Ecological assessment of Browns Creek, Narangba: March 2015

Environmental Monitoring and Assessment Sciences
Department of Science, Information Technology and Innovation

17 August 2015

Prepared by

David Moffatt, Sarah Lindemann and Suzanne Vardy
Environmental Monitoring and Assessment Sciences
Science Delivery Division
Department of Science, Information Technology and Innovation
PO Box 5078
Brisbane QLD 4001

Disclaimer

Citation

DSITI 2015. Ecological assessment of Browns Creek, Narangba: March 2015. Report prepared for the Queensland Department of Environment and Heritage Protection. Department of Science, Information Technology and Innovation Brisbane.

Acknowledgements

Troy Harris and Stephen Cousins, DSITI Environmental Monitoring and Assessment Sciences, assisted with the collection of field data associated with this work.

17 August 2015

Erratum

In DSITIA (2014a) the area of Browns Creek immediately downstream of the quarry was identified as being Stream Health Class C by Moreton Bay Regional Council. Stream Health Class C is considered to be slightly disturbed, loaded and the desired management response is to protect the stream (Nolte 2010). In July 2015 EHP contacted the original author of the studies, Ulrike Nolte, and she clarified that Browns Creek upstream of the Boral quarry was classified as Stream Health Class C, but that Browns Creek downstream of the Boral quarry was classified as Stream Health Class D. Class D is moderately disturbed, strongly loaded and the management action is ‘prevent further degradation’ (Nolte 2010).

The classification of the health of the sections of Browns Creek upstream and downstream of Boral Quarry was inferred from aerial photography, from which land use and riparian vegetation cover were estimated and from which the health of the stream was inferred (Nolte pers. comm.). Further discussion of the Stream Health Class based on data collected from Browns Creek between 2013 and 2015 is contained in this report.

This page is intentionally blank

Executive summary

This document describes a study of the ecological condition of upper Browns Creek, Narangba, conducted during March-July 2015. That study was undertaken to assist the Department of Environment and Heritage Protection with an investigation of potential Environmental Harm caused by the alleged deposition of aggregate from a quarry into the headwaters of Browns Creek. Data on water quality, tree cover within the catchment, and the taxonomic composition of local freshwater fish communities are provided and discussed.

Browns Creek receives substantial groundwater input from multiple springs and consequently the pH (median = 7.2) and electrical conductivity (median = 0.660 mS/cm) of local waters tends to be higher than at sites elsewhere in South East Queensland (SEQ). Nutrient concentrations were, however, notably low. Median values of total nitrogen, ammonia, nitrogen oxides and filterable reactive phosphorus recorded during the study from six samples from four sites were 0.125, 0.010, 0.015 and 0.005 mg/L respectively. Total phosphorus concentration was below the laboratory detection limit of 0.01 mg/L at all six sites along the stream at which samples were collected.

Foliage projective cover within a 50 m wide area about the stream (i.e. 100 m total width) was 44%, whilst the median of a random subsample of about 1,000 stream segments distributed across SEQ was 34%. The canopy cover of woody vegetation about Browns Creek was greater than the majority (64%) of similar-sized streams in SEQ.

A total of five native and one alien fish species were presented in the catch from two reference and three test sites. Only four native species had been caught during earlier work in January 2014, but the two additional species caught during the present study were each represented by just two individuals out of a total catch of 305 fish. Two sites that were devoid of fish during earlier work, two months after 1,012 m^3 of aggregate had been removed from the stream, sustained fish communities with species composition approaching that of reference sites.

Conclusions

- At the time of assessment Upper Browns Creek appears to have been in a moderately disturbed condition in comparison to other streams within SEQ. Water quality within the stream in terms of assessed parameters (pH, electrical conductivity, nutrient concentrations) was very good to excellent. Local fish communities appear to be somewhat depauperate in species in comparison to the number of native species predicted to occur and other streams within the region, but they feature a very low abundance of alien fish species.
- The deposition of aggregate within Browns Creek resulted in widespread loss of aquatic habitat within the stream, but the lost habitat has been partially restored by the extraction of an estimated 1,012 m^3 of aggregate. Sections of stream that were previously devoid of fish now support fish communities in relatively good ecological condition (c.f. other reaches of the same stream).
- The section of Browns Creek affected by the deposition of aggregate may have been, and may still remain, of high conservation significance due to the presence of threatened amphibian species. The stream is also notable for its low nutrient concentrations, very low abundance of alien fish species and its role as a drought refuge.

Contents

List of tables

List of figures

1. Introduction

Boral Resources (Qld) Pty Ltd (Boral) operate a quarry adjacent to a headwater tributary of Browns Creek, Narangba. Since October 2013, the Department of Environment and Heritage Protection (EHP) has been undertaking an investigation into the alleged deposition of quarry aggregate from the Boral site into Browns Creek. Staff from the Department of Science, Information Technology and Innovation (DSITI)[1] have provided scientific support for this investigation.

Boral removed as estimated 1,012 m^3 of aggregate from Browns Creek in late 2013 and in early 2014, DSITI staff undertook a rapid in-stream ecological assessment of the section of stream alleged to be affected by the deposition of quarry aggregate. That assessment was based on physical and chemical water quality parameters and data on the taxonomic composition of aquatic macroinvertebrate and fish communities at potentially impacted test sites and reference sites further downstream (DSITIA 2014a). No difference was found between the macroinvertebrate communities at test and reference sites, however the fish fauna of impacted sites was greatly reduced compared to un-impacted sites (DSITIA 2014a).

In March 2015 EHP requested further comment from DSITI regarding (1) the works conducted by Boral to remove aggregate from Browns Creek and (2) recommendations for future works within the creek such as removing additional material and/or leaving material behind where appropriate. As a result, DSITI staff undertook an assessment of the spatial distribution of aggregate within Browns Creek (DSITI 2015) and repeated the earlier assessment of the ecological condition of local fish assemblages.

This report provides a description of the second ecological assessment and associate findings. The study was undertaken to provide an update on the ecological condition to assist with assessment of the effectiveness of aggregate removal, and whether further aggregate removal works might provide ecological benefit to the in-stream biota.

2. Method

The ecological assessment described here was based on three indicators of ecological condition: (1) water quality, particularly nutrient concentrations, (2) vegetation cover adjacent to the stream and (3) the relative abundance of fish species within the stream. All assessments were undertaken between March and July 2015. Whilst DSITIA (2014a) previously used aquatic macroinvertebrate communities as an indicator of ecological condition, they were not used in the present study due to resource limitations.

2.1 Water quality

Assessment of water quality was based on *in situ* readings of pH and conductivity and the collection of water samples for determination of total nitrogen (TN), ammonia (NH_3), nitrogen oxides (NOx), total phosphorus (TP) and filterable reactive phosphorus (FRP). Quantification of nutrient concentrations within the stream was of particular interest as nutrient concentrations have substantial bearing on the ecological condition of streams. Stream health assessments by the local government authority (Moreton Bay Regional Council, MBRC) have a strong focus on nutrient concentrations, and substantial growth of filamentous algae was visible within stream (Figure 1), which is often indicative of higher than natural nutrient concentrations.

[1] Previously the Department of Science, Information Technology, Innovation and the Arts (DSITIA).

Assessments of water quality were made at four sites along Browns Creek (Figure 2) on 29 July 2015 under base flow conditions. Rainfall data for Mango Hill, about 15 km to the east-southeast, indicate a total of 12.8 mm of rain fell during July with a maximum daily rainfall of 3.4 mm. No rainfall was recorded at Mango Hill from the 24th to the 31st of July.

In situ readings of pH and conductivity were recorded at the time of water sample collection. Collected samples were analysed by Queensland Urban Utilities' National Association of Testing Authorities (NATA) accredited SAS Laboratory. Duplicate samples from two sites were submitted for analysis, as were both a container and field "blank", to check the accuracy of results. The container blank consisted of a standard field sample bottle filled in the DSITI laboratory with analytically clean water. The field blank was also filled with analytically clean water, but was filled in the field under the same conditions as field samples. All samples (field and blanks) were labelled so that SAS Laboratory staff were unaware of the existence of duplicate and/or blank samples.

Figure 1. Filamentous algae growth within Browns Creek observed on 14 July 2015.

Results from the water quality survey were compared to Performance Indicators developed by the Pine Rivers Shire Council (now part of the Moreton Bay Regional Council) (see Nolte and Loose 2004) and later incorporated into the *Environmental Protection (Water) Policy 2009: Pine Rivers and Redcliffe Creeks Environmental Values and Water Quality Objectives* (DERM 2010). Those indicators consisted of an objective and an upper limit for each of four Stream Health Categories (Table 1).

Water sample results were also compared to water quality results derived from 137 sites within South East Queensland (SEQ) visited between 2007-2013 as part of the Healthy Waterways Freshwater Ecosystem Health Monitoring Program (EHMP, Bunn *et al.* 2010). This was done to place results for Browns Creek into the context of results for other SEQ streams and provide more insight into the conservation value of Browns Creek. Water quality data were available from Freshwater EHMP sites for both spring (pre-wet) and autumn (post-wet) seasons, but only data for autumn were used for comparison with results from Browns Creek, which were collected in July and hence most closely aligned in time to the autumn samples.

Table 1. Moreton Bay Regional Council water quality Performance Indicators as cited by Nolte and Loose (2004).

Stream Health Class	Electrical conductivity (µS/cm)		Total Nitrogen (mg/L)		Total Phosphorus (mg/L)	
	Objective	Upper Limit	Objective	Upper Limit	Objective	Upper Limit
A (Clean)	<120	200	≤0.10	0.20	≤0.005	0.010
B (Little loaded)	<200	300	≤0.10	0.30	≤0.010	0.020
C (Loaded)	<280	400	≤0.20	0.30	≤0.020	0.030
D (Strongly loaded)	<400	650	≤0.20	0.75	≤0.030	0.070

2.2 Riparian vegetation

Riparian vegetation was assessed in terms of Foliage Projective Cover derived via the Queensland Government Statewide Landcover and Trees Study (SLATS). Foliage Projective Cover (FPC) is the percentage of ground area occupied by the vertical projection of foliage (= canopy cover of woody vegetation) and values range from “0” (no woody vegetation foliage cover) to “100” (dense woody vegetation foliage cover). Foliage Projective Cover is derived during the SLATS via an automated decision tree classification technique applied to dry season (May to October) Landsat-8 OLI imagery. The method has an accuracy of 85%.

Analysis of FPC data during the present study involved deriving a 50 m buffer around upper Browns Creek and calculating the median FPC within the buffer area. The comparison data set was derived by randomly selecting 1,000 stream segments, i.e. 200 stream segments for each of Strahler stream order one to five (see Figure 3 for an explanation of stream ordering), elsewhere in SEQ using the same method of calculating median FPC. This enabled results for Browns Creek, a 1st order stream based on the Strahler ordering system and the stream network used for this analysis[2], to be compared to both 1st order streams elsewhere in SEQ as well as a representative sample of streams of differing order in SEQ. This accounted for potential differences in the degree of vegetation clearing adjacent streams in different parts of the landscape.

[2] DSITIA (2014) have previously described upper Browns Creek as being a 3rd order stream based on State Government 1:25,000 mapping. The discrepancy in stream order is due to a difference in the method of identifying 1st order streams between mapping datasets. The data used in this study was that produced by Harris (2003), within which 1st order streams are defined as flow pathways with a watershed of c. ≥10 Ha. For State Government 1:25,000 mapping, 1st order streams were visually identified via air photo interpretation and are not necessarily consistent across different air photo interpreters.

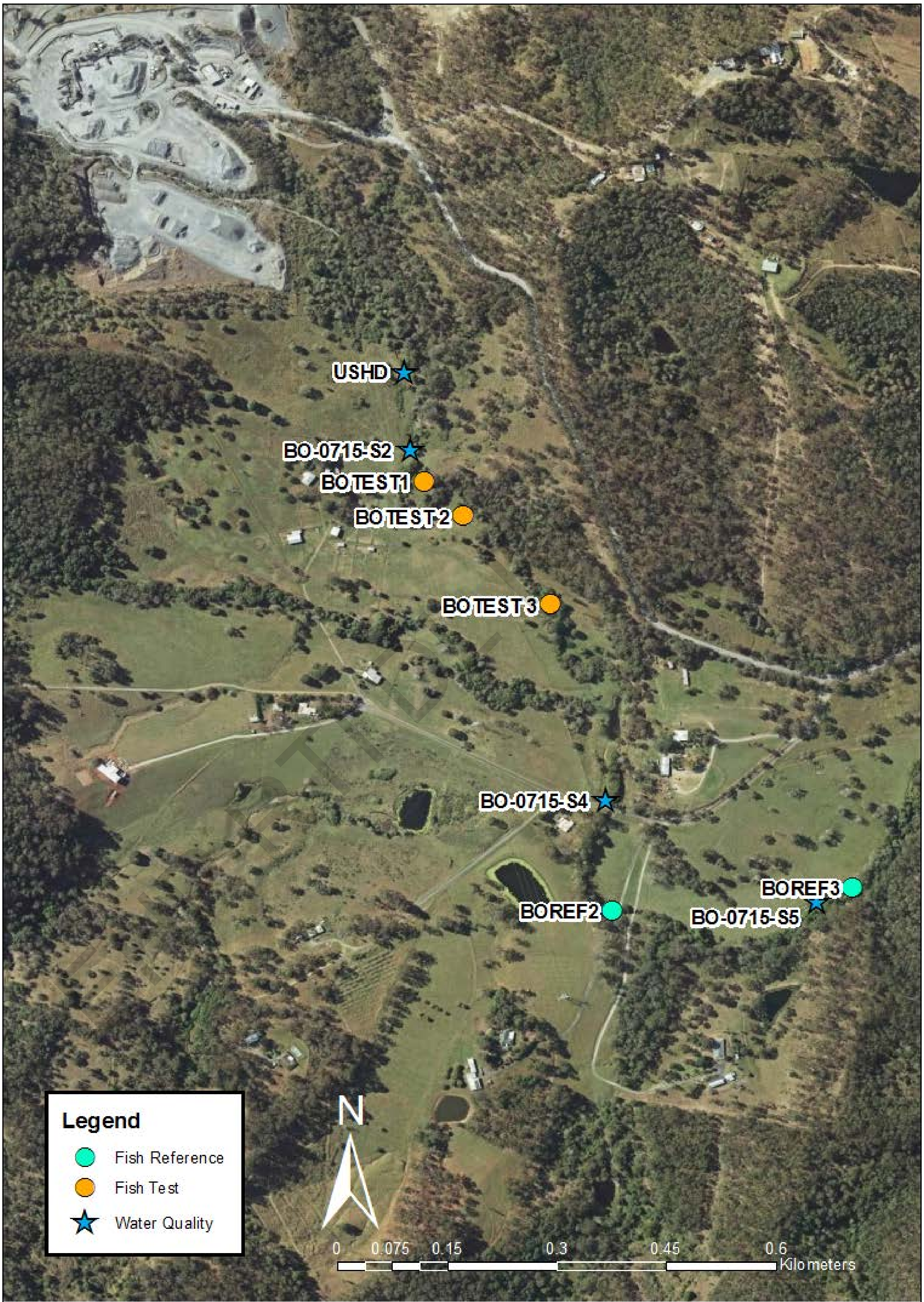


Figure 2. Sampling sites for fish (31 March 2015) and *in situ* water quality parameters and nutrients (29 July 2015).

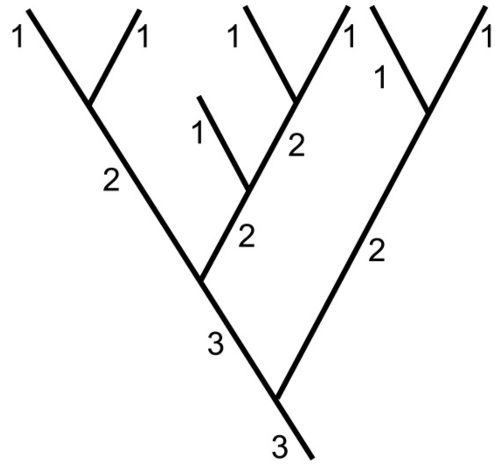


Figure 3. Ordering of the segments of a stream network based on the Strahler system. Headwater streams are designated as 1st order and the product of two 1st order streams joining is a 2nd order stream. The product of two 2nd order streams joining is a 3rd order stream and so on.

2.3 Fish communities

Assessment of fish communities was based on the relative abundance of fish species using backpack electrofishing in the same manner, and at the same three test sites and two reference sites assessed, employed by DSITIA (2014a, Appendix A). Backpack electrofishing was undertaken using a Smith-Root LR24 electrofisher. The fishing effort exerted at each site (Appendix B) was dependent upon the amount of available aquatic habitat, which was generally less at potentially impacted sites than at reference sites.

Fish were netted, identified, counted and stored until the completion of fishing to prevent recaptures. On completion of fishing all fish were released alive near the point of capture unless required for the confirmation of identification in the laboratory.

Interpretation of fish catch data was based on the calculation of Proportion of Native Species Expected (PONSE), Observed to Expected species (OE50) and Proportion Alien indices as used previously for ecological assessment of Browns Creek (DSITIA 2014a). Site-scale variables necessary for the calculation of PONSE and OE50 (Appendix C) were quantified *in situ* and catchment-scale variables (Appendix D) were quantified using existing spatial data.

Values of PONSE, OE50 and Proportion Alien were compared to local water quality objectives (DERM 2010) and values derived for 140 sites elsewhere in SEQ that were assessed bi-annually (spring and autumn) from 2003 to 2015 as part of the Freshwater EHMP.

Change in the taxonomic composition of fish communities from January 2014 to March 2015 was also investigated using Non-Metric Multidimensional Scaling as implemented in PRIMER 6.1 computer software (Clarke *et al.* 2006). Catch by species was 4th-root transformed to balance the influence of species of differing abundance, and a dummy species added to the catch from all sites allow occurrences of no catch to be included in the analysis.

3. Results

3.1 Water quality

Differences in all water quality parameters between samples collected at the same site were ≤0.002 mg/L. Total nitrogen, TP and FRP results for blanks were at or below detection limits (0.01, 0.01 and 0.002 mg/L respectively), but NH_3 and NOx were detected in blanks at low concentrations (≤0.009 mg/L).

The concentration of TN (Table 2) at all sites was lower than the upper limit for MBRC Stream Health Class A and lower than the objective for Stream Health Class C (Table 1). No TP was detected, so results for that parameter were equivalent to a Stream Health Class of A or B (Table 1, Table 2Table 2). The limit of reporting for TP, which is the lowest level at which the analysis laboratory could quantify that parameter (i.e. <0.01 mg/L), was higher than the TP objective for Stream Health Class A, so TP results could not be classified further.

The pH and EC of field samples tended to be higher than that of other sites in SEQ. Percentiles for pH and EC ranged from 52 to 87 (Table 3), meaning that values for those parameters ranged from close to the median of that for other sites in SEQ to higher than that of 80% of other SEQ sites.

The nutrient concentration of field samples (Table 2) was low in relation to the comparison dataset, with corresponding percentiles ranging from 1 to 61 (Table 3), meaning that nutrient concentrations were less than those within at least 39% of other SEQ sites. Total phosphorus concentrations at all Browns Creek sites (percentile = 1, Table 3) were lower than that of 99% of records in the comparison dataset, as was TN at the furthest downstream Browns Creek site (BO-0715-S5). The concentration of both TN and NH_3 were both highest at the furthest upstream site (USHD) and lowest at the furthest downstream site (BO-0715-S5).

The comparison dataset included data from six samples at each of eight undisturbed sites (48 samples) within National Parks with undisturbed watersheds[3] and the mean percentile of TN and TP concentrations within Browns Creek were <20th percentile of values for those sites.

3.2 Riparian vegetation

Aerial photography and corresponding FPC data demonstrated that, apart from at the Boral quarry site, the upper-most portion of the Browns Creek watershed was generally well-forested with natural or selectively cleared tree cover (Figure 4). The section of stream affected by the deposition of quarry aggregate fell within the buffered area used for analysis, and that area had been more extensively cleared, but at least a thin strip of woody vegetation was generally present along the stream. The median FPC within the buffered area about Browns Creek (Figure 4) was 44%, whilst that within buffer areas about other SEQ streams ranged from 31% (1^{st} order streams) to 40% (3^{rd} order streams).

The percentile of FPC for Browns Creek was 65 in terms of the selected subsample of 1^{st} order SEQ streams, meaning that only 35% of 1st order SEQ streams had denser woody vegetation

[3] Noosa River, Great Sandy National Park; East Kilcoy Creek, Conondale National Park; Stony Creek, Bellthorpe National Park; North Pine River, D'Aguilar National Park; Northbrook Creek, D'Aguilar National Park; Enoggera Creek at D'Aguilar National Park; Mudgeeraba Creek, Austinville State Forest and Christmas Creek at the boundary of Lamington National Park;

cover adjacent the stream than occurs at Browns Creek. The percentile for Browns Creek in relation to SEQ streams of order 1 to 5 was 64, very similar to that for only 1st order streams.

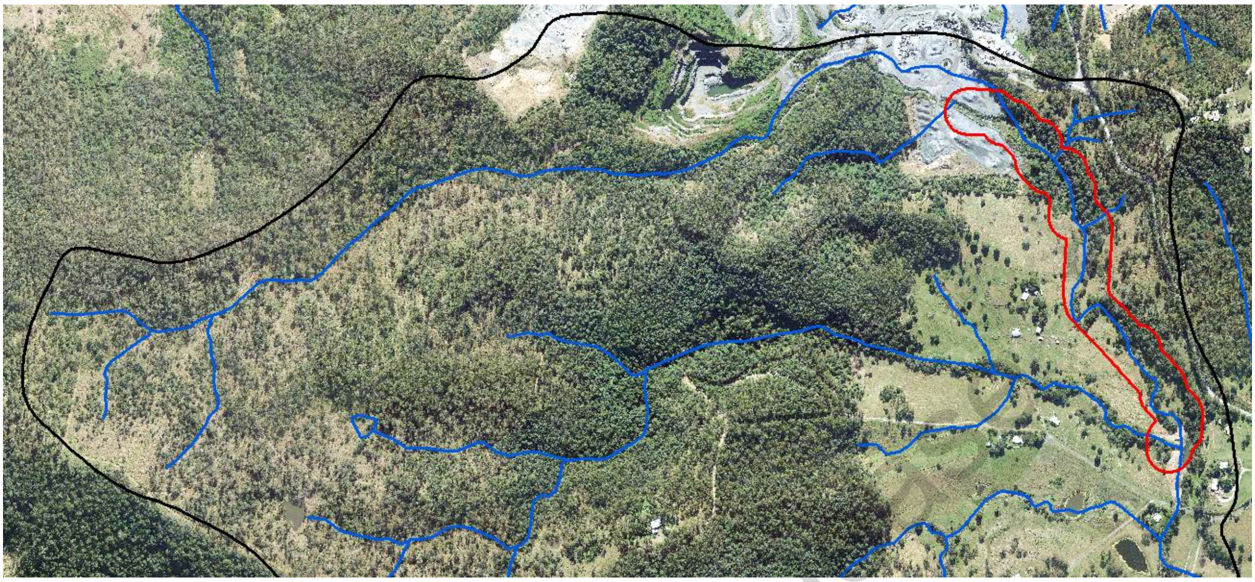
Table 2. Summary of *in situ* and nutrient data from water samples collected in Browns Creek on 29 July, 2015. Sites are listed in order from upstream to downstream. Shading of cells for electrical conductivity (EC), total nitrogen (TN) and total phosphorus (TP) indicates the stream Health Class as per Table 1. Blank samples are not shaded. Units of measure were pH units (pH), mS/cm (EC) and mg/L (for all nutrients).

Sample	pH	EC	TN	NH_3	NOx	TP	FRP
USHD	7.23	0.795	0.190	0.013	0.081	<0.01	0.005
BO-0715-S2	7.77	0.742	0.140	0.013	0.009	<0.01	0.004
BO-0715-S4	7.14	0.579	0.120	0.009	0.004	<0.01	0.005
BO-0715-S4 (duplicate)	NA	NA	0.130	0.011	0.003	<0.01	0.005
BO-0715-S5	7.06	0.576	0.083	0.008	0.021	<0.01	0.002
BO-0715-S5 (duplicate)	NA	NA	0.084	0.006	0.020	<0.01	0.003
Container blank	NA	NA	<0.010	0.005	0.002	<0.01	<0.002
Field blank	NA	NA	0.010	0.009	0.003	<0.01	<0.002

Table 3. Percentilse of values presented in Table 2 in comparison to results for water samples collected in autumn at Freshwater EHMP sites. A percentile of "0" indicates the value was equal to the lowest recorded at Freshwater EHMP sites. A percentile of "100" would indicate a value equal to or higher than the maximum recorded at Freshwater EHMP sites. Extreme values for pH and EC suggest poor ecological condition, whilst low percentile values for TN, NH_3, NOx, TP and FRP indicate better condition.

Site	pH	EC	TN	NH_3	NOx	TP	FRP
USHD	63	81	16	61	60	1	28
BO-0715-S2	87	79	08	61	24	1	22
BO-0715-S4	57	68	04	48	13	1	28
BO-0715-S4 (duplicate)	NA	NA	06	55	08	1	28
BO-0715-S5	52	68	1	43	33	1	4
BO-0715-S5 (duplicate)	NA	NA	1	32	33	1	13
Number of comparison samples	806	807	810	810	810	810	910

(a) Aerial image



(b) Foliage Projective Cover

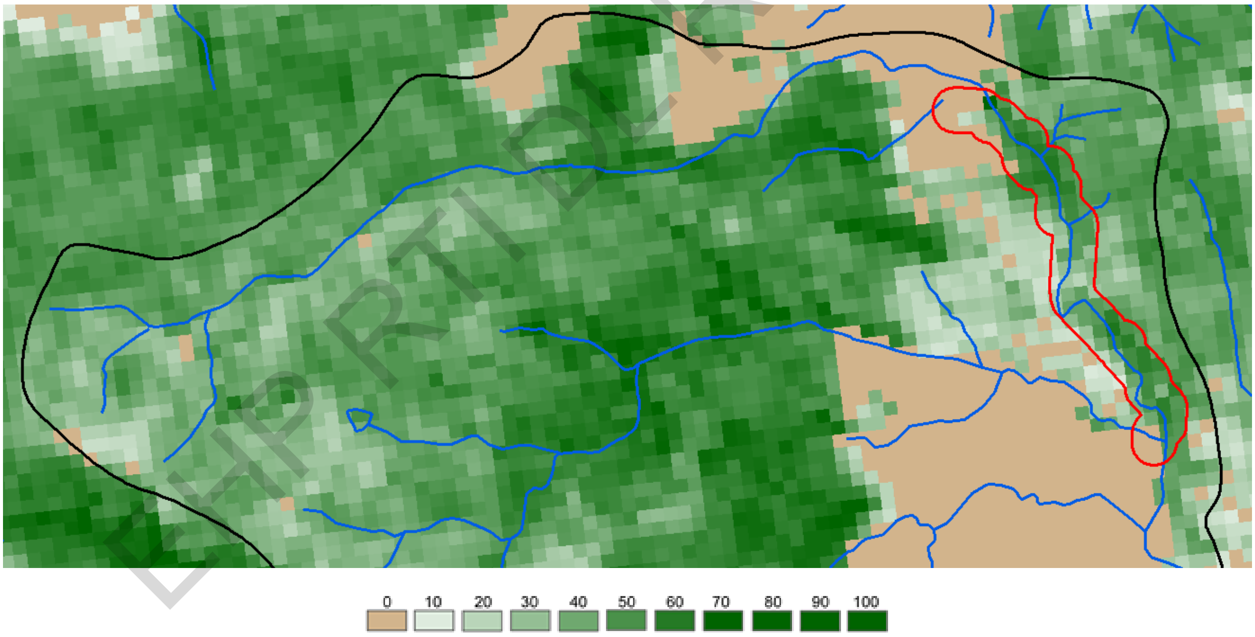


Figure 4. Aerial image (a) and Foliage Projective Cover (b) of the upper Browns Creek catchment, showing waterways (blue lines, State government 1:25K map data), the approximate catchment boundary (black line) and the boundary of the area used for analysis of tree cover (red line). Stream flow is towards the bottom right of the images. The southern section of the Boral Narangba Quarry is visible at the top of the aerial image. The area used for analysis of tree cover excluded a substantial wooded area further upstream.

3.3 Fish communities

A total of 305 fish representing six fish species were recorded during fishing (Table 4). Of those, 233 fish (76.4%) were caught at the two reference sites, and 72 fish (23.6%) were caught at the potentially impacted sites BOTEST1, BOTEST2 and BOTEST3. Only two individuals of a single alien fish species (swordtail *Xiphophorus helleri*) were caught. No native Australian fish species not naturally occurring in the Pine River catchment, i.e. translocated Australian species, were encountered.

Three native fish, Australian smelt, Marjorie's hardyhead and eel-tailed catfish, were predicted by the OE50 model to occur in Browns Creek, but were not caught. Two native fish species, spangled perch and purple-spotted gudgeon, were caught but not predicted by the OE50 model to occur. No site yielded results meeting biological Water Quality Objectives for PONSE or OE50, but all met objectives for Percent alien species, except for site BOREF3 (Table 5) where two swordtail were caught (Table 4).

Percentiles of fish community indices (Table 6) demonstrated that PONSE and OE50 values yielded by all Browns Creek sites except BOREF2 were low (percentile <25, lower values indicate poorer condition) in relation to the comparison dataset. PONSE and OE50 for BOREF2 approximated median values of the comparison dataset. All values for Percent Alien yielded by Browns Creek sites were <=2 (lower = better condition), which was equivalent to the best results possible and hence equivalent to the best in the comparison dataset.

Table 4. Fish catch by species from sites along upper Browns Creek.

Species	Test sites		Reference sites		
	BOTEST 1	BOTEST 2	BOTEST 3	BOREF 2	BOREF 3
Long-finned eel (*Anguilla reinhardtii*)	1	-	-	2	-
Fire-tail gudgeon (*Hypseleotris galii*)	9	9	7	24	65
Spangled perch (*Leiopotherapon unicolor*)	-	-	-	2	-
Duboulay's rainbowfish (*Melanotaenia duboulayi*)	-	15	3	31	42
Purple-spotted gudgeon (*Mogurnda adspersa*)	11	16	1	48	17
Swordtail (*Xiphophorus helleri*)	-	-	-	-	2

Table 5. Indices derived from backpack electrofishing results at Browns Creek sites. Higher values of PONSE and OE50, and lower values of Percent Alien, indicate better ecological condition.

Site type	Site code	PONSE	OE_{50}	Percent alien
Water Quality Objective		100	1.0	0.0
Reference	BOREF2	82.9	0.62	0
	BOREF3	49.7	0.41	2
Potentially impacted	BOTEST1	49.7	0.37	0
	BOTEST2	49.7	0.22	0
	BOTEST3	49.7	0.22	0

Table 6. Percentiles of values presented in Table 5 in comparison to results for Freshwater EHMP sites. Percentile values increase with ecological condition in terms of PONSE and OE50, and decrease with ecological condition for Percent alien.

Site type	Site code	PONSE	OE_{50}	Percent alien
Reference	BOREF2	50	49	0
	BOREF3	17	22	0
Potentially impacted	BOTEST1	17	19	0
	BOTEST2	17	7	0
	BOTEST3	17	7	0
Number of comparison samples		2,688	2,667	2,820

No fish were caught at test sites BOTEST2 and BOTEST3 during January 2014 sampling, but by March 2015 some fish were present at both of those sites and the taxonomic composition of fish species present approached that of reference sites (Figure 5). In contrast, the taxonomic composition of the fish community at site BOTEST1, became less similar to that of reference sites from 2014 to 2015. The taxonomic composition of the two reference sites was relatively stable.

Comparison of the taxonomic composition of fish catch from Browns Creek sites in January 2014 and March 2015 demonstrated that fish had recolonised test sites BOTEST2 and BOTEST3, at which no fish were caught in January 2014, but the taxonomic composition of the fish community at each of those sites was still somewhat dissimilar to that of reference sites.

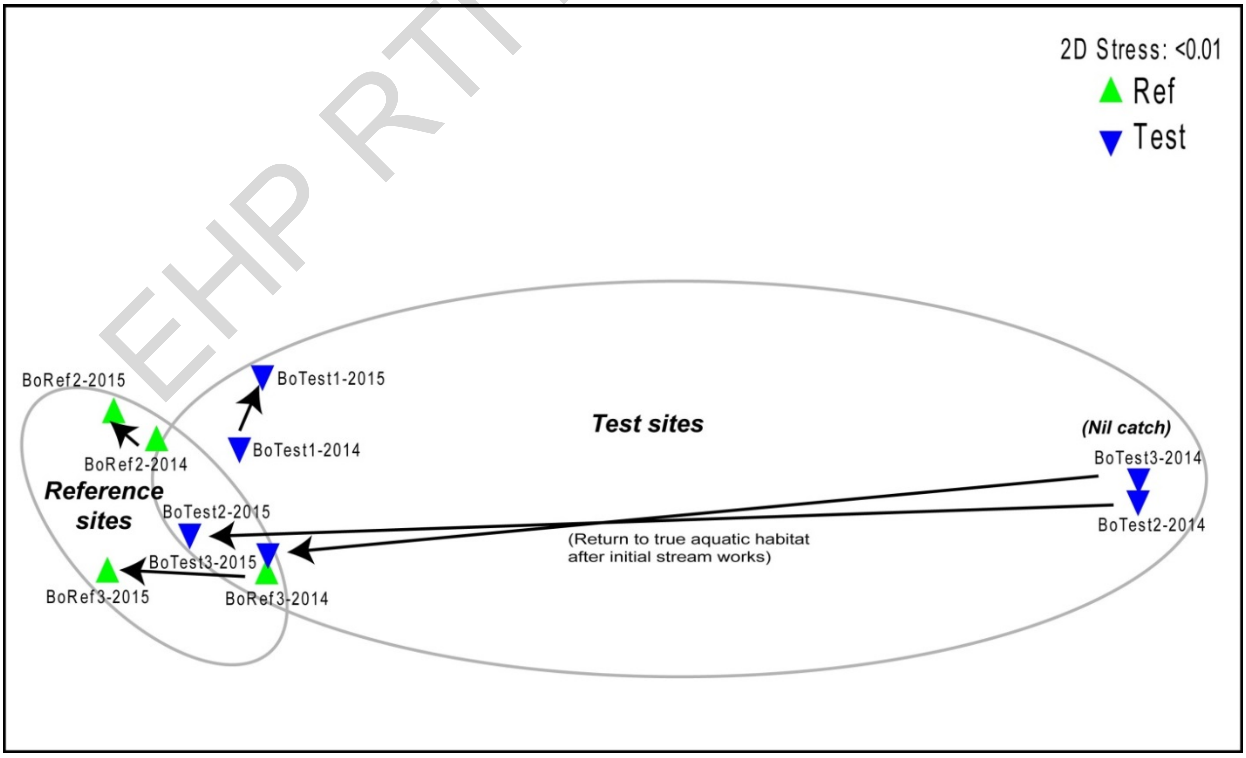


Figure 5. Non-Metric Multidimensional Scaling plot of the taxonomic similarity between fish catch from Browns Creek test and reference sites in January 2014 and March 2015. Labels of plotted points consist of the site code and year of data collection. Arrows show the trajectory of sites between the two sampling occasions.

4. Discussion

DSITIA (2014a) noted that few ecological studies have been conducted of the upper Browns Creek, but data are now available on local groundwater input (Hofmann 2015), the mobility of stream sediment (Hydrobiology 2015), in-stream nutrient concentrations (Hofmann 2015, this study) and local aquatic macroinvertebrate (DSITIA 2014a), fish (DSITIA 2014a, this study), frog (DSITIA 2014b) and turtle fauna (EHP 2015). These data, albeit largely from one-off studies, have provided a much better understanding of the ecology and condition of the stream.

4.1 Ecological condition

Browns Creek receives water from both surface run-off and at least one subterranean aquifer via multiple springs (DSITIA 2014a, Hofmann 2015). The waters of those springs have a high electrical conductivity and nitrate concentration in comparison to stream water derived directly from surface run-off, so water quality within the stream may exhibit substantial spatial and temporal variability in relation to proximity to groundwater inputs and antecedent rainfall. Nolte and Loose (2004) noted that land salinisation does not appear to be a problem in the Pine Rivers area, and soils in isolated locations may release ions to the extent that conductivity is increased. The latter may be reference to other natural groundwater dependent systems in the area. While the electrical conductivity of Browns Creek water is relatively high (c.f. the median for streams in SEQ), that should by no means be interpreted negatively in terms of the ecological condition of the stream as it appears to occur via a natural process. A fundamental aspect of ecological condition assessment is usually that “natural is good”.

With respect to the ecology of SEQ streams, water quality within Browns Creek in terms of basic physicochemical parameters and particularly nutrient concentrations is very good to excellent. Nutrient concentrations within Browns Creek measured during the present study were as low as that of streams within near-pristine areas of SEQ (i.e. undisturbed sites within National Parks), despite a possible low level contamination of water samples as indicated by the detection of NH_3 and NOx in sample blanks[4]. It should be noted that, due to the possibility of sample contamination, nutrient concentrations recorded during the present study present a possible worse-case scenario - real concentrations may have in fact been lower. It should also be noted that these results are only indicative of water quality within the stream as legislated water quality objectives are designed to be compared to the median of repeated sampling, and only single observations were available for comparison to water quality objectives during the present study. Repeated sampling of nutrient concentrations over an extended period of time, e.g. monthly over one year, would be required to provide a more robust result.

The condition of fish communities during the present study was much improved in comparison to that reported previously by DSITIA (2014a). At the time of that earlier work, which was about two months after Boral removed an estimated 1,012 m^3 of removal of aggregate from the stream, fish were absent from two test sites (BOTEST2 and BOTEST3) and DSITIA (2014) suggested that (1) insufficient time had passed for fish to recolonise impacted stream reaches from un-impacted waterholes and/or (2) aquatic habitat within remediated areas was of insufficient quality for fish to recolonise it. The results of the present study indicate the former was true as both sites now sustain fish communities similar to that of the other sites sampled within the system. The local fish community has thus exhibited substantial resilience in recovering from the large disturbance

[4] This probably occurred due to leaching of chemicals from dedicated water sample containers, but is still under investigation.

associated with the deposition of aggregate and the works during late 2013 to remove it. Such resilience to disturbance is a characteristic of a healthy ecosystem.

The ability of Browns Creek to sustain fish life following the removal of aggregate must be regarded with some caution as sampling of fish communities during both 2014 and 2015 was undertaken during the wet season, and the ecological effects of quarry aggregate deposition within the stream are likely to be greatest towards the end of the winter dry season. It is at the end of the dry season that the availability of surface water usually reaches an annual minimum. At the time of 2015 sampling, Browns Creek still contained substantial aggregate deposits (Figure 6, see also DSITI 2015a), which would clearly increase the frequency, magnitude and duration of drying within the affected section of stream. As fish community sampling was undertaken during the wettest time of year, the influence of aggregate deposits on drying of the stream was at an annual minimum, and hence the results presented here most likely describe a best-case scenario.

Figure 6. A hole dug into quarry aggregate deposited on the bed of upper Browns Creek by the senior author on 30 June 2015. Whilst most sections of the stream had surface water present and a small amount of flow, the pictured section had aggregate deposited above the water level of the stream and consequently no surface water. Water was, however, flowing downstream beneath the surface of the aggregate.

Recolonisation by fish of habitats affected by the deposition of aggregate from other sections of Browns Creek demonstrates the importance of maintaining drought refugia, i.e. permanent or near permanent waterholes. During times of low rainfall much of upper Browns Creek dries and aquatic fauna either perish or are sustained by a small area of persistent aquatic habitat. The deposition of aggregate within the creek resulted in extensive loss of surface water, in many ways replicating intensive drought conditions, and fish were only able to recolonise aquatic habitat recreated by the removal of aggregate from unaffected areas. In the absence of aggregate deposition the section of stream affected by aggregate deposition, which receives substantial groundwater input, functions as a refuge for aquatic animals during naturally occurring drought.

4.2 Moreton Bay Regional Council stream condition assessments

Moreton Bay Regional Council (MBRC) undertakes regular assessments of streams within their jurisdiction, which includes Browns Creek, in order "*to determine the state of environmental health and biodiversity values and, as far as possible, determine the pressures and circumstances associated with the state of health of the freshwater reaches of all streams in the Shire*" (AFS 2001). Those assessments are based on collection of field data at 169 sites MBRC 2015a) (~40 sites per year on a 4-year rotation) throughout the local government area, and expert opinion guided by aerial imagery and pre-existing maps is used to infer the condition of streams between sampling sites (AFS 2001). The most upstream site on Browns Creek sampled by MBRC lies at Browns Creek Road, about 2.5 km downstream of the reach affected by the deposition of quarry aggregate.

The MBRC classify streams into one of seven Stream Health Classes, A to G, described in terms of nutrient loads as (A) clean or traces of load, (B) little loaded, (C) loaded, (D) strongly loaded, (E) polluted, (F) strongly polluted and (G) excessively polluted. Since 2001, MBRC have designated Browns Creek upstream of the Boral Narangba quarry as stream health class "C", and downstream of the quarry and beyond as class and beyond as class "D". The Council aims to have the entire stream upstream of Lake Kurwongbah meet the description of stream health class "C" by the year 2031. In 2014 about 50% of the total length of stream within the MBRC area was rated as being of stream health class D (Figure 7). The MBRC describe the required management responses for stream classes as "protect" (classes A to C), "prevent further degradation" (class D) or "repair" (class E to G).

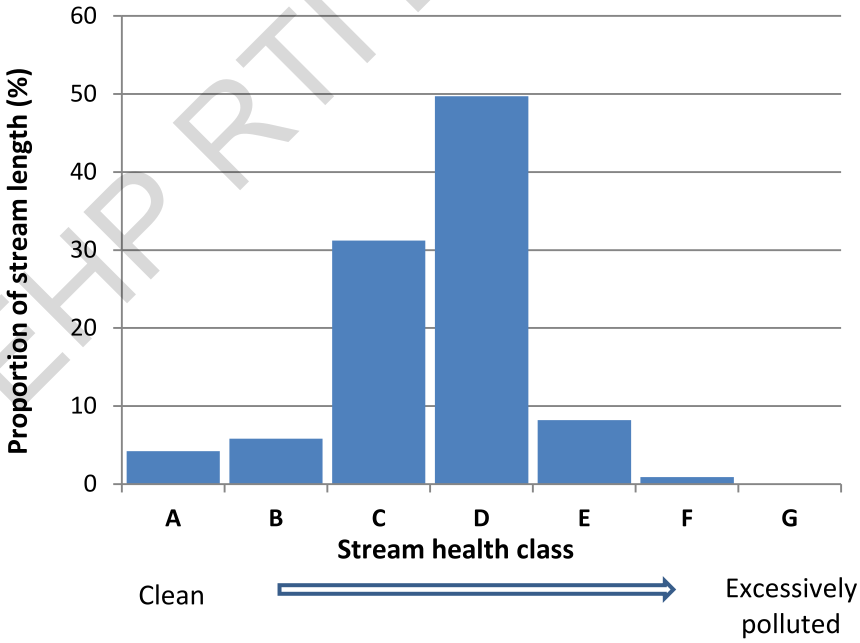


Figure 7. Proportion of stream length within the Moreton Bay Regional Council area by Stream Health Class (data from MBRC 2015b)

While nutrient concentrations are exceptionally low within the upper reaches of Browns Creek, those reaches have been classified by MBRC in terms of their classification system as Stream Health Class C and D, which are respectively "loaded" and "strongly loaded" in terms of nutrients. The MBRC stream health classification system is based on nine performance indicators, being the:

1. Abundance of stream bed aquatic macroinvertebrates;
2. Presence of locally significant and/or rare aquatic algae and macroinvertebrate species;
3. Condition of the stream channel;
4. Amount of suspended solids;
5. Total phosphorus concentration;
6. Total nitrogen concentration;
7. Electrical conductivity;
8. pH (for near-natural catchments); and
9. Concentration of faecal coliform and *E. coli* bacteria (Nolte and Loose 2004).

Condition of the stream channel is based on the extent of clearing of "verge" and stream bank vegetation and the presence/absence of hoofed animals (Appendix 2, Nolte and Loose 2004). Whilst only 35% of 1st order streams in SEQ had denser woody vegetation cover adjacent the stream than occurs at Browns Creek, the condition of the vegetation surrounding Browns Creek would most likely to have been considered as "fair" based on the MBRC system. A "fair" rating is the highest that a stream can reach when hoofed animals have access to the riparian zone. That rating is considered to indicate "moderate to high impact", and automatically downgrades an otherwise high stream class rating of A or B by two steps, i.e. to C and D respectively (AFS 2001). The association of stream health classes C and D with the terms "loaded" and "strongly loaded" in terms of nutrients can thus be quite misleading as a stream classified as one of those classes may actually have low nutrient concentrations. In practice, streams of health class A or B will generally only occur within National Parks encompassing the upper watersheds of a stream. A pristine lowland stream may never be able to be classified as Stream Health Class A simply due to natural spatial variation in water chemistry (AFS 2001). The vast majority (c. 80%) of streams are lumped together as either Stream Health Class C or D (Figure 7).

4.3 Conservation value

DSITIA (2014a) reported that the reaches of Brown Creek impacted upon by the deposition of quarry aggregate are of high conservation value according to Local Government policy, and may have been of high conservation value according to State and Federal legislation due to the possible presence of endangered giant barred frog *Mixophyes iterates*. That conclusion remains unchanged. DSITIA (2014b) undertook a survey of the amphibian fauna of upper Browns Creek and failed to locate any giant barred frog in that area, but reported that habitat along the mid-reaches of Browns Creek, downstream of the section affected by aggregate deposition, was comparable to the habitat of giant barred frog in the adjacent Burpengary Creek catchment. Failure to detect a species during biological surveys is not strong evidence that a species does not occur unless a high degree of effort is exerted in searching for the species and conditions are favourable. DSITIA (2014b) reported that the timing of their survey was not optimal and that further surveys were required to determine if giant barred frog are present in the area. As DSITIA's amphibian survey was the first undertaken in upper Browns Creek, it is not possible to determine if giant barred frog were present in the area affected by the deposition of aggregate prior to that occurring (DSITIA 2014b), and/or if individuals were displaced and/or perished as a result of aggregate removal. It was concluded that there is a high likelihood of the giant barred frog occurring downstream of the section of Browns Creek affected by aggregate deposition (DSITIA 2014b). A single specimen of the tusked frog *Adelotus brevis*, presently listed as "Near Threatened" by the International Union for Conservation of Nature (IUCN 2015) and a regionally-significant priority taxa (EPA 2002), was found in the section of stream affected by the deposition of aggregate.

Apart from the possible or proven existence of threatened amphibian species, upper Browns Creek is notable from an ecological perspective for its low nutrient concentrations, very low abundance of alien fish species, and its role as a drought refuge for aquatic organisms. Prior to the deposition of quarry aggregate in the stream, improvements to the ecological condition of the stream might have been easily gained via restoration of previously cleared sections of vegetation within the watershed, particularly in the riparian zone.

Assessment of conservation value generally covers a wider scope than ecological aspects (Tisdell 2010). Apart from the potential or proven presence of threatened amphibian species, upper Browns Creek has substantial conservation value for its exceptional water quality, including water clarity, which has a high aesthetic and practical value, e.g. as a water supply. While water clarity was not formally assessed as part of the present study, DSITIA (2014a) assessed turbidity in the preceding study and found it to be ≤2 NTU at three of five assessment sites. The senior author has repeatedly visited the stream during 2014-15 and has found the stream to typically be much clearer than the majority of streams in SEQ. The importance of the stream as a water supply for local landholders has been highlighted previously by DSITIA (2014a). The input of groundwater to the stream makes it not only a drought refuge in an ecological sense, but also in an economic sense, as surface water is available for stock and domestic purposes during periods of low rainfall when many streams in SEQ are dry.

5. References

Applied Freshwater Science 2001. *Defining and protecting resources of ecological significance: Health and biodiversity values of streams in the Pine Rivers Shire, Qld*. Report prepared for Environmental Services, Pine Rivers Shire Council, Caboolture.

Bunn S, Abal E, Smith M, Choy S, Fellows C, Harch B, Kennard M and Sheldon F 2010. Integration of science and monitoring of river ecosystem health to guide investments in catchment protection and rehabilitation. *Freshwater Biology* 55 (Suppl. 1), 223–240.

Clarke KR and Gorley RN, 2006. *PRIMER v6: User Manual/Tutorial*. PRIMER-E, Plymouth, 192pp.

DERM 2010. *Environmental Protection (Water) Policy 2009: Pine Rivers and Redcliffe Creeks environmental values and water quality objectives. Basin No. 142 (part), including Hays Inlet and all tributaries of the North Pine and South Pine rivers*. Department of Environment and Resource Management, Brisbane.

DSITIA 2014a*. Investigation into Environmental Harm Due to the Deposition of Quarry Aggregate into Browns Creek, Narangba, Queensland. Report prepared for the Queensland Department of Environment and Heritage Protection*. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

DSITIA 2014b. *Amphibian survey of Browns Creek, Narangba: Investigation of habitat potential for frog species of conservation concern, upper Browns Creek, Narangba*. Report prepared for the Queensland Department of Environment and Heritage Protection. Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts, Brisbane.

DSITI 2015. *Spatial distribution of aggregate in upper Browns Creek, Narangba. Report prepared for the Queensland Department of Environment and Heritage Protection*. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

EHP 2015. *Freshwater turtles within Browns Creek, Narangba, with additional notes on fish and invertebrates*. Queensland Department of Environment and Heritage Protection, Brisbane.

EPA 2002. *Biodiversity Assessment and Mapping Methodology*, Queensland Government, Brisbane.

Harris B 2003. *South East Queensland DEM and stream network*. BMT WBM Pty Ltd for the South East Queensland Healthy Waterways Partnership, Brisbane.

Hofmann H 2015. Statement of Witness: Harald Hofmann.

Hydrobiology 2015. *Assessment of the mobility of sediment: Browns Creek Narangba.* Report prepared for the Queensland Department of Environment and Heritage Protection. Hydrobiology Pty Ltd, Brisbane.

IUCN 2015. *The IUCN Red List of Threatened Species. Version 2015.1*. <www.iucnredlist.org>. Accessed 17 August 2015.

MRBC 2015a. *MBRC Stream Health Monitoring Program – 2015*. Map produced by Geographic Information Services, Moreton Bay Regional Council. www.moretonbay.qld.gov.au/uploadedFiles/moretonbay/environment/waterways/freshwater-stream-health-map.pdf. Accessed 17 August 2015.

MBRC 2015b. *Waterways monitoring* <www.moretonbay.qld.gov.au/stream-health/>. Accessed 17 August 2015.

Nolte U 2010. *Stream Health Monitoring in the Moreton Bay Region: The first Stream Health Map of the entire local government area*. Report prepared for Environment and Local Laws, Moreton Bay Regional Council.

Nolte U and Loose P 2004. *The Stream Health Manual*. Environmental Services Department, Pine Rivers Shire Council, Queensland.

Tisdell C 2010. Conservation Value. Working Paper No. 165, Economics, Ecology and the Environment series. School of Economics, The University of Queensland.

Appendix A: Fish community assessment sites

Site name and description	Photo
BOREF2 Latitude: -27.18695 Longitude: 152.88811	
BOREF3 Latitude: -27.18678 Longitude: 152.89056	

BOTEST1 Latitude: -27.18175 Longitude: 152.88602	
BOTEST2 Latitude: -27.18205 Longitude: 152.88638	
BOTEST3 Latitude: -27.18331 Longitude: 152.88747	

Appendix B: Fishing effort

Electrofishing effort exerted at each Browns Creek fish assessment site. Clock time refers to the time the electrofisher operator was in the water fishing whilst power-on time refers to the actual time spent applying electricity to the water. Both of those measures were lower at “potentially impacted” sites due to a lesser availability of aquatic habitat.

Site type	Site code	Distance (m)	Clock time (min)	Power–on time (sec)
Reference	BOREF2	77	33	1228
	BOREF3	85	34	938
Potentially impacted	BOTEST1	12	6	178
	BOTEST2	105	17	609
	BOTEST3	54	11	499

Appendix C: Site-scale habitat variables

Values of site-scale habitat variables used in predictive models to assess the ecological condition of fish communities. Values are means of multiple measurements or estimates at each site.

Site type	Site code	Width (m)	Depth (cm)	Velocity (m/s)
Reference	BOREF2	4.4	42.6	0
	BOREF3	3.3	40.0	0
Potentially impacted	BOTEST1	1.7	36.0	0
	BOTEST2	1.5	14.6	0
	BOTEST3	2.8	18.1	0

Appendix D: Catchment-scale habitat variables

Values of catchment-scale variables used in predictive models to assess the ecological condition of fish communities.

Site type	Site code	Elevation (m)	Distance to source (km)	Distance to sea (km)	Catchment area (km^2)
Reference	BOREF2	95	2.6	30	1
	BOREF3	95	2.6	30	1
Potentially impacted	BOTEST1	91	2.8	29	1
	BOTEST2	83	3.3	28	4
	BOTEST3	80	3.7	25	4