: Indigenous Fish **POTENTIAL IMPACT: Accidental discharge of untreated wastewater or poor performance of WWTW**		
Impact description:		**Source**: failure or poor performance of the proposed WWTW **Maloti redfin response**: suppressed immune system responses, increased parasite loads, increased susceptibility to and occurrence of bacterial infections and reduced fish condition (Section 3.2)
Proposed mitigation:		• Construct an artificial wetland downstream of the slimes dam to further reduce levels of organic and inorganic waste and sediment loads emanating from the dam and mitigate the effects of accidental wastewater discharge • Interpretative signage and education campaign for mine staff and visitors to highlight the conservation importance of the Maloti redfin and the importance of sound environmental management practices
Nature of impact:	without mitigation	Negative (Direct)
	with mitigation	Negative (Direct)
Extent of impact:	without mitigation	National, International
	with mitigation	National, International
Duration of impact:	without mitigation	Long term
	with mitigation	Long term
Magnitude (intensity) of impact:	without mitigation	Medium
	with mitigation	Low
Consequence of impact:	without mitigation	High
	with mitigation	High
Probability of occurrence:	without mitigation	Probable
	with mitigation	Unlikely
Significance rating:	without mitigation	Major
	with mitigation (residual impact)	Moderate
Confidence rating:		Medium
Irreplaceable loss of resources:		Possibly YES (without mitigation). If wastewater contamination of the Mothae River increased to levels that led to the loss of the Maloti redfin, this would represent an irreplaceable loss of an important population of an endangered fish species.

Table 3.4 Summary table of the impacts of increased wastewater contaminants from non-point source runoff on indigenous fish species.

ASPECT: Indigenous Fish **POTENTIAL IMPACT: Increased wastewater contaminants from non-point pollution sources**		
Impact description:		**Source**: non-point source runoff from site offices, fuel stores, waste disposal sites, parking areas and workshops. **Maloti redfin response**: stress response, avoidance behaviour, impaired immune system response, recruitment failure.
Proposed mitigation:		• Alternative D shows the truck workshop and fuelling station located in the southern catchment adjacent the mine tributary river. It is suggested that the workshop and fuelling station be located 50-100 m away from the active channel. • Minimise and contain runoff from contaminated areas such as truck workshops and fuel stores; • Collect and contain polluted water and route through WWTW; • Channel less-polluted water into slimes dams; • Implement water quality monitoring at high risk points and continuous automated monitoring in the Mothae River • Design and implement an adaptive management strategy to review environmental performance and mitigate unforeseen impacts • Interpretative signage and education campaign for mine staff and visitors to highlight the conservation importance of the Maloti redfin and the importance of sound environmental management practices
Nature of impact:	without mitigation	Negative (Direct)
	with mitigation	Negative (Direct)
Extent of impact:	without mitigation	National, International
	with mitigation	National, International
Duration of impact:	without mitigation	Long term
	with mitigation	Long term
Magnitude (intensity) of impact:	without mitigation	Medium
	with mitigation	Low
Consequence of impact:	without mitigation	High
	with mitigation	High
Probability of occurrence:	without mitigation	Probable
	with mitigation	Probable
Significance rating:	without mitigation	Moderate
	with mitigation (residual impact)	Minor
Confidence rating:		Medium
Irreplaceable loss of resources:		Possibly YES (without mitigation). If contamination in the Mothae River increased to levels that led to the loss of the Maloti redfin, this would represent an irreplaceable loss of an important population of an endangered fish species.

3.3 Water abstraction, impoundment and flow modification

A hydrological analysis of the Mothae River basin as a whole was not available at the time of writing. However, a cursory examination of the basin suggests that the east bank catchments of the Mothae River – of which there are approximately seven – may contribute a significant proportion of the Mean Annual Runoff (MAR) to the river. Freshwater and slimes dams are being considered in two (30%) of these east bank catchments.

The Mothae Conceptual Study (ADP Projects (Pty) 2009) estimated the volume of clean water needed for the first year of operation to be around 2.164 M m^3. Since the MAR of the catchments draining into the slimes and freshwater dams was estimated at only 0.6 M m^3, there is a considerable shortfall in the volume of water available on site. The Conceptual Study therefore suggests that this shortfall be met by impounding the Mothae River. With or without this dam, it is likely that the mine will reduce flow volumes in the Mothae River. This has the potential to alter aquatic habitats downstream. River fish have evolved a variety of adaptations to life in flowing water. It follows that any alteration to river flow, i.e. changes to its magnitude, timing or seasonality, will impact fish populations downstream. Water abstraction and dams are recognised as one of the principal threats to freshwater fish diversity worldwide (Nilsson et al. 2005). They inundate flowing-water habitats, alter the volume and timing of flows, change water quality and temperature regimes downstream, fragment river corridors, block fish migrations and facilitate biological invasions (Nilsson et al. 2005, Revenga et al. 2000, Johnson et al. 2008, Clarkson and Childs 2000).

Second order impacts of dams include cross-sectional, planform and bedform changes to river morphology (Brandt 2000, McCartney and King 2011). Physical habitat integrity is compromised as processes of bed material composition and sorting, sedimentation and scouring are altered. As pointed out in Sections 3.1, the combined effects of an increase in the sediment supply and reduced flows will increase sedimentation rates in the Mothae River with attendant impacts to the Mothae Maloti redfin population.

The Mothae River Maloti redfin population will be particularly susceptible to reduced flows over the dry season when water quality conditions may deteriorate – exacerbated by low temperatures, increased sediment inputs, livestock grazing and nutrient loading. Pools may become shallow enough to freeze over, thereby reducing the availability of fish habitat. Reduced wet season flows will impact spawning and recruitment if there is insufficient water of an adequate quality to provide spawning and/or migration cues or incubate eggs. Table 3.5 summarises the impacts of water impoundment, abstraction and use by an in-channel dam on the Mothae River and Table 3.6 summaries the impact of water abstraction from one of the mine tributaries.

Table 3.5 Summary table of the impacts of water impoundment, abstraction and use (in-channel dams) on indigenous fish species.

ASPECT: Indigenous Fish POTENTIAL IMPACT: Water abstraction and use (in-channel dams)		
Impact description:		**Source**: dam located on the mainstem of the Mothae River **Maloti redfin response**: inundation of flow-water habitat, reduction in the total amount of aquatic habitat, altered flows downstream of the dam, increased sedimentation, degraded habitat conditions, altered temperature regime (Section 3.3)
Proposed mitigation:		• It is recommended that no dam be built on the mainstem of the Mothae River
Nature of impact:	without mitigation	Negative (Direct)
	with mitigation	Negative (Direct)
Extent of impact:	without mitigation	National, International
	with mitigation	National, International
Duration of impact:	without mitigation	Permanent
	with mitigation	Permanent
Magnitude (intensity) of impact:	without mitigation	High
	with mitigation	Low
Consequence of impact:	without mitigation	Very High
	with mitigation	Low
Probability of occurrence:	without mitigation	Definite
	with mitigation	Unlikely
Significance rating:	without mitigation	Major
	with mitigation (residual impact)	Negligible
Confidence rating:		High
Irreplaceable loss of resources:		Possibly YES (without mitigation). If water regulation by a mainstem dam on the Mothae River leads to the loss of the population of Maloti redfin in the river, this would represent an irreplaceable loss of an important population of an endangered fish species.

Table 3.6 Summary table of the impacts of water abstraction and use (off-channel dams) on indigenous fish species.

ASPECT: Indigenous Fish POTENTIAL IMPACT: Water abstraction and use (off-channel dams)		
Impact description:		**Source**: Abstraction of water from dams located on mine tributaries and reduced freshwater inflows **Maloti redfin response**: reduced discharge in the Mothae River, particularly of the dry season will reduce the availability of fish habitat, reduced wet season flows will impact spawning and recruitment (Section 3.3)
Proposed mitigation:		• Institute a water conservation and demand management system regulating all water use by the mine • Interpretative signage and education campaign for mine staff and visitors to highlight the conservation importance of the Maloti redfin and the importance of water conservation
Nature of impact:	without mitigation	Negative (Direct)
	with mitigation	Negative (Direct)
Extent of impact:	without mitigation	National, International
	with mitigation	National, International
Duration of impact:	without mitigation	Long term
	with mitigation	Long term
Magnitude (intensity) of impact:	without mitigation	Medium
	with mitigation	Low
Consequence of impact:	without mitigation	High
	with mitigation	High
Probability of occurrence:	without mitigation	Probable
	with mitigation	Unlikely
Significance rating:	without mitigation	Major
	with mitigation (residual impact)	Moderate
Confidence rating:		Medium
Irreplaceable loss of resources:		Probably not. Impacts will be detectable, but on their own they may not result in a complete loss of the Maloti redfin population.

3.4 Introduction of invasive fish species

Increased access to the river, dam building and human activity in the mine area will increase the risk of invasive fish species such as trout being intentionally introduced. Impounded rivers are known to significantly increase the risk of biological invasion. Non-native fish species are more likely to be introduced into dams for recreational purposes, or to be transferred through water resource infrastructure (Johnson et al. 2008). In this regard, Maloti redfin populations are believed to have disappeared from the Mastoku River primarily as a consequence of the invasion of smallmouth yellowfish via water resource infrastructure for the Katse Dam (Section 2.1.2). Table 3.7 summarises the potential impacts of introduced invasive fish species on the indigenous fish.

Table 3.7 Summary table of the impacts of translocation and invasion by invasive fish species on indigenous fish species.

ASPECT: Indigenous Fish **POTENTIAL IMPACT: Facilitating translocation and invasion by introduced fish species**		
Impact description:		**Source**: intentional introduction of exotic species such as trout by mine staff and/or visitors. **Maloti redfin response**: Predation of Maloti redfin by exotic fish species
Proposed mitigation:		• Interpretative signage and education campaign for mine staff and visitors to highlight the conservation importance of the Maloti redfin and the risks of introducing exotic fish species.
Nature of impact:	without mitigation	Negative (Direct)
	with mitigation	Negative (Direct)
Extent of impact:	without mitigation	National, International
	with mitigation	National, International
Duration of impact:	without mitigation	Permanent
	with mitigation	Permanent
Magnitude (intensity) of impact:	without mitigation	High
	with mitigation	Low
Consequence of impact:	without mitigation	Very High
	with mitigation	Low
Probability of occurrence:	without mitigation	Probable
	with mitigation	Probable
Significance rating:	without mitigation	Major
	with mitigation (residual impact)	Moderate
Confidence rating:		High
Irreplaceable loss of resources:		YES (without mitigation). The introduction of trout or smallmouth yellowfish into the Mothae River or its tributaries would result in the extinction of an important endangered fish population

3.5 Cumulative impacts

Cumulative impacts refer to the interactive, incremental effects of mining activities that individually may not pose a threat to river fish populations, but which together and over time may result in a decline in population abundances or a loss of the population from the site. Thus, while sediment bearing runoff from the Mothae mine may not, by itself, pose a significant threat to Maloti redfin populations, when combined with contaminants and reduced water quantities, the combined affect may cause undue stress to populations.

A potential interactive impact is the link between the quality of water in the Mothae River impacted by mining (Section 3.1 and 3.2) and its quantity (Section 3.3). A reduced volume of water as a result of abstraction and/or impoundment reduces mean water column velocities which results in sediment settling out of suspension and reducing the permeability of gravels and cobbles. A reduced volume of water will also increase the concentration of any contaminants and nutrients won't be flushed through the system effectively. If these impacts occur at a critical time of the year, i.e. over the spawning period, they may result in fish egg and larval mortality and recruitment failure. Successive recruitment failure over a number of years may lead to the decline, and possible localised extinction of the population.

The potential loss of another Maloti redfin population from the Matsoku River catchment due to cumulative impacts; is considered an impact of high significance that highlights the importance of managing individual impacts in each of the categories identified and assessed above (Sections 3.1 to 3.4).

4. MONITORING PLAN (FISH)

4.1 Introduction

This section describes the rationale, objectives and methodology of a programme to monitor Maloti redfin populations downstream of the Mothae Diamond Mine in order to assess the effectiveness of environmental management practices and the recommendations contained in this document. It includes a description of the key indicators used to assess the status of fish populations, outlines equipment and personnel requirements, describes assessment methodologies. It also identifies high risk points where habitat monitoring needs to take place and where automated monitoring devices must be situated.

4.2 Rationale

In order to be assured that the measures taken to mitigate mining impacts are being effective, regular, precise and consistent estimates of fish population statistics, i.e. relative abundance and size structure, together with individual health and condition, are required. Fish are important components of river ecosystems because they are long-lived and integral to aquatic food webs. They are considered key indicators of environmental change because of their varied life history strategies and sensitivity to a wide range of hydrologic and water quality variables (Kleynhans 1999, Karr 1981, Fausch *et al*. 1990). Fish monitoring protocols are generally developed from baseline data that define existing reference (or near natural) conditions obtained either from studies of unimpacted river reaches, or studies undertaken prior to any disturbance. Following a period of monitoring, trends away from or towards natural can then be assessed and corrective management interventions implemented. These management interventions are triggered by Thresholds of Potential Concern (TPCs) (Section 1).

4.3 Objectives of the Fish Monitoring Programme

The objectives of fish component of the Monitoring Programme are to:

- routinely measure a set of pre-defined indicators that will detect trends in fish populations in the Mothae River, Lesotho affected by mining activities;
- detect shifts in the fish community and population size structure, recruitment success, relative abundance and distributions that may result from mining operations;
- assess whether the objectives of the Environmental Management Plan are being met;
- assess fish response against TPCs in order to provide input to the auditing, evaluation and review process and provide guidance with respect to adaptive management strategies.

4.4 Data collection

Fish community composition should be sampled at Environmental Monitoring Sites consistent with the sites sampled during the course of the Baseline Survey, i.e. Mot-2C, Mot-2D, Mot-3A, Mot-3B, Mot-3C, Mot-3D, Trib-2A and Trib-2B.

4.4.1 Activities

The fish monitoring comprises two main activities (1) fish community composition and population structure and (2) assessment of fish habitat and water quality conditions.

4.4.2 Frequency of data collection

It is suggested that sampling take place twice a year, in the beginning (September) and towards the end (February) of the wet season. Sampling towards the end of the wet season will provide an indication of recruitment success for the year.

4.4.3 Fish sampling

The reaches of the Mothae River of interest to this study are located in a relatively high gradient headwater and mountain foothill zone, seine gill nets, and fishing rods are not considered suitable. This is mainly because of:

- the cobble-boulder substratum;
- the absence of large pools and sandy beaches suitable for these gear types;
- the high flows, and difficulties encountered with sampling the main current;
- Thus electrofishing is considered the most appropriate sampling technique.

Electrofishing should be conducted along the margins and thalweg of the active channel and in the side channels. Starting from the most downstream end of the site, the electrofishing team should proceed in an upstream direction for a distance of *c.* 150 – 200 m using a side-to-side sweeping motion with the anode. Geographical coordinates of the upstream and downstream limits of the electrofished reach should be recorded using a handheld GPS unit.

Stunned fish should be captured either by the electrofisher unit operator using a net fitted to the anode, or by the assistant using a landing net. The assistant is responsible for the care and transport of the fish in buckets or livewells during the electrofishing operation. Fishing effort should be recorded as time (hours) and this should be kept as constant as possible – between 30 and 45 minutes. Captured fish should be identified, enumerated and their Fork Length (FL, mm), Total Length (TL, mm) recorded on the ‘Fish Survey Datasheet’ provided in Section 2.3. Their weight (grams) should be measured using an electronic scale accurate to ≤ 1 g for smaller fish. Any external anomolies (deformities, parasites or lesions) should be noted and recorded.

4.4.4 Habitat assessment

A rapid visual assessment of fish habitat should be conducted after each fish survey. The habitat assessment has been designed to evaluate the quality of the fish habitat at each site by means of a range of instream, channel and bank morphological features using basic equipment and minimum sampling effort. It is based on the hydraulic biotope and geomorphological habitat classification systems described in Kleynhans (1999) and Rowntree and Wadeson (1999). The reach to be assessed should correspond to the same 150-200 m reach that was electrofished - note that the habitat assessment should take place after the fish survey to avoid disturbance.

The habitat assessment proposed here is a transect-based semi-quantitative estimate of the proportion of physical habitat types available to fish species at each site. It is suggested that the reach be divided into between five and ten transects spaced at *c*. 20 m intervals which should correspond to the electrofished reach. The transect should begin at the edge of the macro-channel and extend to the thalweg (the middle of the active channel) if the river is uncrossable. This should limit errors associated with estimating habitat characteristics on the opposite bank should the river be uncrossable. To facilitate estimates of habitat unit lengths, the macrochannel width should be obtained from the topographic survey information.

Habitat features relevant to fish are grouped into four classes: (1) substratum size; (2) flow-depth; (3) flow type and (4) fish cover. The classes have been adapted from their original groupings to reflect those most relevant to fish.

(2) **Fish Cover Classes**: estimate of cover in the form of vegetation or substratum used by fish to avoid detection by aerial or aquatic predators.

Category		Description
Overhanging vegetation	OV	Vegetation overhanging ≥0.3 m, <0.1 m above surface
Undercut banks/root wads	UB	Banks overhanging ≥0.3 m and <0.1 above surface
Aquatic and emergent macrophytes	AM	Submerged and emergent water plants

(3) **Substratum Classes**: estimate of the proportion and size of the bed particles available to fish to use for hydraulic and predation cover or for reproduction in the case of lithophilous spawners.

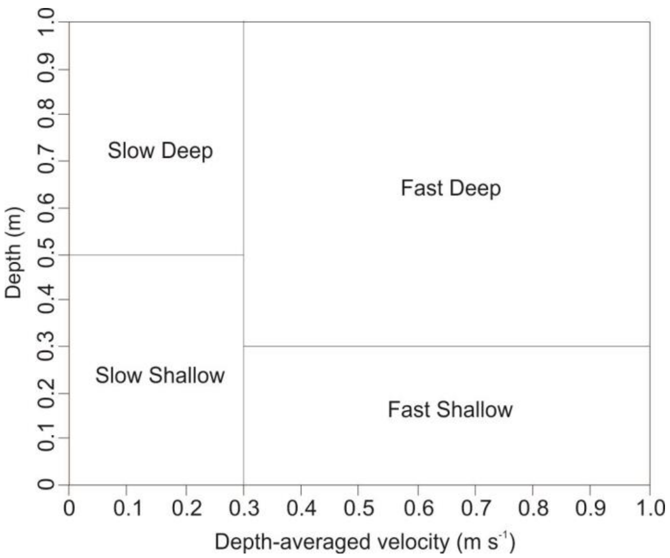
Category		Size	Description
Silt/Sand	SS	<0.063-2	mud to course grit
Gravel	GR	2-16	finger nail to length of small finger
Small Cobble	SC	64-128	wrist to halfway along finger
Large Cobble	LC	128-256	elbow to wrist
Boulder	B	>256	> armpit to wrist
Bedrock	BR		Slabs of rock

(4) **Flow Types**: classification of flow types. The ‘Flow’ column is an aid for identifying the appropriate ‘Flow Classes’ defined in (2) above.

Category		Description	Flow
Dry	D	No water	
No Flow	NF	No water movement	Slow
Barely Perceptible Flow	BPF	Smooth surface, suspended sediment movement evident	Slow
Smooth Boundary Turbulent	SBT	Smooth surface, streaming flow, upward movement of suspended sediment	Fast
Rippled surface	RS	Low transverse ripples across direction of flow	Fast
Standing Waves	SW	Broken and unbroken/undular standing waves	Fast

(5) **Flow-Depth Classes**: estimate of the proportion of available habitat in each of the flow and depth classes (summarised in that follows). The ‘Flow types’ described in (3) below provide a guide for classifying estimated current speed into ‘Fast’ or ‘Slow’.

Current Speed	Current Depth		Description
Slow (<0.3 m/s)	Shallow (<0.5 m)	SS	shallow pools and backwaters
Slow (<0.3 m/s)	Deep (>0.5 m)	SD	deep pools and backwaters
Fast (>0.3 m/s)	Shallow (<0.3 m)	FS	rapids and riffles shallow runs
Fast (>0.3 m/s)	Deep (>0.3 m)	FD	deep runs rapids and riffles



Transect locations should be selected based on distinct changes in river morphology such as single-channel vs. multi-channel reaches or pools vs. rapids. Starting at the beginning of the transect from the macro-channel edge, habitat units are defined at 1 m intervals within a 1 m wide belt transect either side of the measuring tape or meter rule. Within this unit, habitat features are assessed based on the four categories suggested above: fish cover, largest substratum class[2], flow type and flow-depth class. Current speed for the flow-depth classes can be estimated from the flow type. This information is entered into the 'River Habitat Assessment – Fish Component' datasheet provided in Section 4.6. Only wetted habitats need be assessed. Where the channel is dry – on a mid- or side-channel bar for instance – it is not necessary to record substratum or cover classes, only the width of the bar. If habitat conditions are relatively uniform over a distance of more than a meter, this can be indicated on the datasheet in the appropriate block and the habitat conditions characterised for the estimated distance. Habitat unit lengths can be measured to the point that the channel is safely wadeable. Beyond this point the length of habitat features will need to be estimated to the thalweg. A photograph should be taken of each transect and its number recorded on the datasheet.

4.5 Continuous discharge and turbidity monitoring

The following variables should be monitored continuously in the Mothae River: (1) water level, (2) turbidity.

Water level and discharge monitoring equipment

- Water level data loggers accurate to 0.01 m accuracy
- Stainless steel housing
- Electromagnetic flow meter for establishing a rating curve.

Turbidity monitoring equipment

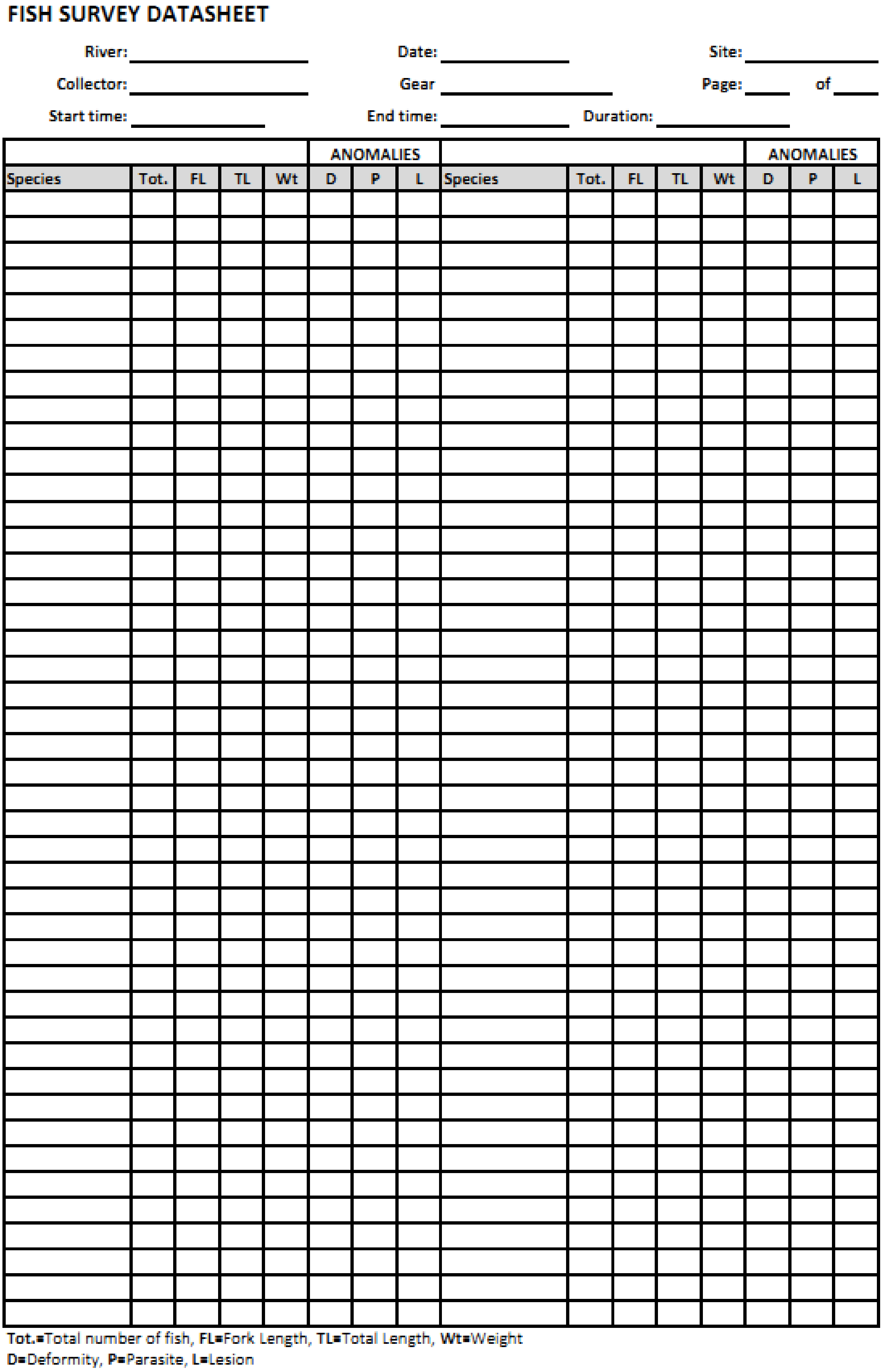
- Water level data loggers accurate to 0.01 m accuracy
- Stainless steel housing

Both these units should be installed directly downstream of the mine tributary. A second turbidity meter should be installed upstream of the mine tributary as a control.

---

[2] The largest substratum class is recorded since this is the size most likely to provide hydraulic cover to fish

4.6 Datasheets



FISH SURVEY DATASHEET

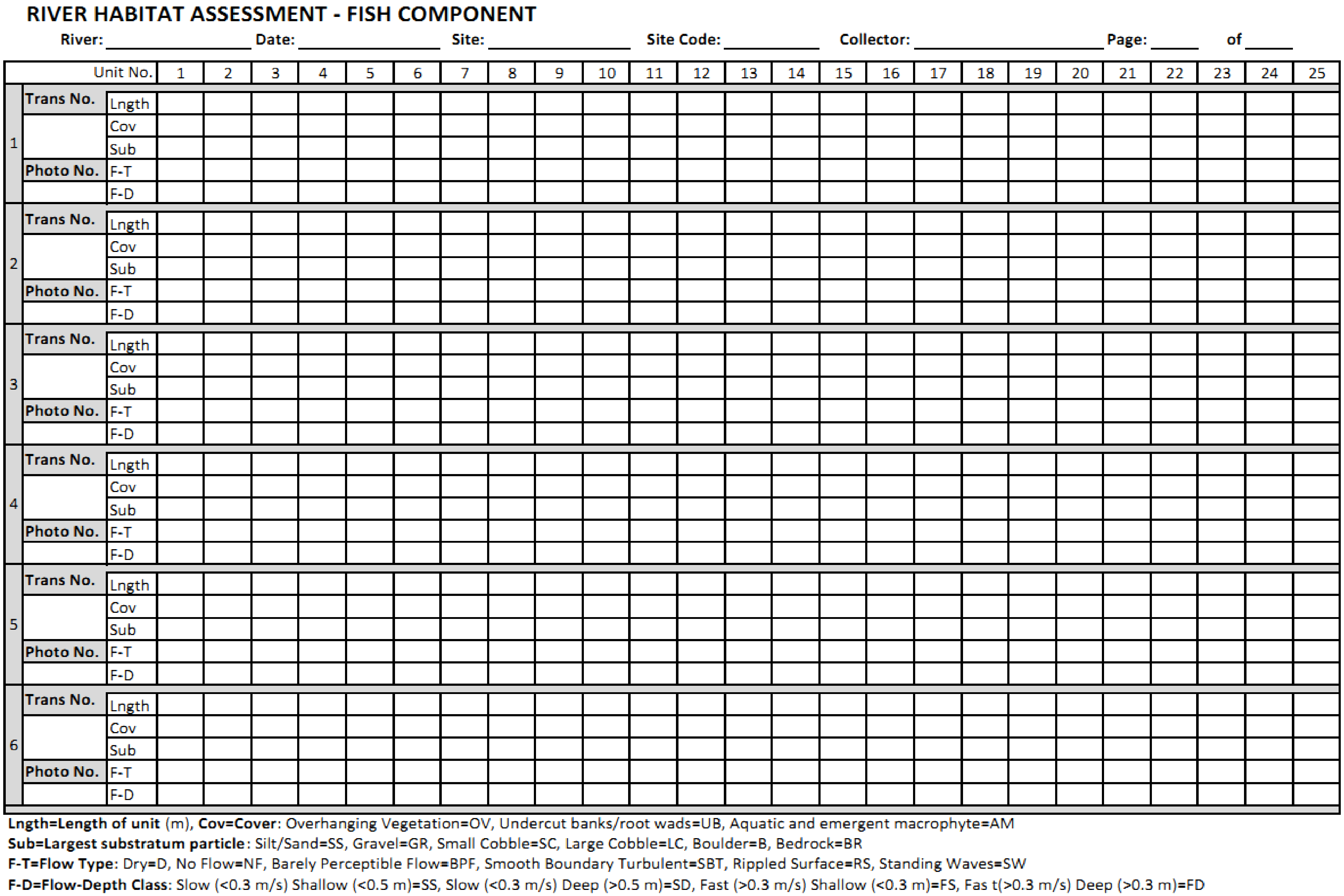
River: ____________ Date: ____________ Site: ____________

Collector: ____________ Gear ____________ Page: _____ of _____

Start time: ____________ End time: ____________ Duration: ____________

					ANOMALIES								ANOMALIES		
Species	Tot.	FL	TL	Wt	D	P	L	Species	Tot.	FL	TL	Wt	D	P	L

Tot.=Total number of fish, **FL**=Fork Length, **TL**=Total Length, **Wt**=Weight
D=Deformity, **P**=Parasite, **L**=Lesion



RIVER HABITAT ASSESSMENT - FISH COMPONENT

River: ____________ **Date:** ____________ **Site:** ____________ **Site Code:** ________ **Collector:** ________________ **Page:** ____ **of** ____

		Unit No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	**Trans No.**	Lngth																									
		Cov																									
		Sub																									
	Photo No.	F-T																									
		F-D																									
2	**Trans No.**	Lngth																									
		Cov																									
		Sub																									
	Photo No.	F-T																									
		F-D																									
3	**Trans No.**	Lngth																									
		Cov																									
		Sub																									
	Photo No.	F-T																									
		F-D																									
4	**Trans No.**	Lngth																									
		Cov																									
		Sub																									
	Photo No.	F-T																									
		F-D																									
5	**Trans No.**	Lngth																									
		Cov																									
		Sub																									
	Photo No.	F-T																									
		F-D																									
6	**Trans No.**	Lngth																									
		Cov																									
		Sub																									
	Photo No.	F-T																									
		F-D																									

Lngth=Length of unit (m), **Cov=Cover**: Overhanging Vegetation=OV, Undercut banks/root wads=UB, Aquatic and emergent macrophyte=AM

Sub=Largest substratum particle: Silt/Sand=SS, Gravel=GR, Small Cobble=SC, Large Cobble=LC, Boulder=B, Bedrock=BR

F-T=Flow Type: Dry=D, No Flow=NF, Barely Perceptible Flow=BPF, Smooth Boundary Turbulent=SBT, Rippled Surface=RS, Standing Waves=SW

F-D=Flow-Depth Class: Slow (<0.3 m/s) Shallow (<0.5 m)=SS, Slow (<0.3 m/s) Deep (>0.5 m)=SD, Fast (>0.3 m/s) Shallow (<0.3 m)=FS, Fas t(>0.3 m/s) Deep (>0.3 m)=FD

4.7 Personnel requirements and equipment

Fish population monitoring should be conducted by a suitably qualified and competent biologist trained in fish ecology, sampling and data analysis techniques. The incumbent should preferably have a sound knowledge of the local fish fauna and training in electrofishing techniques. At least one assistant is required in the field to aid with data transcription, fish transport and capture.

A SAMUS Model 725G portable electric fishing device powered by a 12 V battery with a trailing cathode and a 300 mm ring anode is recommended as this is relatively inexpensive compared to other models available on the market. It has a maximum output power of 650 Watts and an output voltage of 1000 V. The cathode should be of braided copper wire and the 2 m long catcher rod should be fitted with a ring anode of *c*. 300 mm in diameter. Pulse frequency should be set at between 50 and 100 Hz and pulse duration at between 0.03 and 0.05 seconds. It is advisable that both members of the team wear polarized sunglasses to reduce water surface reflections and aid fish capture. A list of equipment requirements for fish capture and measurement appears below.

Fish Capture	SAMUS Model 725G electroshocker unit Deep cycle battery (2 × 7 Amp, 12 V) Electrodes (trailing cathode & 30 mm ring anode on a 2 m catcher rod) 12 V battery charger Waders Landing net Buckets 5L (lids) Polarized sunglasses
Fish measurement	Electronic balance (1 g accuracy) Spring balance Plastic bags Fish measuring board Phenoxytol or clove oil
Data collection	Datasheets Clipboard Pencil Camera
Habitat assessment	Handheld Global Positioning System (GPS) 100 m measuring tape 1 meter rule

4.8 Database management and analysis

- Calculate CPUE (no. of fish/hour) for each electofished site and average across each reach (control and impact);
- Provide length frequency histograms at suitable length-class intervals for each species in each reach and site;
- Calculate the relative proportions of each size class in relation to the total abundance of the population;
- Relative abundance together with population age-structure calculated using the growth curve reported in Section 2.4 can then be used to as an index of fish population health and condition.
- From the habitat assessment, the relative proportions of each habitat variable, summed for each site, can be represented on frequency

distributions. From channel measurements, total wetted width can also be calculated.

- All data should be backed-up and submitted to a central database management facility for safe-keeping.

5. Thresholds of Potential Concern (TPCs)

Gillson and Duffin (2007: 309) define TPCs as “a set of operational goals that define the upper and the lower levels along a continuum of change in selected environmental indicators”. Although all natural systems are variable, they operate within certain constraints which, if exceeded, cause fundamental and irreversible changes to ecosystem structure and function. The goal of setting TPCs is therefore to identify and define those levels, monitor fish population and assemblage responses and implement adaptive management procedures when approaching or exceeding TPCs.

In all ecological assessments, the choice of reference conditions is challenging, particularly when assigning quantitative or semi-quantitative estimates to TPCs. In general, reference conditions for the evaluation of TPCs are set based on historical records from the river under consideration, or from other rivers with comparable characteristics. Where reference conditions are not known, Bozzetti and Schulz (2004) suggest using the highest score in the catchment as the reference condition. We suggest this latter approach for monitoring fish population s in the Mothae River.

5.1.1 TPCs for Maloti redfin

The following TPCs were estimated from the baseline monitoring survey reported in Chapter 2. Note that these are preliminary figures obtained from a survey conducted during the least favourable time of the year for sampling (April). They are based on the gear type, specifications and effort reported on in Chapter 2, i.e. a SAMUS electrofisher, covering 100 – 300 m river lengths at sites Mot-2C, Mot-2D, Mot-3A, Mot-3B, Mot-3C, Mot-3D, Trib-1A and Trib-1B. Relative abundances are reported as mean, minimum and maximum across all sites. These TPCs will need to be revised once information from the first monitoring survey at a more suitable time of the year (Nov-Mar) becomes available.

Table 5.1 TPCs set for Maloti redfin based on the relative abundances (on. Fish/river length and no. fish/hour) reported in Chapter 2 for all sites Mot-2C, Mot-2D, Mot-3A, Mot-3B, Mot-3C, Mot-3D, Trib-1A and Trib-1B sampled in July.

		No. Fish/100 m River Length		*No. Fish/hour*	
Indicator		**Expected (current)**	**TPCs**	**Expected (current)**	**TPCs**
Maloti redfin	Mean	6.7	3.5	0.0028	0.015
	Min	2.9	0	0.0014	0
	Max	9.6	2.9	0.0037	0.0014

5.1.2 TPCs for Water quantity and quality parameters

Currently, no long term baseline data exist for the hydrology or water quality conditions of the Mothae River. Long term datasets are essential for the assessment and monitoring of potential impacts since, as already pointed out; the severity of the impact is related not only to its magnitude, but also to its duration. This is especially important for hydrology where thresholds can only be determined based on a knowledge of antecedent conditions. For turbidity it is suggested that a minimum

TPC of 500 mg/*l* for a period > 20 days be set. However, this figure be revised once one full year's monitoring has been completed.

5.1.3 TPCs for physical habitat conditions

Similarly for physical habitat conditions, no baseline data exists for the Mothae River on physical habitat. Reference conditions and TPCs for these conditions can be set only after the first monitoring survey has been completed.

6. CONCLUDING REMARKS

The Maloti redfin is a high profile and irreplaceable species. The discovery of a previously undocumented population of this fish in the Mothae River generated considerable interest and debate in scientific and conservation circles and it loss from this river system will have national and international ramifications. As part of their impact mitigation and conservation plan, Lesotho Highlands Development Authority (LHDA) has suggested translocating fish to other catchments. However, the number of unimpacted rivers that can support Maloti redfin population is diminishing, with the Mothae River being one of the few rivers still supporting a relatively pristine population. This represents a unique opportunity for Mothae Diamonds to consider environmental factors early in the design and implementation of fully-scale mining in the Matsoku River catchment and to enforce best practice when it comes to environmental management within and beyond the boundaries of its lease area.

7. REFERENCES

ADP Projects (Pty). 2009. Mothae Conceptual Study: water system. Report prepared by ADP Projects (Pty) for Lucara Diamonds (Mothae Project). 21 pp.

Arthington, A.H.; Rall, J.L. and Kennard, M.J. 1999. Specials Report: Fish. *Consulting Services for the establishment and monitoring of the Instream Flow Requirements for river courses downstream of LHWP Dams Report No. LHDA 648-F-18*. 80 pp.

Barnard, K.H. 1938. Description of a new species of fresh-water fish from Natal. *Annals of the Natal Museum,* 8**,** 525-528.

Bergstedt, L.C. and Bergersen, E.P. 1997. Health and movements of fish in response to sediment sluicing in the Wind River, Wyoming. *Canadian Journal of Fisheries and Aquatic Sciences,* 54**,** 312-319.

Bernet, D.; Schmidt-Posthaus, H.; Wahli, T. and Burkhardt-Holm, P. 2000. Effects of wastewater on fish health: an integrated approach to biomarker responses in brown trout (Salmo trutta L.). *Journal of Aquatic Ecosystem Stress & Recovery,* 8**,** 143.

Bozzetti, M. and Schulz, U.H. 2004. An index of biotic integrity based on fish assemblages for subtropical streams in southern Brazil. *Hydrobiologia,* 529**,** 133-144.

Brandt, S.A. 2000. Classification of geomorphological effects downstream of dams. *Catena,* 40**,** 375-401.

Cambray, J.A. and Meyer, K. 1988. Early ontogeny of an endangered, relict, cold-water cyprinid from Lesotho *Oreodaimon quathlambae* (Barnard, 1938). *Revue d'hydrobiologie tropicale,* 21**,** 309-333.

Clarkson, R.W. and Childs, M.R. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. *Copeia,* 2000**,** 402-412.

Davey, S.; McDonald, D.J. and Ollis, D.J. 2007a. Baseline Environmental Assessment – Mothae Diamond Prospecting Project, Lesotho. *Consulting report prepared for Motapa Exploration Limited by AMATHEMBA Environmental Management Consulting cc*. 44 pp.

Davey, S.; McDonald, D.J. and Ollis, D.J. 2007b. Draft Environmental Management Plan – Mothae Diamond Prospecting Project, Lesotho. *Consulting report prepared for Motapa Exploration Limited by AMATHEMBA Environmental Management Consulting cc*. 31 pp.

Fausch, K.D.; Lyons, J.; Karr, J.R. and Angermeier, P.L. 1990. Fish communities as indicators of environmental degradation. *In:* ADAMS, S. M., ed. Biological indicators of fish stress. American Fisheries Society, Symposium 8, 1990 1990 Bethesda, Maryland.

Gephard, S.R. 1978. Observations of the three allopatric populations of the Maluti minnow, *Oreodaimon quathlambae* (Barnard) with notes on its evolution, ecology, spawning and conservation. *Journal of the Limnological Society of Southern Africa,* 4**,** 105-111.

Gillson, L. and Duffin, K.I. 2007. Thresholds of potential concern as benchmarks in the management of African savannahs. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 362**,** 309-319.

Greenwood, P.H. and Jubb, R.A. 1967. The genetic identity of *Labeo quathlambae* Barnard (Pisces, Cyprinidae). *Annals of the Cape Provincial Museums,* 6**,** 17-37.

IUCN. 2010. *2010 IUCN Red List of Threatened Species. Version 2010.4.* www.iucnredlist.org [Online]. [Accessed 7 June 2011 2011].

Johnson, P.T.J.; Olden, J.D. and Vander Zanden, M.J. 2008. Dam invaders: impoundments facilitate biological invasions into freshwaters. *Frontiers in Ecology and the Environment,* 6**,** 357-363.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries,* 6**,** 21-27.

Kleynhans, C.J. 1999. The development of a fish index to assess the biological integrity of South African rivers. *WATER SA-PRETORIA-,* 25**,** 265-278.

McCartney, M. and King, J.M. 2011. Use of decision support systems to improve dam planning and dam operation in Africa. *Research for Development Series - 02* CGIAR Challenge Program on Water and Food. 74 pp.

McKim, J.M. 1977. Evaluation of tests with early life stages of fish for predicting long-term toxicity. *Journal of the Fisheries Board of Canada,* 34**,** 1148-1154.

Mol, J.H. and Ouboter, P.E. 2004. Downstream Effects of Erosion from Small-Scale Gold Mining on the Instream Habitat and Fish Community of a Small Neotropical Rainforest Stream. *Conservation Biology,* 18**,** 201-214.

Munson, B.H.; Axler, R.; C, H.; G, H.; G, M. and C, R. 2008. *Water on the Web: Turbidity* [Online]. Duluth, Minnesota. Available: http://www.waterontheweb.org/under/waterquality/turbidity.html [Accessed 18 August 2011].

Nilsson, C.; Reidy, C.A.; Dynesius, M. and Revenga, C. 2005. Fragmentation and flow regulation of the world's large river systems. *Science,* 308**,** 405.

Ollis, D.J. 2009. Mothae Diamond Prospecting Project, Lesotho. Report on water quality and aquatic macroinvertebrate monitoring. *Consulting report prepared for Motapa Exploration Limited by the Freshwater Consulting Group*.

Pike, T. and Tedder, A.J. 1973. Rediscovery of *Oreodaimon quathlambae* (Barnard). *Lammergeyer,* 19**,** 9-15.

Poulin, R. 1992. Toxic pollution and parasitism in freshwater fish. *Parasitology Today,* 8**,** 58-60.

Rall, J.L. 1999. *Development of a conservation program on Pseudobarbus quathlambae in the catchment area of phase 1B of the Lesotho Highlands Water Project.* PhD PhD, Rand Afrikaans University.

Rall, J.L. and Sephaka, T. unpublished. Report on the status of the Maloti Minnow (*Pseuodobarbus quathlambae*) based on IFR preliminary data collection.

Revenga, C.; Brunner, J.; Henninger, N.; Kassem, K. and Payne, R. 2000. *Pilot analysis of global ecosystems: freshwater systems*, World Resources Institute.

Rivier, B. and Seguier, J. 1985. Physical and biological effects of gravel extraction in river beds. *In:* ALABASTER, J. S. (ed.) *Habitat modification and freshwater fisheries.* Rome: FOA.

Rondorf, D.W. 1976. New locations of *Oreodaimon quathlambae* (Barnard, 1938) (Pisces, Cyprinidae) populations. *South African Journal of Science,* 72**,** 150-151.

Rowntree, K.M. and Wadeson, R.A. 1999. A hierarchical geomorphological model for the classification of selected South African rivers. *WRC Report No. 497/1/99* Water Research Commission, Pretoria. 334 pp.

Skelton, P. 2000. Flagships and fragments — perspectives on the conservation of freshwater fishes in southern Africa. *African Journal of Aquatic Science,* 25**,** 37 - 42.

Skelton, P.H. 1980. *Systematics and biogeography of the redfin Barbus species (Pisces: Cyprinidae) from southern Africa.* PhD, Rhodes University.

Skelton, P.H. 1988. A taxonomic revision of the redfin minnows (Pisces, Cyprinidae) from southern Africa. *Annals of the Cape Provincial Museums,* 16**,** 201-307.

Sutherland, A. and Meyer, J. 2007. Effects of increased suspended sediment on growth rate and gill condition of two southern Appalachian minnows. *Environmental Biology of Fishes,* 80**,** 389-403.

Swartz, E.R. 2005. *Phylogeography, phylogenetics and evolution of redfins (Teleostei, Cyprinidae, Pseudobarbus).* PhD, University of Pretoria.

Tilquin, C. and Lechela, L. 1995. Strategies for fish production in lowlands reservoirs, Lesotho. *Aquaculture for Local Community Development Programme (ALCOM)* FOA, Rome (Italy). 83 pp.

Tsai, C. 1978. Impact of Wastewater Treatment Plant Discharges.

Wyatt, L.; Baker, A. and Berlinsky, D. 2010. Effects of sedimentation and periphyton communities on embryonic Rainbow Smelt, <i>Osmerus mordax</i&gt. *Aquatic Sciences - Research Across Boundaries,* 72**,** 361-369-369.