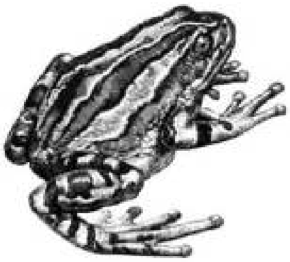
FINAL
Baseline Ecological Assessment Report
Cudgera Creek and Kerosene Inlet, Tweed Coast
Tweed Shire Council

AUSTRALIAN WETLANDS PTY LTD

BB08030d

18/01/2010

Project control



Job name: Baseline Ecological Assessment Report

Cudgera Creek and Kerosene Inlet, Tweed Coast

Job number: BB08030c

Client: Tweed Shire Council

Contact: Tom Alletson

Prepared by: Australian Wetlands Pty Ltd

70 Butler Street

Byron Bay, NSW, 2481

P | (02) 6685 5466 F | (02) 6680 9406

E | byron@wetlands.com.au

Date	Revision	Prepared by	Reviewed by
29 June 2009	A	D. Wassman S. Holloway	M. Bayley
14 July 2009	B	D. Wassman S. Holloway J. Boyd A. Reichelt-Brushett	M. Bayley
12 October 2009	C	D. Wassman S. Holloway J. Boyd A. Reichelt-Brushett	S. Holloway
18 January 2010	D - Final	As above	T. Alletson

Disclaimer: The information and subsequent recommendations contained within this report have been informed by information made available to Australian Wetlands at the time of preparation and is assumed to be accurate. The intention of the report is to assist Council's decision making concerning the development of management responses and detailed designs and should not be acted upon without further consultation with appropriately qualified practitioners.

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1. Introduction

Australian Wetlands has been commissioned by the Tweed Shire Council (TSC) to undertake a baseline ecological health assessment for the Cudgera Creek estuary at Hastings Point and Kerosene Inlet on Letitia Spit Fingal Head, NSW. The project involves the collection and identification of benthic macroinvertebrates, water and sediment quality assessment as well as on-site assessment of seagrass health.

The assessment of Cudgera Creek was deemed necessary due to increasing concerns that recent development within the catchment is leading to estuarine degradation. Of particular concern are elevated levels of suspended solids, increased nutrient loading, and runoff from acid sulfate soil areas that may be attributed to catchment activities such as development, agriculture and sewerage treatment plant (STP) outflows. Anecdotal evidence suggests that these impacts, among a suite of other impacts, may be leading to alterations in the estuary's community structure – specifically the abundance of some benthic species as well as the density and extent of seagrass coverage.

The assessment of Kerosene Inlet was prompted by anecdotal evidence that the health of the system may be showing signs of decline, in spite of its catchment being largely under developed. Kerosene Inlet has extensive seagrass beds and is located near the mouth of the Tweed River. In order to gain an understanding of the health of the system and detect future changes in ecosystem health, the baseline ecological assessment undertaken in Cudgera Creek was replicated at the Kerosene Inlet.

This study is seen as a way to not only provide initial estuarine health data and a snapshot assessment of the ecosystem/s, but also as an opportunity to develop a methodology for data collection and assessment techniques that may be used by a variety of organisations for future studies and monitoring. Australian Wetlands invited Southern Cross University to participate, adding value to the study by incorporating more extensive sediment contaminant analyses at the Environmental Analysis Laboratory (EAL) in Lismore.

1.1 Project scope, aims and limitations

TSC has received information from community groups suggesting that the Cudgera estuarine system has been placed under increased pressure due to recent development within its catchment. It has been suggested that the development and associated run-off may have led to a decline in both the water quality and the soft-sediment invertebrate communities within the Cudgera Creek. Such a concern is difficult to definitively answer without robust investigations spanning high temporal and spatial replication.

The aim of this report is to establish a monitoring plan which can act as a basis for future monitoring of the Cudgera Creek, which if implemented, will assist in determining the ecological trajectory of Cudgera Creek via the spatial and temporal analysis of the ecological assessment of the Cudgera Creek ecosystem.

On the basis of this aim the following tasks have been identified:

- Desktop Assessment of existing water quality and ecological data,
- Literature Review,
- Sampling design,
- Site Investigations – including an assessment of the benthic macroinvertebrates, seagrass beds, sediment analysis and in-situ water quality,
- Produce Final Estuarine Health Assessment Report.

1.2 Background

Both Cudgera Creek and Kerosene Inlet are individually under pressure from advancing development and increasing population. Impacts to Kerosene Inlet may be somewhat more indirect due to its almost off-channel location on the Tweed River and proximity to the mouth of the Tweed River which would exert significant flushing pressure on this system. It will, none the less, receive, and be impacted by, many of the contaminants entering the Tweed River. Cudgera Estuary by contrast is far less open to the influence of the marine environment and has a moderately developed catchment, with further development and population pressures continually encroaching on the estuary and its biota.

Both systems hold important local and regional significance as places of recreational and environmental importance and concerns about the effect of recent and past anthropogenic pressures on the current state of the systems have been raised by community members. In response to these on-going concerns, TSC has committed to undertaking this baseline assessment to enhance their understanding of both systems' physical and biological characteristics. These characteristics, once established, will form the foundation against which the findings of future studies can be compared.

1.3 Site Descriptions

1.3.1 Cudgera Creek

Cudgera Creek is located at Hastings Point, NSW (Figure 1). Cudgera Creek meets the sea at Hastings Point where the natural entrance is kept open most of the time due to the geomorphology of the headland and longshore movements (Australian Wetlands, 2004). There are three major branches of the creek:

- Christies Creek, opposite the main entrance
- Cudgera Creek main channel, which runs south approximately 3.5km to Pottsville, draining the Cudgera Creek locality in the west and surrounding agricultural lands
- An arm of Cudgera Creek, which continues south, draining SEPP14 Wetland southwest of Pottsville shopping centre.

The Cudgera Creek catchment is approximately 50km^2 in size, comprising large forested remnants, agricultural land, residential developments including Koala Beach and Seabreeze Estates and several new developments that discharge stormwater to the creek.

The catchment also includes the Hastings Point STP, treating effluent to tertiary level and pumped to a dune injection system behind the beach north of Hastings Point. Historically, in times of flood or when sewage pump station fails, effluent can overflow into Christies Creek and subsequently into Cudgera Creek (Australian Wetlands, 2004).

FIGURE 1. LOCATION OF CUDGERA CREEK, HASTINGS POINT, NORTHERN NSW.

FLORA AND FAUNA

There are numerous threatened flora and fauna recorded within or near the Cudgera Creek catchment including shorebirds, sedge frogs and bat species. A search of the Atlas of NSW Wildlife of a $10km^2$ region found 38 threatened terrestrial animal species and 28 flora species. During historic and current site investigations, many aquatic fauna species were seen, with the estuary floors in many places covered to varying degrees with worm and yabbie holes. Stingray feeding depressions were noted (Australian Wetlands, 2004) in the mid-sections of the system indicating the presence of a developed trophic food chain in the estuaries.

There are patchy seagrass beds throughout the creek, however the extent of overall biomass loss/growth is not known due to the lack of regular monitoring.

Water Quality

Tweed Shire Council has been undertaking long-term water quality monitoring at a number of sites within the Cudgera Estuary since 1999. Water quality data has been analysed for the years 2000 to 2008 below.

As displayed in Table 1 and Figure 2, the water quality results indicate that the range of several parameters in Cudgera Estuary is considered normal, notably pH, temperature, salinity an turbidity. The long-term monitoring shows the sample site furthest from the mouth (CGR4) is either close to, or exceeding, water quality objectives (Tweed Shire Council guideline for Tweed River Catchment) for TP, TN, suspended solids and dissolved oxygen (Table 1). Median values for dissolved oxygen and TN also exceed WQOs at site CGR3 (Table 1).

TABLE 1: MEDIAN WATER QUALITY RESULTS OF LONG-TERM MONITORING IN THE CUDGERA ESTUARY (DATA COURTESY OF THE TWEED SHIRE COUNCIL). BOLD NUMBER REFLECTS EXCEEDANCE OF TWEED SHIRE COUNCIL'S WATER QUALITY GUIDELINES FOR THE TWEED RIVER. LOR = LIMIT OF REPORTING. SAMPLES GENERALLY TAKEN EVERY 1-2 MONTHS FROM 2000 – 2008.

Statistical parameter	**FC**	**Temp.**	**DO**	**Sal.**	**pH**	**Chl. a**	**SS**	**TN**	**TP**	**Turb.**
	cfu/ 100mL	**°C**	**mg/L**	**ppt**		**ug/L**	**mg/L**	**mg/L**	**mg/L**	**NTU**
LOR	**10**							**0.05**	**0.03**	
Site CGR1										
N	81	83	83	83	83	82	83	76	70	32
Missing	4	2	2	2	2	3	2	9	15	53
Mean	160	22.8	6.27	32.3	7.82	1.60	11.49	0.52	0.04	6.51
Std. Error of Mean	64.1	0.3	0.10	3.50	0.07	0.28	1.47	0.06	0.00	1.89
Median	18.0	22.4	6.30	33.0	8.10	0.85	7.00	0.40	0.03**	2.70
Std. Deviation	577	2.9	0.93	31.9	0.67	2.57	13.41	0.50	0.04	10.71
Site CGR2										
N	80	82	82	82	82	82	81	78	69	32
Missing	3	1	1	1	1	1	2	5	14	51
Mean	549	23.2	6.48	25.3	7.63	2.36	12.7	0.64	0.04	8.33
Std. Error of Mean	260	0.3	0.14	1.21	0.08	0.37	1.50	0.07	0.00	2.09
Median	64.0	23.3	6.50	28.5	7.90	1.45	7.80	0.42	0.03**	3.30
Std. Deviation	2326	3.2	1.24	11.0	0.73	3.31	13.5	0.64	0.04	11.8
Site CGR3										
N	81.0	82	82	82	82	79	81	77	71	32
Missing	2.00	1	1	1	1	4	2	6	12	51
Mean	315	22.2	5.83	20.6	7.41	2.89	12.8	0.70	0.04	10.5
Std. Error of Mean	95.6	0.4	0.15	1.37	0.08	0.44	1.60	0.07	0.00	2.06
Median	84.0	22.0	**5.80**	23.9	7.55	1.80	9.00	**0.60**	0.03**	6.05
Std. Deviation	861	3.3	1.35	12.38	0.71	3.87	14.4	0.65	0.04	11.65
Site CGR4										
N	72	76	76	76	76	76	73	76	76	31
Missing	4	0	0	0	0	0	3	0	0	45
Mean	501	21.7	5.63	17.3	7.38	6.04	15.4	0.72	0.06	11.6
Std. Error of Mean	253	0.4	0.16	1.36	0.07	1.00	1.50	0.09	0.01	2.00
Median	110	21.8	**5.50**	16.2	7.50	3.40	**11.0**	**0.52**	**0.05****	7.80
Std. Deviation	2146	3.7	1.40	11.8	0.63	8.72	12.8	0.75	0.05	11.1
ANZECC Guideline (2000)	150		80-110%		7.0-8.5	4.0		0.3	0.03	0.5-10
DECC Guideline (2006)	150		80-110%		7.0-8.5	4.0		0.3	0.03	0.5-10
Tweed Shire Council Guideline	**<14**		**>6.0**		**7.0-9.0**	**<10**	**<10**	**<0.5**	**<0.05**	

DECC (2006) and ANZECC (2000) water quality criteria for protection of aquatic ecosystems.
Tweed Shire Council's adopted water quality guidelines for the Tweed River.
** Close to the general LOR for many TP analysis techniques.

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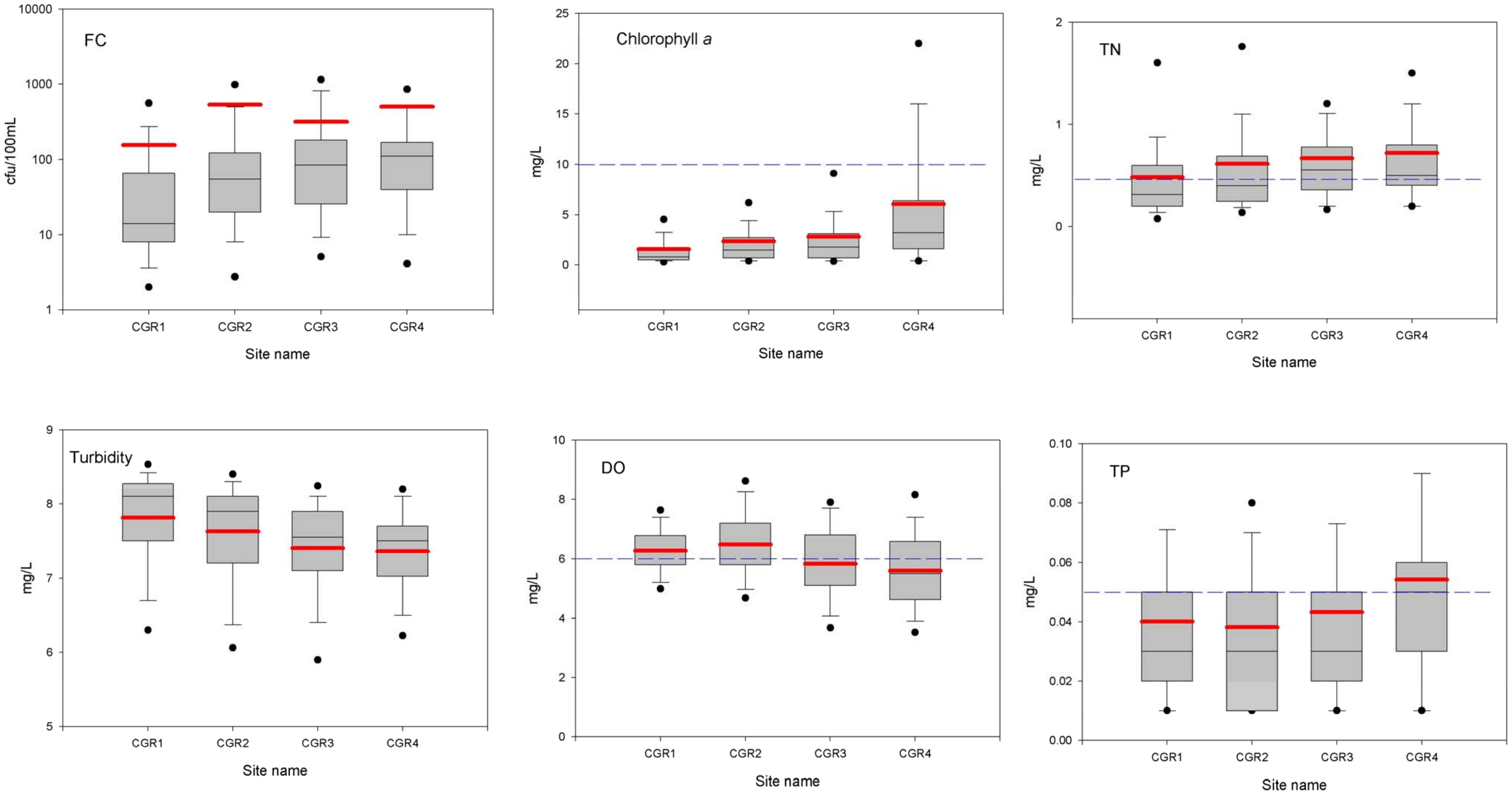

FIGURE 2: BOX AND WHISKER PLOTS FOR THE MAIN GUIDELINE WATER QUALITY VARIBLES REPORTED BY TSC. RED LINE REPRESENTS MEAN, GREY LINE THROUGH CENTRE OF BOX INDICATES MEDIAN, LOWER AND UPPER BOX LIMIT REPRESENT 25TH AND 75TH PERCENTILES, WHISKER EXTENT REPRESENTS 10TH AND 90TH PERCENTILES, BLACK DOTS SHOW 5TH AND 95TH PERCENTILES, BLUE DASHED LINE = TSC WATER QUALITY OBJECTIVE.

1.3.2 Kerosene Inlet

Kerosene Inlet is located approximately 1.5km from the mouth of the Tweed River (Figure 3). Located on the Letitia Spit, the catchment of Kerosene Inlet is largely undisturbed, though there appears to be some pressure relating to unauthorised access by 4WD, particularly at the northern end. Despite the undeveloped catchment immediately surrounding the inlet, it is still subject to some degree of flushing from the Tweed River, and is therefore exposed, at least partially, to the pressures on the Tweed River.

Flora and Fauna

There are numerous threatened flora and fauna recorded within or near Kerosene Inlet catchment including numerous shorebirds, sedge frogs and bat species. A search of the Atlas of NSW Wildlife of a 10km^2 region found 43 threatened terrestrial animal species and 24 flora species.

Water Quality

The water quality of the inlet is largely unknown. This baseline assessment forms an attempt at gaining an insight into the water quality of the inlet. Concerns have been raised regarding a possible decline in the systems health and there is a general assumption that the expanding sand bar at the mouth of the inlet may be restricting the tidal flushing required to maintain satisfactory water quality objectives.

FIGURE 3: LOCALITY MAP OF KEROSENE INLET.

2. Methodology

As this initial study by Australian Wetlands is a baseline assessment, we imposed a goal of providing a simple, expedient, yet scientifically rigorous methodology that could be adopted and easily replicated by universities or community groups in future studies. It was important to undertake a thorough literature review prior to the on-ground works to determine the most appropriate methodology. The review was targeted at establishing current scientific knowledge in four main areas:

- The use of one or multiple species as indicators of overall estuarine health;
- The generally adopted or 'best practise' methodology for estuarine sampling;
- The current state of knowledge on estuarine sampling; and,
- The current state of knowledge on spatially relevant (studies in close proximity to Cudgera Creek) estuarine sampling.

The following literature review details the information obtained relating to these matters which then informed the methodology for the Cudgera Creek/Kerosene Inlet sampling.

2.1 Literature Review

2.1.1 Use of Indicator Species in Estuarine Assessments

The use of biological indicators in the assessment of environmental health has been an area of significant research for many years. In many instances the use of physio-chemical or abiotic sampling methodologies can be problematic (Goodsell *et al*, In Press). The differences lie in what each sampling method can detect. While contamination and disturbance can be measured with abiotic sampling, the physical or biological responses to these (pollution and impact) cannot be detected or measured using physio-chemical sampling methods (Goodsell *et al.* In Press). Contamination and disturbance are often characterised by pulse events, which can be easily missed when relying on abiotic measurements alone. Biotic surveys can in contrast detect the pulse-like or spiked nature of contamination events through changes in community composition along a spatial or temporal gradient (Calabretta & Oviatt, 2008; Goodsell *et al.* In Press).

Since responses to pollution and impact are expressed in changes to population dynamics and behavioural or pathological responses in organisms, the need has been recognised to utilise biological indices to provide an indication of current state and long-term trends in an environmental system (Goodsell *et al.* In Press). In addition to this, there is a growing understanding that changes to community structure in inherently dynamic and variable environments such as estuarine systems are less reliable indicators of system health than a single biotic response by a single taxon (Barton, 2003).

For a particular taxon to be suitable as an indicator of a particular environmental impact it is important to demonstrate that there is a causal link between the taxon's biological response (e.g. changes in abundance or spatial distribution) and the environmental variable of concern (e.g. contamination, habitat alteration) (Pinto *et al.,* 2009; Borja & Dauer, 2008; Barton, 2003; Goodsell *et al.* In Press).

For the purposes of this assessment two species were identified as possible bio-indicators of the health of the Cudgera estuary. The first, *Mictyris longicarpus* (Soldier Crab) is a conspicuous invertebrate of estuarine sand and mud flats, forming large feeding groups as the tide recedes. The second possibility was *Callianassa australiensis* (Ghost shrimp or Yabby), again a common and abundant species on estuarine intertidal sand and mud flats.

Both of these species could be ideal indicators as they are readily collectable, identifiable, are indigenous to eastern Australia and have a certain status as a feature of a healthy estuary (Barton, 2003). In addition to this it would seem, on the surface, that these species play a key role in overall estuarine functioning, transferring energy from lower trophic levels (zooplankton and phytoplankton) to higher trophic levels (fish and larger crustaceans). Given their position in the trophic food web it would also be plausible to assume that alterations to the community structure associated with these species may have direct impacts on other populations within the estuary. Unfortunately after extensive searches, no literature was found on the use of either of these species as bio-indicators for estuarine health. As such, the causal relationship between biological response and impact could not be demonstrated for these species without further investigation.

After a review of the literature and the absence of the requisite information on the two possible indicator species it was no longer considered possible to use a single species as an indicator of the health of Cudgera Estuary and Kerosene Inlet. However, it is recommended that studies into the applicability and suitability of these species as bio-indicators be undertaken.

2.1.2 Estuarine Sampling Methodology

The need to understand the health of estuarine systems and anthropogenic effects upon them has provided the incentive to define an appropriate sampling methodology (Simpson *et al.,* 2005). The generally accepted process for scientific investigation involves the selection of sampling locations and times, the use of replicates and the use of reference locations which can be used to compare results. The ultimate objective of this general practise is to ensure that sufficient samples are collected and analysed at appropriate spatial and temporal scales so as to enable the testing of a hypothesis with the correct degree of statistical power (Simpson *et al.,* 2005).

Specific techniques for sampling benthic invertebrates within estuarine environments are many and varied and depend on the objectives of the study, location or site specific constraints. However all generally involve the collection of a quantity of sediment containing target organisms, followed by a process for separating sediment and organisms (usually in-situ) and the preservation of the retained sediment and organisms for laboratory identification (Bakalem *et al.,* 2009; Calabretta & Oviatt*,* 2008; Marum, 2007; Hastie & Smith, 2006; Simpson *et al.* 2005; Thompson, 2005; Batley *et al.,* 2002; Gamito & Futado, In Press).

For the physical collection of sediment, two main techniques are employed. For sub-tidal environments the use of van Veen or Eckman grab samples are appropriate (Marum, 2007; Hastie & Smith, 2006). While for intertidal sampling the use of PVC hand cores are the generally adopted sampling instruments (Hirst & Kilpatrick, 2007; Salas *et al.,* 2006; Simpson *et al.*, 2005; Thompson, 2005). One study reviewed used a hand core, operated by SCUBA divers in a sub-tidal situation (Calabretta & Oviatt, 2008). No justification was given for this methodology, however Simpson *et al.* (2005) also mentions this technique as a possibility, presumably where greater positioning or volumetric accuracy is required.

The size of the hand core appears to vary both in diameter and depth of penetration. While most studies have a penetration depth of 100mm (Calabretta & Oviatt, 2008; Hirst & Kilpatrick, 2007; Simpson *et al.,* 2005) one study reviewed had a penetration depth of 300mm (Thompson, 2005). Core diameter in other studies was found to be either 100mm (Simpson *et al.,* 2005) or 150mm (Hirst & Kilpatrick, 2007; Thompson, 2005). There is no specific justification for penetration depth except that the depth chosen should provide a representative sample of the site, which is determined by a pilot study (Simpson *et al.,* 2005). However the critical factor across all the studies was to ensure the volume of sediment retained and the portion of the sediment column sampled was consistent across all samples (Simpson *et al.,* 2005). The number of replicate core samples also appears to be largely arbitrary, but with the majority collecting either 4 or 5 replicate samples (Thompson, 2005).

Selection of sieve size tended to be fairly uniform across all reviewed studies at 1mm (Bakalem *et al.,* 2009; Marum, 2007; Hastie & Smith, 2006; Simpson *et al.* 2005; Thompson, 2005; Batley *et al.,* 2002; Gamito & Futado, In Press). One study used 0.5mm for intertidal work and 1mm for sub-tidal work, though there was no justification provided for this choice (Salas *et al.,* 2006). In the two reviews of sampling methodology the general consensus appeared to be that sieve mesh size varied from 0.5mm to 1mm to achieve desired retention of the benthic invertebrates (Simpson *et al.,* 2005; Batley *et al.,* 2002). The choice of 1mm mesh size by most authors appears to be based on the assumption that 1mm will capture adult macroinvertebrates and exclude juveniles of the species, though a study by Calabretta & Oviatt (2008) used a 0.5mm mesh aperture and based this choice on their assessment of the adult macroinvertebrates size range. The reason for the general exclusion of juveniles and indeed larval stages is that these are harder to identify and due to age may not display a common, community response changes to a perceived impact (Calabretta & Oviatt, 2008; Hirst & Kilpatrick, 2007; Simpson *et al.,* 2005).

All studies reviewed preserved samples in-situ with either ethanol or formalin. The choice of product seems arbitrary, and those that using formalin in-situ ultimately used ethanol once in the labs for long-term storage of the samples (Puente & Diaz, 2008; Salas *et al.,* 2006).

In all studies reviewed, water was sampled and measured for physico-chemical parameters. In addition sediment was collected from the same location as the fauna sampling and analysed ex-situ for grain size and physico-chemical variables. Sediments were collected to ensure sites were comparable with respect to grain size (Simpson *et. al.,* 2005).

Laboratory identification of the benthic macroinvertebrates is another area in which discrepancies were observed amongst studies reviewed. The majority of studies identified the invertebrates to the lowest taxonomic level possible, usually species level (Puente & Diaz, 2008; Hastie & Smith, 2006; Salas *et al.,* 2006) however one study identified down to subspecies (Thompson, 2005). Despite this, in three separate articles the authors suggest that identification to family level is suitable to detect community alterations in benthic macroinvertebrates (Marum, 2007; Simpson *et al,* 2005; Macfarlane & Booth, 2001). In fact Macfarlane and Booth (2001) suggest that identification to family level outperformed species level identification when reflecting community change in response to an impact. They do, however, maintain that for natural disturbance and variability identification to species level would be more appropriate.

2.1.3 State of Knowledge – Estuarine Sampling

It is now well understood that estuaries are ecologically and commercially significant assets, amongst some of the most ecologically productive ecosystems on earth. Unfortunately estuaries are subject to extreme anthropogenic impacts from a variety of sources (McClusky & Elliot, 2004). Industrial, commercial, residential and municipal waste created from an ever expanding population invariably finds its way to the estuaries. These waste loads carry a variety of organic and inorganic pollutants that can have variable impacts on the health and ecosystem functioning of an estuary (Machado *et al.,* 2002). Continual increase of coastal urban populations and their associated pollutant loads has led to significant concerns about the health of Australia's estuaries, and spawned a desire to understand how they respond to contamination and disturbance. The need has also been identified to develop approaches which enable estuarine health to be assessed rapidly.

Traditionally, aquatic systems, including estuaries, have always been analysed and assessed based on data gained from water and sediment sampling, however there have always been inherent problems associated with analysing these media (Rainbow, 1995). Because pollutant loads are often diffuse in such expansive environments, concentrations in water are often below detection limits and can be highly variable (Villares *et al*., 2001). Sediment offers a better medium in this respect, as pollutants accumulate in sediments making them easier to measure and can also provide a more stable indication of fluxes in pollutant loads (Rainbow and Phillips, 1993). However in sediments, contaminant accumulation and the concentrations available to biota are affected by physicochemical characteristics such as pH, salinity, oxygen, particle size and organic content (Meyer, 2002). Therefore, contaminant concentrations in sediments and waters, as determined by chemical analyses alone, cannot be reliably used to assess the likely toxicity of contaminants to biota (Gosavi *et al.,* 2004). As a result, aquatic organisms have become increasingly popular in the assessment of contamination (Simpson *et al.,* 2005; Batley *et al.,* 2002).

Much of the investigation into biotic response to contamination is based on a study by Pearson and Rosenburg (1978) which found that there was a predictable and repeatable response by biota along a spatial or temporal gradient of pollution.

Most studies continue to confirm these findings with communities displaying changes, either positive or negative based on distance along a contamination gradient (Salas *et al.,* 2006). However, as estuarine environments are inherently dynamic and variable there is the continued confounding variable of the effect of sediment and hydrological regime on benthic community composition (Hirst and Kilpatrick, 2007). That is, these physical variables will exert greater control over composition than could be attributed to some form of contamination. This was found to be the case in a study by Macfarlane & Booth (2001) where they found difficulties in determining community changes in an environment with diffuse and low levels of contamination and inherently low species diversity. A second study that supports this finding was conducted in an estuary with a clear spatial gradient from a pollution source (Calabretta & Oviatt, 2008). In this study it was found that as the distance from the anthropogenic pollution source increases the influence of hydrodynamic regime and sediment size exerted a greater control on community composition than contamination (Calabretta & Oviatt, 2008). However the burden of evidence suggests that there are detectable differences in community composition based on levels of some contaminants (Bakalem *et al.,* 2009; Calabretta & Oviatt*,* 2008; Marum, 2007; Hastie & Smith, 2006; Simpson *et al.* 2005; Thompson, 2005; Batley *et al.,* 2002; Gamito & Futado, In Press).

The use of reference sites has been largely avoided in preference for repeated, nested sampling at the same location as a result of these perceived inherent differences in morphodynamics (Hirst & Kilpatrick 2007). Most studies that have attempted using reference locations have selected adjacent tributaries or arms of the same estuarine system that are considered to be isolated from the impact (Hirst & Kilpatrick 2007). In an attempt to establish the suitability of reference sites, Hirst and Kilpatrick (2007) undertook an assessment of within and between estuarine community composition. The findings suggest that, as ascertained by others, there is inherent variability within estuarine systems, leading to significantly different community composition at different locations within an estuary, regardless of the presence or absence of an impact, but relatively little variation between systems (Hirst & Kilpatrick 2007). This suggests that as long as attempts are made to ensure the estuarine systems are approximately similar in matters such as catchment size and geology and openness to the sea, and that sampling locations are spatially similar (same distance from mouth or headwaters) then the use of reference locations may be applicable in comparing impacted and non-impacted estuaries. This final point is critical when considering the use of reference locations and is discussed further in the following section.

Regardless of the decision to use a reference location or not, all literature reviewed confirmed the need to undertake long-term studies of estuarine systems to counteract the effect of the inherent variability of these systems.

2.1.4 Spatially Relevant Examples

There is only limited availability of studies that are both geographically proximal to Cudgera Creek and also assess macrobenthic faunal assemblages. The first of these was a comparative study between the benthic macroinvertebrate communities of intermittently closed and open estuaries and those present in permanently open estuaries (Hastie & Smith, 2006). The second study was a baseline assessment of two estuaries to determine how changes to effluent discharge from STP's have affected the benthic macroinvertebrate communities (Marum, 2007). The study included Tallow Creek and Belongil Creek, with Jerusalem Creek as a reference site.

Both studies have a single distinct difference to the study in Cudgera Creek and Kerosene Inlet in that they were exclusively sub-tidal assessments and both investigated intermittently closed systems. However, other general sampling methodologies (sieve size, preservation of samples, recording of physio-chemical water variables and sediment analysis) remained consistent with the majority of other investigations reviewed.

In the intermittent versus permanently open comparative study, significant differences in benthic macroinvertebrate community structure were observed between all intermittent estuaries, open estuaries and between intermittent and permanently open estuaries (Hastie & Smith, 2006). The variation between open and intermittent estuaries is explicable and possible due to highly variable physio-chemical parameters and tidal regimes and general hydrodynamic difference (Hastie & Smith, 2006). However reasoning for variations between similar estuarine types, i.e. open versus open, is less clear. This finding is at odds with that of Hirst and Kilpatrick (2007) who suggest that variability between estuaries is sufficiently small so as to make them comparable and suitable in an impact/no-impact study. However in the Hirst & Kilpatrick (2007) example a concerted effort was made to select estuaries within close proximity of each other (35km total coastline), similar catchment sizes (330km^2) and similar tidal regimes (2-3 meters). While for the intermittent versus open comparison study the catchment sizes (for open estuaries) varied considerably, from 148km^2 to 25km^2 and the physical separation was greater also at approximately 60km. No data was available on tidal regimes of the open estuaries (Hastie & Smith, 2006).

In the study relating to STP effluent levels and their effects on the macrobenthic invertebrates, significant differences were detected between reference and impact locations for both richness and abundance of macroinvertebrates (Marum, 2007). The study also found that in the impacted locations the community composition was generally dominated by one or two species, generally suspension or deposit feeders and states that this is generally evidence of a disturbed system (Marrum 2007). The control location by contrast had a more even composition of trophic groups, reflective of a less disturbed system (Marum, 2007). The study does however caution against drawing absolute conclusions about the state of the estuaries due to the well understood, inherent variability of these dynamic systems and suggests that ongoing monitoring is required to draw more accurate and rigorous conclusions about community composition in response to impacts (Marum, 2007).

2.1.5 Recommendations for Current Methodology

Based on the reviewed literature, the following section outlines recommendations for the direction, purpose and methodology for the sampling at Cudgera Creek and Kerosene Inlet.

The adopted sampling methodology has been governed by the knowledge that at this time there will be no pilot study conducted prior to the start date and that the goal of this assessment is to provide baseline data which can be used as a start point for other long-term monitoring projects by community groups or universities. For this reason it was assumed that the following constraints be placed on the study design:

- The field work should not be excessively onerous;

- Materials used should be readily available;
- To ensure the best chance of accurate community representation hand cores of 150mm diameter and 300mm depth should be used with 5 replicate samples per station;
- To balance identification times and capture of adult macroinvertebrates, 1mm mesh aperture size should be used for the sieve bags;
- Physio-chemical parameters in water and sediment need to be recorded; and
- Sediment needs to be collected for grain size analysis.

In the absence of a single species for which a causal link between biological response and perceived impact can be demonstrated, the study will need to focus on the assessment of current and future community dynamics to determine changes relating to potential impacts. This should not however preclude further investigation into finding a suitable bio-indicator. At this time the Soldier Crab (*Mictyris longicarpus*) presents itself as a best possible candidate for this role.

Laboratory macroinvertebrate identification to family level was deemed appropriate based on the following:

1. The goal of allowing replication of this study by a variety of users that may not have the necessary taxonomic skills to identify to species level
2. Numerous recent studies have found that identification and synthesis of data at family and even phylum level has resulted in no loss of sensitivity in detecting community change. One study purports that the taxonomic resolution of family actually increases detection of community alteration in response to anthropogenic impacts (Pagola-Carte 2002, Macfarlane & Booth 2000).

A reference individual should be preserved for each species to aid future identification work. However as family data will be recorded during the identification it is suggested that statistical comparison be conducted between family level data to establish if family level identification will detect community level alterations.

2.2 Field Work

2.2.1 Sampling Locations

Site selection was informed by the outcomes of consultation with Tweed Shire Council, community representatives and the accessibility and representativeness of particular locations. It must be noted that on the allocated week of field work, the entire north coast region, especially the Tweed Coast, was subject to extreme weather and oceanic conditions. This resulted in some of the lower estuary sampling sites not being appropriate for sampling (i.e. no exposed tidal sand flats) and timing, logistical and economic reasons informed final site selection.

In Cudgera Creek, the two locations for macroinvertebrate sampling, seagrass assessment and water quality sampling were selected so that the middle and lower portions of the estuary were represented. An additional goal was to select a location within Cudgera Creek that would be spatially relevant to the confluence of Christies and Cudgera Creeks. Unfortunately due to extreme weather conditions on the day of sampling the downstream site had to be replaced with a site that still received water from both Christies and Cudgera Creeks but was upstream of the main confluence. Both locations had suitable sand banks, exposed at low tide from which manual sampling could be conducted. Figure 4 shows the location of the macroinvertebrate, seagrass and water quality sampling sites of Cudgera Creek. Appendix B shows the GPS coordinates of each transect.

The Kerosene Inlet site was again selected after consultation with Tweed Shire Council and informed by the ease of access and representativeness. Only one location was sampled in this initial study (Figure 5). This location had a beach slope that was fully exposed at low tide, and was fully subjected to the tidal influence of the Tweed River. All measurable data was collected at this location, specifically, seagrass, macroinvertebrates, sediment and water quality. Appendix B shows the GPS coordinates of all transects.

Sediment toxicology sampling was undertaken at ten locations, including two sites at Kerosene Inlet. The location of these sites is provided in Table 2 and represented as red dots in Figure 4.

TABLE 2: SITES SELECTED FOR SEDIMENT ANALYSIS IN CUDGERA CREEK (ADAPTED FROM BOYD & REICHELT-BRUSHETT 2009).

Site		Description
Site 1	Intertidal shoal	10m to shore, sandy, mangrove riparian veg.
Site 2	Behind Point development	5m to shore, sandy, near seagrass, mangrove riparian veg, reducing sed.
Site 3	Koala Beach bridge	highly reducing black sediment, mangrove & she oak riparian veg.
Site 4	Environment Park footbridge	highly reducing black sediment, mangrove & she oak riparian veg.
Site 5	Cudgera Creek Rd bridge	drainage from melaleuca swamp, thick riparian veg.
Site 6	Seabreeze retention pond	from observation deck, high levels of macroalgae (limited sample)
Site 7	Behind Seabreeze	1m from shore, downstream from canefields
Site 8	Cudgera Cr. behind Koala B.	1m from shore, muddy, mangrove riparian veg.
Site 9/10	Kerosene Inlet	Seagrass sampling area on western side of inlet

FIGURE 4: LOCATION OF SEDIMENT, MACROINVERTEBRATE AND SEAGRASS SAMPLING IN CUDGERA CREEK (GPS CO-ORIDINATES FOR MACROIVERTEBRATE AND SEAGRASS SAMPLING ARE PROVIDED IN APPENDIX B)

🔵 = location of sampling for macroinvertebrate, seagrass and sediment grain size analyses

🔴 = location of sampling for sediment toxicology analyses

🔵 = location of sampling for macroinvertebrate, seagrass and sediment grain size analyses

🔴 = location of sampling for sediment toxicology analyses

FIGURE 5: SEDIMENT, MACROINVERTEBRATE AND SEAGRASS SAMPLING LOCATION AT KEROSENE INLET (GPS CO-ORDINATES ARE PROVIDED IN APPENDIX B)

2.2.2 Macroinvertebrate Sampling

At each site three transects were measured, with each transect separated by approximately 10 meters. On each transect there were six sampling stations, Station 1 located at the effective high tide line to Station 6 located at the effective low tide mark. The stations were spaced equally and identified with wire and flagging tape – 18 samples taken from each location. The use of transects was employed to remove the risk of non-random sampling bias. Plate 1 illustrates a typical macroinvertebrate sampling location.

Collection of the macroinvertebrate samples was done by inserting a PVC core (150mm diameter, 300mm deep) into the sediment, then placing the sediment core in a screening bag (1mm aperture). At each sampling Station, five replicate cores were taken and pooled into the one screening bag. The bag was immediately rinsed in the water to remove excess sediment. The remaining contents were then emptied into clear plastic containers and preserved with 70% ethanol solution and returned to the lab for sorting and identification.

While the original proposal was to undertake the sampling over two consecutive days, poor weather prevented this from occurring. Sampling was undertaken over three days, 23, 24 and 29 April 2009.

PLATE 1: TYPICAL MACROINVERTEBRATE SAMPLING LOCATION

2.2.3 Water and Sediment Analysis

Physico-chemical water quality measurements were taken prior to any seagrass or macroinvertebrate sampling and were done using a Horiba U-10 multi parameter probe. Parameters measured were - pH, Dissolved Oxygen (DO), Salinity, Conductivity and Temperature.

Sediment samples for grain size analysis were collected at the completion of the macroinvertebrate sampling. Samples were taken from Stations 1, 3 and 6 on each transect from each location. Sediment was collected using a PVC core (diameter 50mm, 300mm deep) so as to match the sediment profile from which the macroinvertebrates were collected. At each sediment collection point, three replicate PVC cores were taken. Sediment samples were labelled and stored in plastic zip-lock bags and refrigerated for later analysis in the lab.

Sediment samples for toxicology assessment were retrieved by Van Veen grab at 10 locations along the creek, covering approximately 3.5km (See Table 2).The first eight were taken in Cudgera Creek and the remaining two were taken at the same sites as seagrass assessment in Kerosene Inlet (see section 2.3.3). The Van Veen grab was deployed mainly from a canoe and from bridges. Once collected, the samples were placed in a plastic bag and immediately stored on ice, transported on the same day to the laboratory and frozen prior to analyses.

2.2.4 Seagrass Assessment

For the seagrass assessment a single transect was marked through an appropriately sized patch of seagrass. Along each transect, 10 sampling points were marked and identified with wire and flagging tape. At each sampling station, a $0.5m^2$ quadrat was placed on the seagrass. In each quadrat the percentage seagrass cover, height and epiphytic cover was recorded. Seagrass cover was calculated based on the presence or absence of seagrass roots within each grid square of the quadrat. Height was determined by averaging three random seagrass strands within the quadrat. Epiphytic cover was determined based on the presence or absence of epiphytic growth able to be felt by running fingers along the length of several blades of seagrass within the quadrat. Plate 2 illustrates a typical seagrass sampling station.

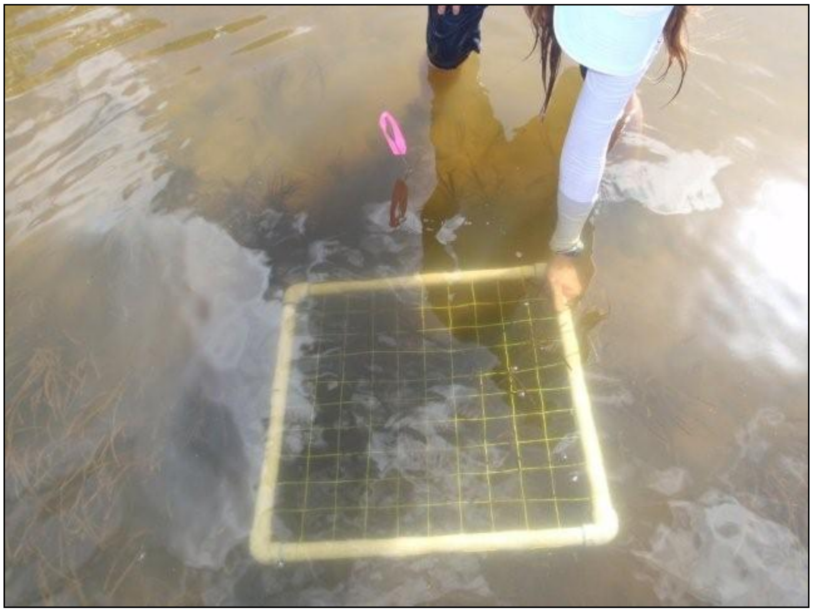

PLATE 2: TYPICAL SEAGRASS SAMPLING STATION

2.3 Laboratory Analysis

2.3.1 Macroinvertebrate Identification

The preserved macroinvertebrate samples were returned to the University of the Sunshine Coast labs where each sample was further sieved through a 250µm sieve to remove any final silts but retain all captured target organisms (≥1mm).

Each sample was analysed under a dissecting microscope to first remove all macroinvertebrates from the sample. The organisms were then identified to family level using appropriate taxonomic keys (Table 3). The family and the total number of organisms for each family group were recorded for each sample.

While 18 samples for each location were collected, one of the goals of this study was to determine the effort (more or less than 18 samples per site) required by future studies to satisfactorily measure the abundance and composition of the systems (i.e. to determine the scale required by further studies). This can then be translated into hours of sampling time and thus the cost of undertaking meaningful and well directed follow-up studies. During laboratory analysis we aimed to determine how many samples needed sorting and identification before no new species were discovered. During this process it was determined that after 13 samples no new species were being discovered and there were no sharp or abnormal changes in the abundance or frequency of identified species.

A reference set of all species collected has been preserved and provided to Tweed Shire Council for comparison purposes in future studies.

TABLE 3: LIST OF TAXONOMIC KEYS USED TO IDENTIFY BENTHIC MACROINVERTEBRATES

Taxon	Source
Crustacea	Poore (2002), Stoddart & Lowry (2003), Davie (2002a), Davie (2002b)
Polychaeta	Wilson et al (2003)
Mollusca	Wilson (1993)

2.3.2 Sediment Analysis

Sediment collected for toxicant analyses was a two-fold process. Total metals were determined by hot acid digest and analyses using ICP-MS. Sediment samples collected from four sites were stored in solvent washed glass jars and sent to Wollongbar agriculture for pesticide analyses. TN, TOC, and TS were analysed at the EAL using LECO CNS2000.

Sediment collected for grain size analysis was returned to the University of Southern Cross labs for analysis. The methodology employed follows the wet and dry sieving method outlined in Lewis and McConchie (1994).

2.4 Data Analysis

As this is an initial baseline assessment there is little need for high powered statistical analysis, particularly since the aim is not to compare the sites against one another but to get a broad understanding of the current community structure of macroinvertebrates and the health and extent of seagrass. For this reason data has generally been represented using univariate measurements to summarise the attributes of the communities. At all sites the abundance, taxonomic richness and Shannon Diversity Index will be calculated. Where appropriate the data has been graphically represented.

In instances where statistical tests, such as t-tests have been used, as is the case for comparisons between the two Cudgera Creek sites, the data has been normalised using an arcsinh transformation, due to the large number of zero counts.

Statistical analysis of the grain size for each site involved the construction of a frequency histogram to display the distribution of the different sediment size classes. Additional data was calculated for each site including, mean, standard deviation, kurtosis and skewness using the method of moments technique (Lindholm 1987).

3. Results

3.1 Macroinvertebrate Community

3.1.1 Cudgera Creek

A total of 12 families of benthic macroinvertebrates were identified during sampling at Cudgera Creek (Table 4) with a cumulative total of 131 individuals collected during sampling (Table 5). Table 4 also indicates the locations within the estuary each family was found.

Results obtained for Cudgera Creek have been presented for each site individually as well as the cumulative results for the estuary. Table 5 describes the richness, abundance and Shannon Diversity Index for Cudgera Creek. The data suggests that there is very little variation in these parameters; richness, abundance and Shannon Diversity, between the two sites and between the sites and the estuary as a whole.

TABLE 4: FAMILIES OF BENTHIC MACROINVERTEBRATES COLLECTED DURING SAMPLING AT CUDGERA CREEK AND THE LOCATIONS IN WHICH THEY WERE FOUND.

Family	Upstream	Downstream
Crustaceans		
Haustoriidae	X	X
Mictyridae	X	X
Penaeidae		X
Odicerotidae	X	X
Molluscs		
Mactridae	X	X
Donacidae	X	X
Naticidae	X	
Epitoniidae	X	
Nassiriidae		X
Tellinidae		X
Polychaetes		
Glyceridae	X	X
Nephytidae	X	X

TABLE 5: RICHNESS, ABUNDANCE AND SHANNON DIVERSITY FOR THE CUDGERA CREEK SAMPLING LOCATIONS AND THE CUMULATIVE RESULTS FOR THE ESTUARY.

Site	**Richness**		**Abundance**		**Shannon Index (H')**
	Mean/Sample	**Total**	**Mean/Sample**	**Total**	
Upstream	2.46	9	5.08	66	1.67
Downstream	2.15	8	5	65	1.47
Cudgera Total	**2.31**	**12**	**5.04**	**131**	**1.74**

While statistical analysis at this preliminary baseline stage would not generally be considered rigorous, a t-test assuming equal variances was calculated for richness and abundance data to compare the upstream and downstream sites. In both instances t-tests determined that there was not a statistically significant difference in the abundance ($P \leq 2.06$, df=24) or richness ($P \leq 2.06$, df=24) of the two sites within Cudgera Creek.

Figures 6 and 7 graphically illustrate abundance data for the upstream site at Cudgera Creek. Figure 5 clearly indicates that the crustacean taxonomic group contribute significantly to the overall abundance at this site, followed by molluscs. However, it is evident from Figure 6 that one family within each major group was the major contributor to abundance. Within the crustaceans it is clear that the haustoriid amphipods contributed the majority of the overall abundance of this group, with the next greatest contribution by the mictyridae family, specifically the Soldier Crab, *Mictyris longicarpus*. For the molluscs the bivalve family, mactridae, most notably Little Trough Clam (*Spisula trigonella*), were of greatest significance with respect to abundance, while for the polychaeta the glyceridae family were appreciably the dominant contributor to relative abundance.

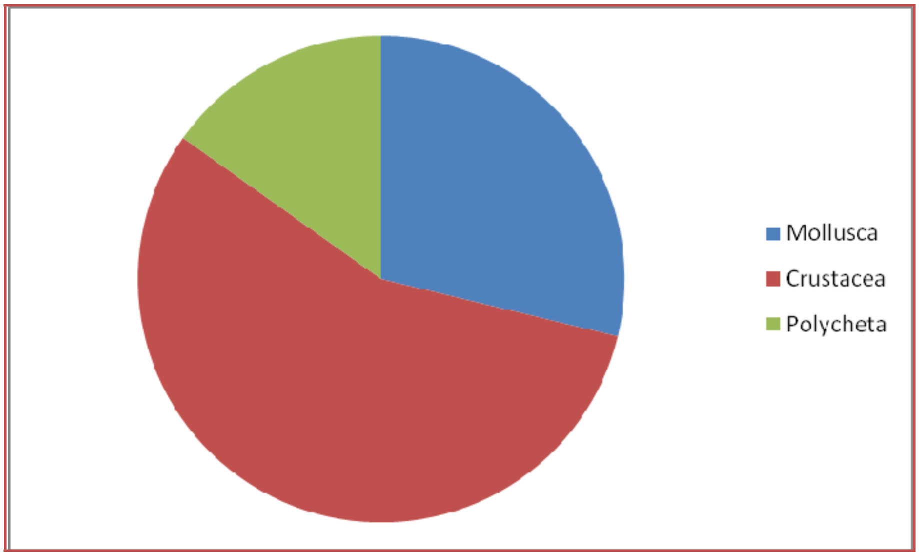

FIGURE 6: PERCENTAGE CONTRIBUTION OF MAJOR TAXONOMIC GROUPS TO THE TOTAL ABUNDANCE AT THE CUDGERA CREEK UPSTREAM SITE.

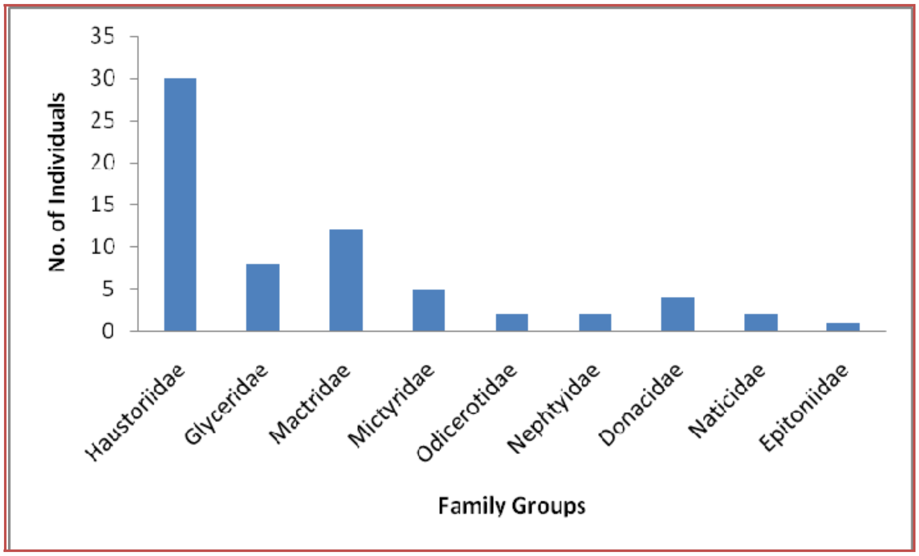

FIGURE 7: TOTAL NUMBER OF INDIVIDUALS PER FAMILY GROUP FOR THE CUDGERA CREEK UPSTREAM SITE.

Despite the richness, abundance and Shannon Diversity values for the two locations being comparable, there is a notable point of difference between the downstream and upstream and sites. This pertains to the dominant family group, which for the downstream location was a molluscan family, mactridae (Figures 8 and 9). While as mentioned previously it was the crustacean families that dominated the upstream site. At the downstream site the crustacean groups where the next most dominant, again the haustoriid amphipod family was the dominant group within the crustaceans. However in contrast to the upstream site, the second largest crustacean contributor was the family penaeidae, of which the juvenile Eastern King Prawn (*Penaeus plebejus*) was the most common, replacing the mictyrid crustaceans from the upstream site. Glyceridae was again the major contributor for the polychaeta, with the contribution of the other polychaeta family, nephtyidae, reduced in comparison to the upstream site.

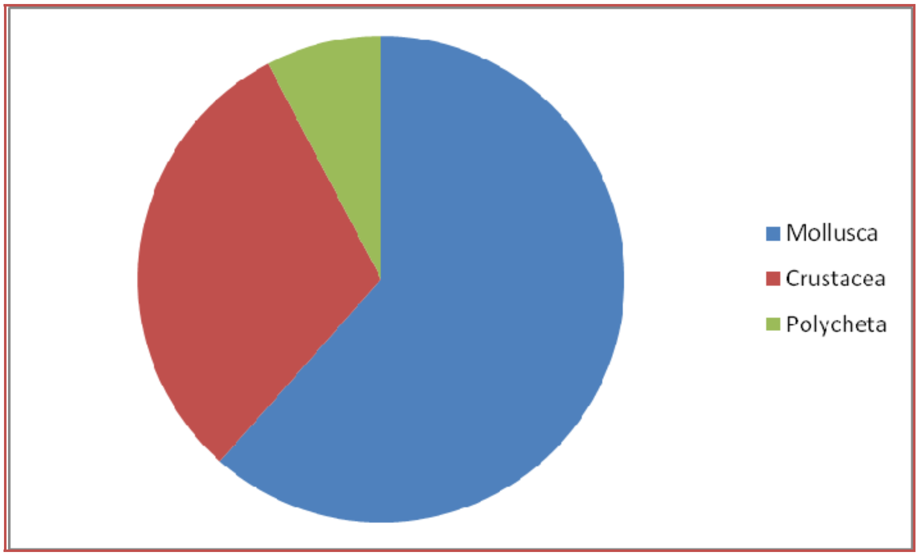

FIGURE 8: PERCENTAGE CONTRIBUTION OF MAJOR TAXONOMIC GROUPS TO THE TOTAL ABUNDANCE AT THE CUDGERA CREEK DOWNSTREAM SITE.

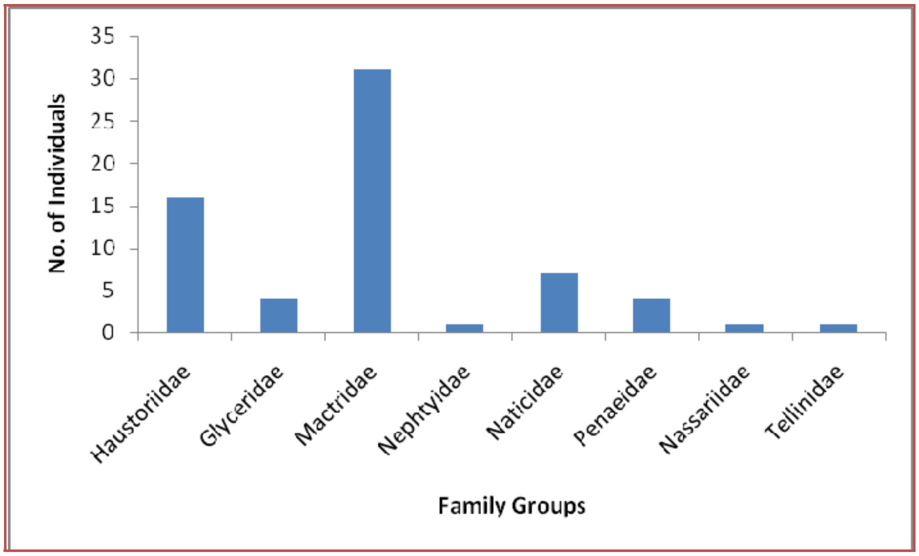

FIGURE 9: TOTAL NUMBER OF INDIVIDUALS PER FAMILY GROUP FOR THE CUDGERA CREEK DOWNSTREAM SITE.

In combining the data for the two sites it is clear that for the estuary as a whole the two major taxonomic groups that dominate the abundance are the crustaceans and the molluscs (Figure 10). Once again there is clearly a major contributing family for each. Of the molluscs, the bivalve family mactridae is the clearly dominant group, while of the crustaceans, it is evident that the haustoriid amphipods is the most abundant crustacean family (Figure 11).

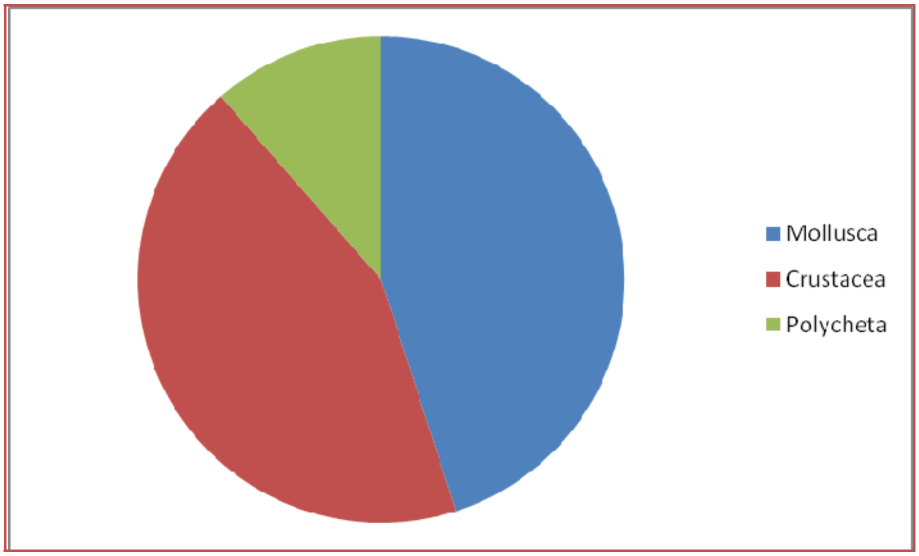

FIGURE 10: PERCENTAGE CONTRIBUTION OF MAJOR TAXONOMIC GROUPS TO THE TOTAL ABUNDANCE FOR CUDGERA CREEK.

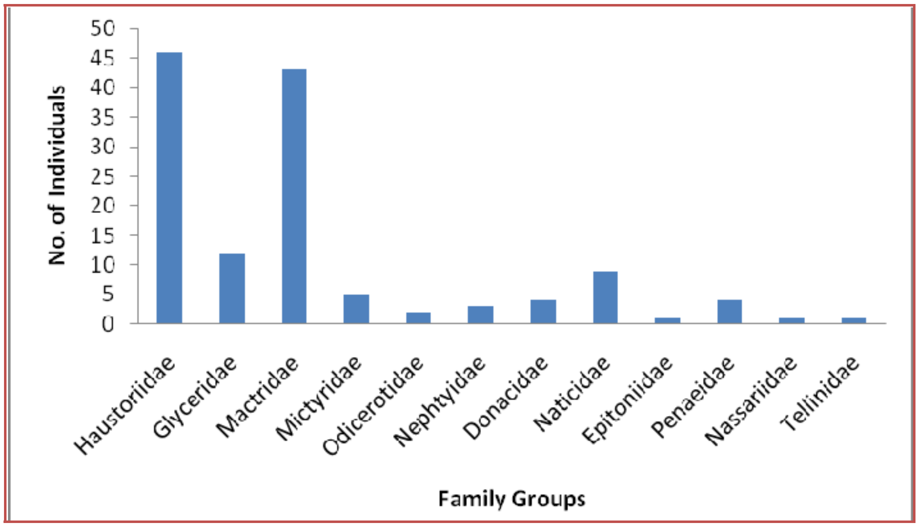

FIGURE 11: TOTAL NUMBER OF INDIVIDUALS PER FAMILY GROUP FOR CUDGERA CREEK.

3.1.2 Kerosene Inlet

Sampling at Kerosene Inlet produced a total of 13 family groups of benthic macroinvertebrates with a cumulative total of 106 individuals sampled. Table 6 shows the family groups encountered during sampling at Kerosene Inlet. Of the groups, the crustacean families clearly contribute to the overall site richness, contributing seven out of the thirteen families.

Table 7 below presents the richness, abundance and Shannon Diversity Index results for the sampling location in Kerosene inlet. Kerosene Inlet was found to have, on average 8.15 individuals per sample with a mean of 2.46 families in each sample. Shannon Index for Kerosene Inlet was found to be 1.69.

TABLE 6: LIST OF THE BENTHIC MACROINVERTEBRATE FAMILYS FOUND DURING SAMPLING AT THE MOUTH OF KEROSENE INLET.

Crustaceans	Molluscs	Polychaetes
Haustoriidae	Donacidae	Glyceridae
Mictyridae	Naticidae	Nephytidae
Penaeidae	Nassiriidae	
Odicerotidae	Veneridae	
Cirolanidae		
Ocypodidae		
Mysidae		

TABLE 7: RICHNESS, ABUNDANCE AND SHANNON DIVERSITY FOR THE KEROSENE INLET SAMPLING LOCATION.

Site	Richness		Abundance		Shannon Index (H')
	Mean/Sample	Total	Mean/Sample	Total	
Mouth of Inlet	2.46	13	8.15	106	1.69

Figures 12 and 13 illustrate abundance data for the site. The crustacean families are clearly the greatest contributors to the sites overall abundance (Figure 11) in addition to providing the greatest contribution to the site taxa richness (Table 6). Similar to Cudgera Creek, the haustoriid amphipods comprised the largest portion of the crustacean abundance, however there is also significant contribution by the isopod family cirolanidae and the decapod crustacean family mictyridae, specifically the Soldier Crab (Figure 13). In contrast the mollusc families were found to be neither numerically dominant nor particularly diverse. However, the contribution by the mollusc families to their overall abundance is more even when compared with the polychaeta and crustacean families. The Nephtydae was the most abundant polychaete family.

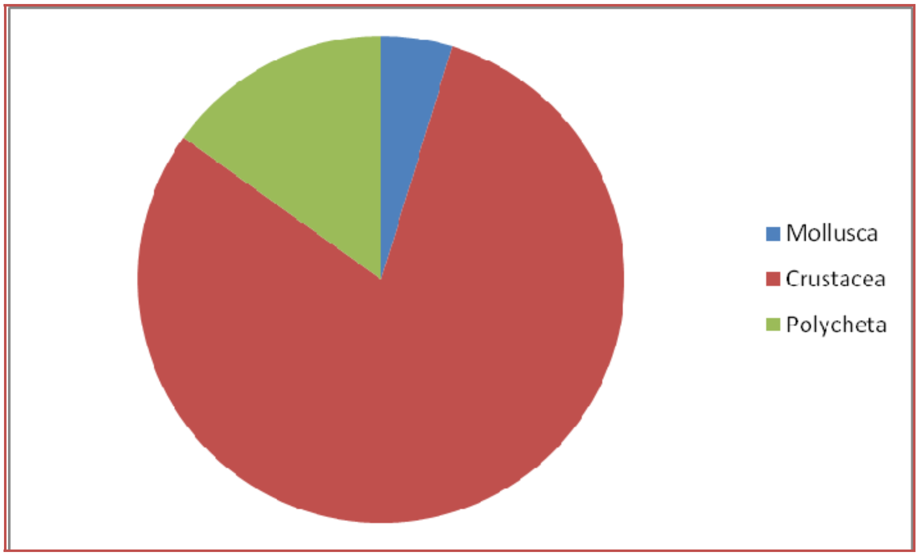

FIGURE 12: PERCENTAGE CONTRIBUTION OF MAJOR TAXONOMIC GROUPS TO THE TOTAL ABUNDANCE FOR KEROSENE INLET.

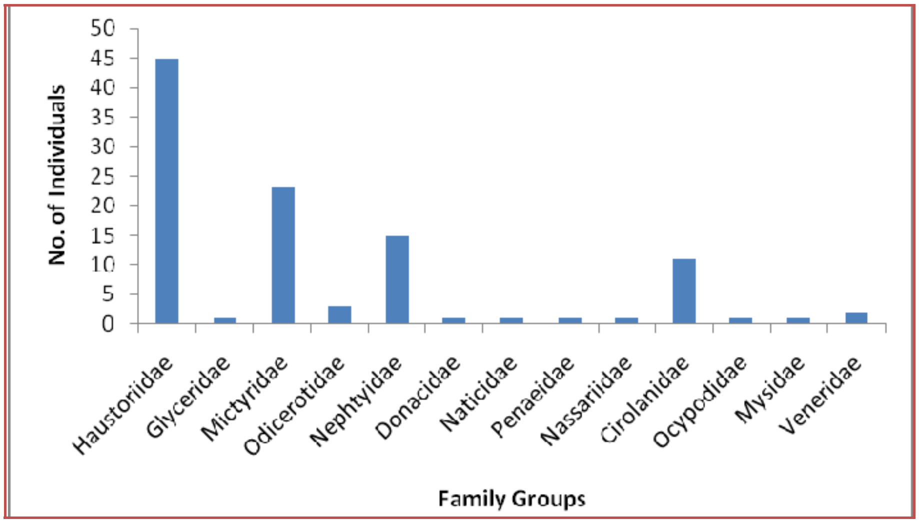

FIGURE 13: TOTAL NUMBER OF INDIVIDUALS PER FAMILY GROUP FOR KEROSENE INLET.

3.2 Water and Sediment Analysis

3.2.1 Cudgera Creek

During sampling, standard physico-chemical parameters were tested at each of the locations within Cudgera Creek (Table 8). While there is some variation between the sites, the variation would not be considered substantial. Interestingly the pH measurements for both sites are marginally alkaline, at 7.9 and 7.4 for the upstream and downstream sites respectively. A further notable point of difference was salinity. Specifically that the upstream site, which was further from the mouth, was more saline (3.63%) than the downstream site (3.15%), however both were approximately equal to the average salinity of seawater.

Figures 14 and 15 show the grain size distribution for the two sampling locations, from these graphs it is evident that there is little differentiation in the grain size distribution for the sites. This is further substantiated by the mean grain size, which was similar for both locations, at 0.31mm for the upstream site and 0.36mm for the downstream site. Both sites also have the same bi-modal distribution, whereby two size classes contribute to the overall grain size distribution. Both sites are classified as sand, by the commonly used textural nomenclature of Udden-Wentworth. Appendix A contains the grain size analysis data obtained from EAL at Southern Cross University.

TABLE 8: PHYSIO-CHEMICAL WATER QUALITY PARAMETERS FOR THE CUDGERA CREEK SAMPLING LOCATIONS.

Parameter	Upstream	Downstream
DO (mg/L)	6.3	5.1
pH	7.9	7.4
Conductivity (uS/cm)	54.3	48.4
Temperature (°C)	22	21.2
Salinity (%)	3.63	3.15

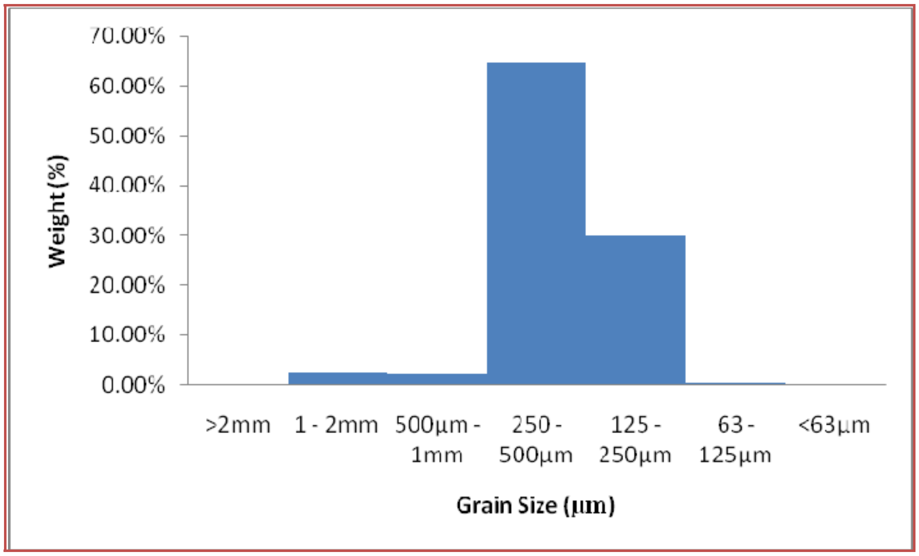

FIGURE 14: GRAIN SIZE DISTRIBUTION ANALYSIS FOR THE UPSTREAM SITE IN CUDGERA CREEK.

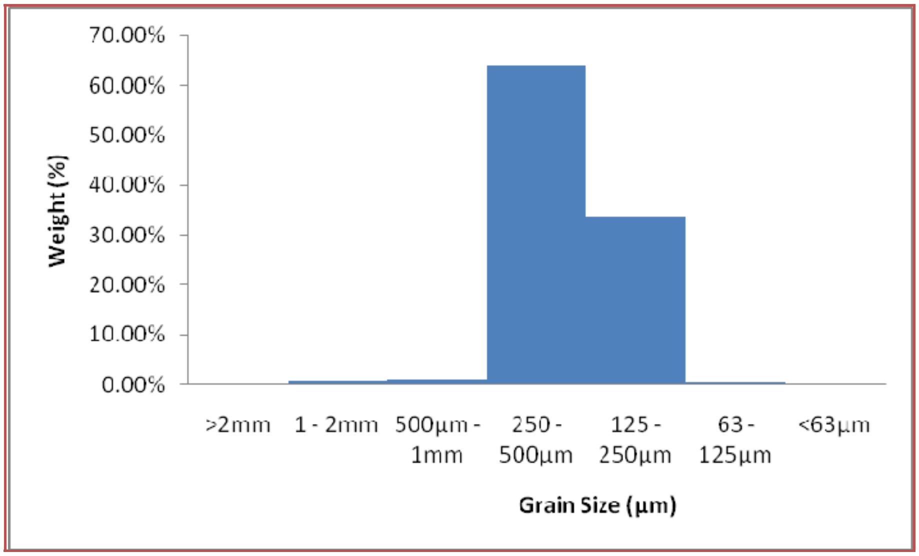

FIGURE 15: GRAIN SIZE DISTRIBUTION ANALYSIS FOR THE DOWNSTREAM SITE IN CUDGERA CREEK.

Sediment toxicology results for Cudgera Creek indicate that, generally, the measured parameters fall within guideline levels. However Site 4 (Environment Park footbridge) had elevated sulfur levels as well as measured metal concentrations that exceed the ANZECC (2000) Interim Sediment Quality Guidelines (ISQG) – low trigger values. Sites 1 (Intertidal shoal) and 5 (Cudgera Creek Rd bridge) were also found to have metal concentrations above ISQG low trigger values (Table 9).

Further analysis of three samples found no organochlorine or organophosphate pesticides in the samples, nor were any hydrocarbons detected in the sediment samples (Table 10).

TABLE 9: SEDIMENT ANALYSES RESULTS FOR CUDGERA CREEK SAMPLES COLLECTED APRIL 20, 2009 (ADAPTED FROM BOYD & REICHELT-BRUSHETT 2009).

	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 4 (2)**	**Site 5**	**Site 7**	**Site 8**	**ANZECC ISQG Low (mg/kg)**	**ANZECC ISQG High (mg/kg)**
Moisture content (% moisture	20.16	19.50	21.75	60.87	73.95	43.84	33.87	65.75		
Total Carbon (%C)	0.13	0.24	0.58	7.33	6.56	4.47	1.63	6.39		
Total Nitrogen (%N)	0.01	0.02	0.02	0.47	0.41	0.26	0.10	0.33		
Reduced Inorganic Sulfur (%)	0.02	0.06	0.11	**3.10**	**3.2**	0.02	0.01	1.09		
METALS										
Silver (mg/Kg)	***1.4***	<0.1	<0.1	<0.1	0.4	***1.3***	0.3	0.4	1.0	3.7
Arsenic (mg/Kg)	2.7	1.0	2.1	***22.9***	***20.4***	3.2	7.0	12.7	20	70
Lead (mg/Kg)	1.2	1.2	1.4	22.3	21.7	20.0	9.7	10.8	50	220
Cadmium (mg/Kg)	<01	<01	<01	0.4	0.4	0.1	0.1	0.2	1.5	10
Chromium (mg/Kg)	3.3	2.2	2.2	20.1	18.2	6.1	5.3	10.5	80	370
Copper (mg/Kg)	0.7	1.2	1.1	16.4	15.5	17.4	6.8	9.7	65	270
Manganese (mg/Kg)	9.5	6.4	6.7	78.6	76.4	31.4	91.5	92.3		
Nickel (mg/Kg)	0.9	0.5	0.7	7.8	9.9	2.6	9.2	0.6	21	52
Selenium (mg/Kg)	0.2	0.2	0.3	2.3	2.4	0.6	0.8	1.8		

	Site 1	Site 2	Site 3	Site 4	Site 4 (2)	Site 5	Site 7	Site 8	ANZECC ISQG Low (mg/kg)	ANZECC ISQG High (mg/kg)
Zinc (mg/Kg)	7.7	6.6	10.4	192	***261***	46.8	39.5	61.4	200	410
Mercury (mg/Kg)	<01	<01	<01	<01	<0.1	<01	<01	<01	0.15	1.0
Iron (mg/Kg)	0.161	0.100	0.230	3.283	3.102	0.514	1.587	1.991		
Aluminium (mg/Kg)	0.089	0.062	0.137	1.178	1.089	0.449	0.589	1.419		

Bold italic sample exceeds the ANZZECC and ARMCANZ (2000) ISQG -Low trigger values for sediment quality and is below the ISQG -high trigger value.

Bold indicates high Sulfur content.

TABLE 10: PESTICIDE ANALYSIS FOR THREE CUDGERA CREEK SAMPLES (TAKEN FROM BOYD AND REICHELT-BRUSHETT 2009).

Analyte	Sample 1	Sample 2	Sample 3
	Site 1	Site 4	Site 7
Moisture %	19	75	31
PESTICIDE SCREEN			
4, 4 DDT (mg/Kg)	<0.2	<0.2	<0.2
Methoxychlor (mg/Kg)	<0.2	<0.2	<0.2
Other organochlorine pesticides (mg/Kg)	<0.05	<0.05	<0.05
Demeton (total) (mg/Kg)	<1	<1	<1
Other organophosphate pesticides (mg/Kg)	<0.5	<0.5	<0.5
Total Petroleum Hydrocarbons			
C10-C14 Fraction (mg/Kg)	..	<50	..
C15-C28 Fraction (mg/Kg)	..	<100	..
C29-C36 Fraction (mg/Kg)	..	<100	..
Sum of C10-C36 (mg/Kg)	..	..	..

3.2.2 Kerosene Inlet

Table 11 details the results of the initial physico-chemical monitoring at Kerosene Inlet. Dissolved oxygen levels were good, at 7.4 mg/L, ph was recorded at 7.9 with salinity levels at a comparable percentage to seawater at 3.5%. Figure 16 gives the grain size distribution for Kerosene Inlet. This site was found to have a uni-modal distribution, with the predominant size class being 125-250µm. Mean grain size was 0.20mm and using the Udden-Wentworth nomenclature the sediment found at this site is classified as sand.

Sediment analysis of the Kerosene Inlet site found that none of the samples returned results that are above the relevant ANZECC and ARMCANZ guidelines for sediment quality (Table 12).

TABLE 11: PHYSIO-CHEMICAL WATER QUALITY PARAMETERS FOR THE KEROSENE INLET SAMPLING LOCATION.

Parameter	Mouth of Inlet
DO (mg/L)	7.4
pH	7.9
Conductivity (uS/cm)	53
Temperature (°C)	23.5
Salinity (%)	3.5

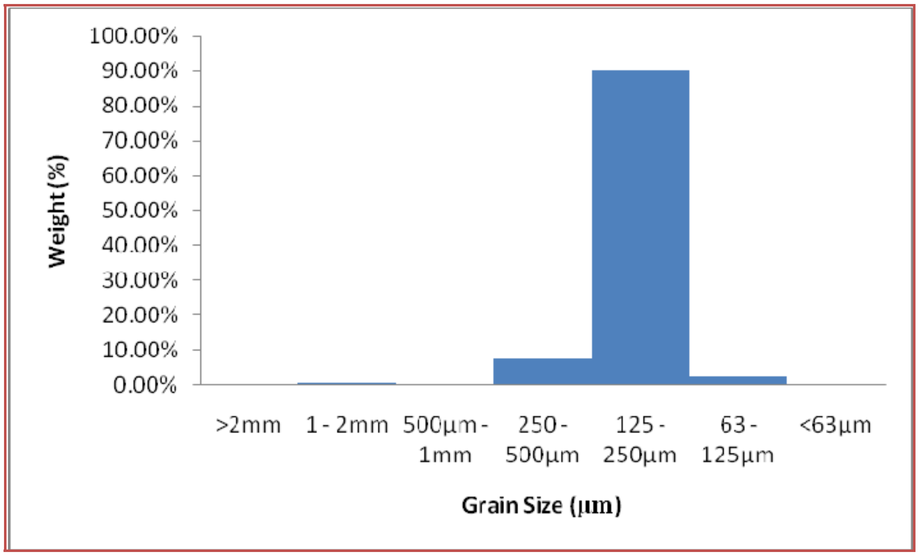

FIGURE 16: GRAIN SIZE DISTRIBUTION ANALYSIS FOR THE KEROSENE INLET SAMPLING LOCATION.

TABLE 12: SEDIMENT ANALYSES RESULTS FOR KEROSENE INLET
(ADAPTED FROM BOYD & REICHELT-BRUSHETT 2009).

	9	10	ANZECC ISQG*-Low (mg/kg)	ANZECC ISQG-High (mg/kg)
Moisture content (% moisture	20.83	23.15		
Total Carbon (%C)	0.26	0.68		
Total Nitrogen (%N)	0.01	0.03		
Reduced Inorganic Sulfur (%)	0.03	0.13		
METALS				
Silver (mg/Kg)	0.0	0.6	1.0	3.7
Arsenic (mg/Kg)	2.1	3.7	20.0	70
Lead (mg/Kg)	1.1	2.4	50	220
Cadmium (mg/Kg)	<0.1	<0.1	1.5	10
Chromium (mg/Kg)	4.3	7.5	80	370
Copper (mg/Kg)	0.8	2.5	65	270
Manganese (mg/Kg)	11.5	27.8		
Nickel (mg/Kg)	1.9	4.3	21	52
Selenium (mg/Kg)	0.2	0.4		
Zinc (mg/Kg)	7.6	18.1	200	410
Mercury (mg/Kg)	<0.1	<0.1	0.15	1.0
Iron (mg/Kg)	0.171	0.487		
Aluminium (mg/Kg)	0.109	0.295		

ISQG = ANZECC (2000) Interim sediment quality guideline

3.3 Seagrass Assessment

3.3.1 Cudgera Creek

Zostera capricorni was the only seagrass species found in Cudgera Creek. Seagrass data collected in Cudgera Creek shows a difference in two parameters between the sites (Table 13). Of particular note is the difference in height and epiphyte cover. It was found using t-tests that there was a significant difference between the sites for height ($P \geq 2.00$, df=58) and epiphyte cover ($P \geq 2.10$, df=18), with the upstream seagrass being greater in height and lover in epiphyte cover. There was no significant difference between sites for percentage seagrass cover ($P \leq 2.10$, df=18). The raw data for the seagrass assessment is provided in Appendix B.

3.3.2 Kerosene Inlet

There were two seagrass species found at the Kerosene Inlet site: *Zostera capricorni* and *Halophila ovalis.* The initial seagrass assessment for Kerosene Inlet found that the average height was 20.3cm, with a substantial coverage of epiphytes at 31.5%. However the overall extent of seagrass cover was good at 98%.

TABLE 13: HEIGHT, PERCENTAGE COVER AND EPIPHYTE COVER FOR SEAGRASS BEDS AT THE CUDGERA CREEK SAMPLING LOCATIONS AND THE ESTUARY AS A WHOLE.

Site	Mean Height (cm)	Seagrass Cover (%)	Epiphyte Cover (%)
Upstream	36.23	93	0.2
Downstream	24.93	82	27
Estuary Total	**30.58**	**87**	**13**

TABLE 14: HEIGHT, PERCENTAGE COVER AND EPIPHYTE COVER FOR SEAGRASS BEDS AT THE KEROSENE INLET SAMPLING LOCATION.

Site	Mean Height (cm)	Seagrass Cover (%)	Epiphyte Cover (%)
Mouth of Inlet	20.3	98	31.5

4. Discussion

The primary consideration that must be made is the inherent variability of estuarine systems (Hirst and Kilpatrick, 2007). Estuarine systems, indeed all sand and mud shores, are renowned for a high degree of spatial and temporal variation (Simpson *et al.* 2005). It is therefore important to qualify the findings of this study with the fact that it provides only a single snapshot of the estuarine system at the time of sampling. To fully understand the state of these systems it is critical that further research is undertaken to compliment this baseline assessment. Only then can scientifically robust inferences about the health of the estuary and perhaps more importantly, trends in biological communities within it, be made.

The study undertaken in 2009 has provided useful information against which future research can be compared and contrasted. It has provided a clear and relatively practical methodology which could be adopted by a variety of interest groups.

4.1 Water quality

The results of water quality monitoring at the two macroinvertebrate sampling locations in Cudgera Creek indicate that the parameters measured do not, in most instances, differ significantly from the long-term averages detected in the Tweed Shire Council monitoring program. The exception to this is the dissolved oxygen levels detected at the downstream site. During the sampling event DO levels were recorded at 5.1mg/L, which is below the long term average for the estuary of 6.0 mg/L, and noticeably below the long term average for TSC monitoring station 1 of 6.4mg/L, which is the most proximal to the downstream site monitored in this study. It should be noted that the water quality results from this study only provide a snap shot at the time of sampling. All the measured parameters are known to fluctuate, even daily in the case of DO, as such the results of the TSC long-term monitoring give a far more reliable indication of the estuary's water quality. Sampling was also undertaken following a period of heavy rainfall which would have affected the water quality at the time of sampling.

As was discussed briefly in Section 1.2.1, the results of long-term monitoring in the estuary indicate that there may be issues in relation to total nitrogen, total phosphorous concentrations and some cause for concern with respect to dissolved oxygen. Some of these parameters exceed or are close to exceeding the Water Quality Objectives (WQO) for the Tweed River catchment. Of particular interest is the level of nitrogen and phosphorous especially in light of the seagrass monitoring undertaken. As is discussed in Section 4.2, the seagrass surveyed in this study was found to have significant epiphyte growth and/or attached particulate matter on the leaves. Elevated nutrients and suspended solids have been identified as the leading cause of these two characteristics which are known to impact the growth, survivability and expansion of seagrass in estuaries (Morris *et al.* 2007, Frankovich & Zieman 2005, Udy & Dennison 1997, Abal & Dennison 1996).

As was noted in section 1.2.2, there has been no long-term water quality monitoring within Kerosene Inlet. For this reason it is difficult to accurately and confidently postulate on the water quality within the inlet from an ambient or long-term perspective. However comparisons can certainly be made between the snap shot results and the Water Quality Objectives for the Tweed River catchment. In all instances it was found that all parameters were within the guideline limits as outlined in the WQO for the catchment. Importantly however this study did not assess Nitrogen or Phosphorous concentrations within the inlet. In light of the results from Cudgera Creek for these parameters and the possible flow-on effects to the seagrass in that system, it may be that a similar issue is revealing itself in Kerosene Inlet, given the epiphytic cover assessed during the survey here.

4.2 Macroinvertebrates

The macroinvertebrate community within the Cudgera Estuary was generally characterised by a low abundance of macroinvertebrates, dominated by one or two families of macroinvertebrates. For the upstream site the dominant family was the haustoriid amphipod. This family of benthic macroinvertebrate is known to be a surface scavenger and in some instances will display predatory characteristics. At the downstream site, there was still a notable presence of the haustoriids, however the most abundant family was the mollusc family mactridae. This family of bivalve are relatively small surface filter feeders. One possible explanation for the dominance of these two groups is the suggestion that in more disturbed environments there is generally a community composition trend towards small surface feeding groups (Gastron *et al* 1998). This is supported by the generally accepted estuarine paradigm which notes that as an estuarine system trends towards higher levels of disturbance there is a reduction in factors such as biomass and a reduction in diversity due to the dominance by small opportunistic species (Pearson & Rosenburg 1978). However it should be noted that any observed changes in community composition may arise as a result of both anthropogenic and natural disturbance. Other studies into the health of estuarine systems also found a higher percentage of filter feeders and opportunistic scavengers or collectors in the more disturbed systems (Marum 2007). Though it has been stated previously, comparisons between estuaries can be fraught with difficulty due to their inherent variability.

Shannon Diversity Index calculations for the two sites within Cudgera Creek, suggest that both locations are similarly diverse at 1.67 and 1.47 for the upstream and downstream sites. The calculated index score is notably comparable with the calculated index for other systems which are known to be subject to anthropogenic disturbance (Marum 2007). Further evidence of the similarity between the sites can be found in their abundance and diversity, both of which were found to not significantly differ from each other. From a macroinvertebrate community perspective it could be inferred that both locations are controlled by similar factors, be they physical, such as tidal action or grain size or related to some anthropogenic disturbance.

One possibly worthwhile comparison is with Jerusalem Creek, at one time put forward as a potential reference location for this study. This location is generally considered to be one of the most pristine estuarine environments in northern NSW. In an unrelated study there were a number of findings from Jerusalem Creek that distinctly contrast the findings from Cudgera Creek. In the study by Marum (2007) Jerusalem Creek was found to have a far more balanced array of trophic groups (i.e. collectors, predators, filter feeders). This directly contrasts the findings in this estuary. A further point of differentiation was the taxa richness, which for Jerusalem Creek estuary was 28, compared to 12 for Cudgera Creek.

The findings and postulations put forward at this time can only be considered suggestive inference and further assessment would be required to determine if the low taxonomic richness and dominance by a narrow group of macroinvertebrates in Cudgera Creek is an on-going trend, and indeed whether this is directly related to some form of impact or disturbance.

Kerosene Inlet, by contrast possessed a relatively diverse array of taxa. In all there were 13 different family groups identified with a total abundance of 106 individuals at the single sampling location. In addition to this, the trophic groups were more evenly represented, while the scavenging haustoriids and the deposit feeding Soldier Crab from the family mictyridae were the dominant groups by abundance, other trophic groups such as grazers, predators and filter feeders were well represented. By using the same paradigm discussed above it could be inferred that this location is subject to less natural and/or anthropogenic disturbance. Further investigation and perhaps additional sites within the inlet would help to elucidate this suggestion.

On the matter of using this location in Kerosene Inlet as a reference site for Cudgera Creek; it is felt at this time that there are a number of factors that would preclude this from occurring. Principally there is a major difference in beach morphodynamics at this location. While it would still be considered a low energy system, the beach morphology is far more indicative of a low energy reflective sandy beach than the low energy depositional environment of Cudgera Creek. This is evidenced by the presence and quite high abundance of the cirolanid isopods, which are generally found in the upper shore, at the top of and above the highest astronomical tide line (Thompson 2005, Poore 2002). There was a second, possibly more suitable site in Kerosene Inlet, but difficult access prevented sampling there on this occasion. It is recommended that this site be included in future sampling, irrespective of its use as a reference location for Cudgera Creek.

4.3 Seagrass

Seagrass beds are an important component of any estuarine system, however they are susceptible to a number of disturbances, principally, reduced light availability (Abal & Dennison 1996) and increased nutrient loading (Morris *et al.* 2007, Frankovich & Zieman 2005, Udy & Dennison 1997). Both of these disturbances have been attributed to anthropogenic activities, such as increased farming and development in a catchment (Abal & Dennison 1996).

The seagrass beds, consisting solely of *Zostera capriconi*, that were assessed in Cudgera Creek did display some of the characteristics that would be expected from a nutrient enriched and higher turbidity environment, however this trend was not uniform across the sites. The upstream site was found to be in relatively good health, the average coverage was found to be 93% and epiphytic growth was negligible at 0.2%. However, during sampling it was evident that there was significant coverage of the seagrass leaves by suspended particulate matter. An increase in attached particulate matter has been attributed to a possible future increase in epiphytic growth on seagrass (Frankovich & Zieman 2005).

The downstream site by contrast was found to have a significantly higher coverage of epiphytes at 27% as well as attached particulates and the percentage of seagrass cover was reduced at 82% though this was found to be not significant. The higher coverage by epiphytes at the downstream location is of some concern. Increased epiphytic growth has been linked to increased nutrient and turbidity loading in estuarine waterways (Morris *et al.* 2007, Frankovich & Zieman 2005) and can lead to significant reductions in the health of seagrass beds due to the autotrophic epiphytes outcompeting the seagrass for the light and nutrients required for growth (Frankovich & Fourqurean 1997). Heights of the seagrass beds were found to be significantly different between sites and at both locations the beds were restricted to narrow bands in a similar depth range, despite there being an abundance of nearby benthos. While nearby benthos was deeper it was still within the theoretical depth range (maximum of 1.2m to 2.6m) of *Zostera capricorni.* Light penetration is known to be the principal controlling factor for seagrass growth and location. Consequently in more turbid environments the depth range in which *Z. capricorni* can exist will be reduced (Abal & Dennison 1996, Pollard & Greenway 1993). It is worth noting that the downstream seagrass site is a lower energy environment than the upstream. This may contribute to nutrient and particulate matter accumulation.

The seagrass beds in Kerosene Inlet were found to have good coverage, with an average of 98%. The average height of the seagrass was found to be 20.3cm, this appears to be quite small, however, this is a function of the very shallow depths observed in the areas of seagrass that were sampled, rather than limitations associated with light penetration. A very interesting observation was the high level of epiphytic growth which was found to be on average 31.5%. Given the surrounding catchment of Kerosene Inlet remains largely un-developed it is likely that if nutrient loading is indeed responsible for this epiphytic growth, it has entered the system through the Inlet’s confluence with the Tweed River. Additionally the mouth of the inlet has a partial rock weir or barrage, that while allowing inflows from the Tweed River does not allow full flushing of the inlet. It is possible that this lack of flushing may amplify the nutrient loads in the Inlet.

In addition to the epiphytic growth encountered during sampling, there appears to be a more wide ranging coverage of epiphytes over other areas of seagrass in the inlet. One area in particular, identified during an initial site visit had advanced epiphytic growth that was clearly smothering the seagrass (Plate 3). While this area was outside the sampling location for this study, it none the less adds credence to the presumption that there may be an underlying issue, possibly elevated nutrients, in the system leading to this detrimental level of epiphytic growth. Another possible reason for the enhanced epiphytic growth on the seagrass beds within Kerosene Inlet is the reduced presence of macro/micro invertebrate graziers that actively feed on the epiphytic growth attached to seagrasses. Obviously, this investigation did not quantify seagrass macro/micro invertebrate grazing, thus no conclusive comment can be made other than further, targeted investigations into reasoning's behind the enhanced epiphytic growth on seagrasses within Kerosene Inlet be undertaken.

PLATE 3: ADVANCED EPIPHYTIC GROWTH ON SEAGRASS IN KEROSENE INLET DISCOVERED OUTSIDE SAMPLING AREA.

4.4 Sediment

Sediment toxicology results indicate that while metal concentrations were predominantly below trigger values, as outlined in the sediment quality guidelines of ANZECC and ARMCANZ, two contaminants, zinc and arsenic, exceeded ISQG low trigger values at site 4 (Table 9). Where the lower ANZECC ISQG trigger value is not exceeded, it is unlikely that there will be any biological disturbance for organisms inhabiting that sediment. If the lower trigger value is exceeded, the guidelines recommend either management action or conducting additional site-specific studies to determine whether this exceedance poses a risk to the ecosystem (ANZECC, 2000).

It is important to note that concentrations of these metals at the remaining sites did not exceed, indeed were well below guideline levels (Table 9). Levels of silver at sites 1 and 5 were found to be above the ISQG low trigger values. Again the other sites did not display levels of this contaminant the exceed guideline limits (Table 9). Elevated zinc levels have been linked to runoff from galvanised surfaces and discharges from sewerage treatment plants. Discharges from sewerage treatment plants have also been identified as a possible cause for elevated silver concentrations in sediments. Elevated arsenic has been associated with the use of fungicides in agriculture and leached compounds from treated timber as well as a by-product of the oxidation of pyritic soils (Burton *et al.* 2008).

While the high metal concentrations of zinc, silver and arsenic mentioned above appear to be generally limited to a small spatial extent, elevated levels of iron and aluminium were found to be more wide ranging with sites 4,5,7 and 8 all recording high concentrations of these metal contaminants (Table 9). The remaining sites were found to have much lower levels and this has been attributed to the sites proximity to the influence of the marine environment. Both of these metals are natural in soils and marine sediments, and in small concentrations pose no threat. However elevated levels can be extremely harmful to marine organisms and the estuary as a whole should they be mobilised, which can occur if pH drops into the acidic range.

While long-term water monitoring of the estuary has found that the pH on average is 7.5 (Table 8), there were a number of data points within the monitoring that returned a pH of 4 or below (acidic) (Boyd and Reichelt-Brushett, 2009). This is indicative of discharge of significant amount of acid from ASS and may have caused short term, perhaps localised mobilisation of potentially dangerous levels of iron and aluminium.

From a sedimentalogical perspective, sediment metal concentration results for Kerosene Inlet reveal that this location is quite healthy. None of the measured parameters exceeded the relevant guideline levels, as opposed to levels found in Cudgera Creek. This would appear to reflect the largely undeveloped nature of the land surrounding the inlet, as opposed to the Cudgera Creek catchment, which has a high level of agricultural drainage in ASS.

5. Conclusions and Recommendations

Estuarine systems are prone to a high degree of variability in all the ecological and physico-chemical parameters assessed in this study. It has been emphasised throughout that the best course of action in relation to gaining a greater, more detailed understanding of the Cudgera Estuary condition and trend over time is to undertake regular and replicable assessments of all parameters assessed here. This is perhaps the most critical conclusion and recommendation. However despite the aforementioned variability it is possible to draw some broad-brush conclusions in relation to the two systems that have been studied.

- The Cudgera Estuary macroinvertebrate community was characterised by small surface feeding individuals and low abundance.

- The Shannon Diversity Index calculated for the Cudgera Estuary macroinvertebrates was within the range of Index values calculated for other known systems within the region.

- The seagrass beds in Cudgera Estuary, while generally healthy, did show signs of epiphytic growth and attached particulate matter.

- The seagrass beds in Cudgera Creek appear to be limited to a narrow strip, predominantly on the eastern side of the estuary, despite large areas of benthos within the theoretical depth range for *Z. capricorni*, suggesting some evidence of limitation. Given that the pattern of seagrass growth in Cudgera has been consistent for many years, and turbidity seems to be generally acceptable based on long term water quality median results, light penetration would not be the immediate cause for concern.

- Sediment quality in Cudgera Estuary is generally within acceptable levels for all contaminants, however there is cause for some concern in relation to zinc, silver and arsenic at some locations and more wide ranging concerns with respect to iron and aluminium concentrations.

- The concentrations and type of sediment contaminants suggests they are terrestrially derived and related to oxidation of pyrite within ASS rather than background marine or estuarine derived.

- Long-term water quality monitoring by the Tweed Shire Council suggests that the Cudgera Estuary is under some pressure in relation to nitrogen and phosphorous, which exceed or nearly exceed a range of WQO for the catchment.

- Snap shot water quality monitoring undertaken for this study did not deviate significantly from the long-term results, with the exception of DO which was below the long-term trend at one site.

- The Kerosene Inlet macroinvertebrate community was characterised by a more diverse community structure and was found to be relatively abundant. However the community structure at the sampling location reflects a low energy sandy shore more so than a depositional environment.

- Seagrass beds in Kerosene Inlet were found to be generally healthy, however epiphytic growth was evident and this may be indicative of elevated nutrient loads.

- Sediment quality in Kerosene Inlet was of good quality, and did not exceed guideline triggers. This is most probably due to the undeveloped nature of the catchment.

- The measured parameters in Kerosene Inlet did not exceed WQO for the catchment.

The following matters are considered to be important recommendations to be considered in light of the findings from this assessment and with a view to undertaking further assessment in the future.

- Replicated assessments should be conducted at least annually, at the same time of year.
- If bi-annual replication was deemed possible the additional sampling occasion should be in the opposing season (i.e. Jan. and Aug.).
- Additional sampling locations should be identified in Cudgera Estuary; preferably the sites should represent the lower, middle and upper estuary.
- At each location the total number of macroinvertebrate samples collected can be reduced to 13 (from 18).
- Although long-term water quality monitoring continues, snap-shot monitoring must continue in conjunction with macroinvertebrate sampling and should be expanded to include nitrogen and phosphorous.
- An additional location should be added to Kerosene Inlet sampling, though accessibility issues will need to be addressed.
- Some form of long-term water quality monitoring, inclusive of nitrogen and phosphorous should be implemented in Kerosene Inlet, particularly in light of this study’s findings in relation to the seagrass beds.
- In light of the known inherent variability in macroinvertebrate communities, even within an estuary, it is recommended that both locations continue to be sampled and assessed independently.
- It is recommended that sediment toxicology assessment continues to be run concurrently with the other biological assessments.
- In accordance with ANZECC ISQ Guidelines, additional site-specific studies should be conducted to determine whether any exceedances of low trigger values for zinc, silver and arsenic pose a risk to the ecosystem.

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Appendix A: Grain Size Analysis for Cudgera Creek and Kerosene Inlet

SAMPLE ID	Lab Code	>2mm Gravel/ Organic Matter	1 - 2mm Very Coarse Sand	500µm - 1mm Coarse Sand	250 - 500µm Medium Sand	125 - 250µm Fine Sand	63 - 125µm Very Fine Sand	<63µm Mud (Silt/Clay)
DA1	A3143/1	0.00%	0.39%	0.78%	62.26%	35.80%	0.58%	0.19%
DA3	A3143/2	0.00%	0.77%	1.15%	61.04%	36.47%	0.38%	0.19%
DA6	A3143/3	0.39%	0.59%	0.78%	60.78%	36.86%	0.39%	0.20%
DB1	A3143/4	0.00%	0.36%	1.63%	67.03%	30.62%	0.18%	0.18%
DB6	A3143/5	0.00%	1.00%	1.20%	66.33%	31.27%	0.20%	0.00%
DB3	A3143/6	0.00%	2.39%	1.39%	61.55%	34.26%	0.40%	0.00%
DC1	A3143/7	0.00%	0.00%	0.80%	66.33%	32.67%	0.20%	0.00%
DC3	A3143/8	0.20%	1.19%	0.99%	63.76%	33.47%	0.20%	0.20%
DC6	A3143/9	0.00%	0.40%	1.00%	65.86%	32.53%	0.20%	0.00%
FA1	A3143/10	0.00%	0.20%	0.20%	4.97%	91.65%	2.78%	0.20%
FA3	A3143/11	0.00%	0.20%	0.20%	5.36%	92.46%	1.79%	0.00%
FA6	A3143/12	0.00%	0.60%	0.20%	6.81%	90.38%	2.00%	0.00%
FB1	A3143/13	0.00%	0.20%	0.20%	9.74%	88.07%	1.59%	0.20%
FB3	A3143/14	0.00%	0.20%	0.20%	8.20%	89.40%	2.00%	0.00%
FB6	A3143/15	0.00%	0.00%	0.20%	6.51%	90.53%	2.76%	0.00%
FC1	A3143/16	0.00%	0.80%	0.60%	6.76%	88.67%	2.98%	0.20%
FC3	A3143/17	0.00%	0.00%	0.20%	9.40%	88.60%	1.80%	0.00%
FC6	A3143/18	0.00%	0.20%	0.20%	7.00%	89.20%	3.20%	0.20%
UA1	A3143/19	0.60%	2.60%	2.00%	50.60%	43.20%	0.80%	0.20%
UA3	A3143/20	0.00%	2.62%	2.01%	65.79%	29.38%	0.20%	0.00%

SAMPLE ID	Lab Code	>2mm Gravel/ Organic Matter	1 - 2mm Very Coarse Sand	500µm - 1mm Coarse Sand	250 - 500µm Medium Sand	125 - 250µm Fine Sand	63 - 125µm Very Fine Sand	<63µm Mud (Silt/Clay)
UA6	A3143/21	0.00%	1.99%	2.19%	68.53%	26.89%	0.20%	0.20%
UB1	A3143/22	0.00%	2.21%	2.01%	65.06%	30.52%	0.20%	0.00%
UB3	A3143/23	0.00%	2.53%	3.70%	59.06%	34.50%	0.19%	0.00%
UB6	A3143/24	0.00%	2.18%	2.18%	69.84%	25.40%	0.20%	0.20%
UC1	A3143/25	0.00%	4.21%	2.20%	61.52%	31.66%	0.40%	0.00%
UC3	A3143/26	0.00%	2.40%	2.59%	69.06%	25.75%	0.20%	0.00%
UC6	A3143/27	0.20%	2.56%	2.37%	72.78%	21.50%	0.39%	0.20%

Note:
1: The Dry and Wet Sieving Analysis method was used for this grain size determination (Method of: Lewis and McConchie, 1994. Analytical Sedimentology. Chapman and Hall, USA.)

D = Downstream site in Cudgera Creek

U = Upstream site in Cudgera Creek

F = Kerosene Inlet

Appendix B: Seagrass and Water Quality Survey Data

Seagrass Survey

Site	Height (cm)			Mean Height	% Cover	% Epi Cover	Species	Start/Finish co-ords
U1	26	41	35	**34**	80	0		28°22'00.7"S 153°34'22.8"E
U2	34	37	43	**38**	95	2		
U3	25	30	38	**31**	96	0		
U4	33	32	33	**33**	80	0		
U5	34	38	27	**33**	98	0		
U6	27	45	52	**41**	98	0		
U7	45	46	44	**45**	100	0		
U8	41	45	32	**39**	95	0		
U9	32	37	37	**35**	90	0		
U10	30	34	34	**33**	100	0		28°22'00.7"S 153°34'24.1"E
D1	25	19	29	**24**	70	10		28°21' 27.9"S 153°34'17.6"E
D2	26	27	26	**26**	100	0		

Water Quality

Parameter	Reading
DO (mg/L)	6.3
pH	7.9
Conductivity (uS/cm)	54.3
temp (°C)	22
Salinity (%)	3.63
Sampled at 8:20am	
Parameter	**Reading**
DO (mg/L)	5.1

Macroinvertebrate Transect

Coordinates

Transect	Start
UA	28°21'59.6"S 153°34'21.6"E
UB	28°21'59.6"S 153°34'21.6"E
UC	28°21'59.5"S 153°34'21.4"E
Transect	**Start**
DA	28°21'27"S 153°34'15"E

D3	0	0	0	**0**	0	n.a.		
D4	25	22	36	**28**	88	30		
D5	26	28	41	**32**	90	30		
D6	25	30	24	**26**	95	25		
D7	30	29	31	**30**	100	20		
D8	35	34	30	**33**	93	10		
D9	26	35	29	**30**	95	50		
D10	21	22	17	**20**	90	70		28°21' 28.5"S 153°34'19.3"E
K1	24	15	16	**18**	100	50		28°10' 36.7"S 153°33'00.2"E
K2	26	22	18	**22**	100	50		
K3	16	14	20	**17**	100	20		
K4	10	7	9	**9**	100	20		
K5	21	13	14	**16**	100	10		
K6	29	20	25	**25**	100	20		
K7	27	37	41	**35**	100	20		
K8	21	26	16	**21**	95	25		
K9	33	21	31	**28**	85	50	ZC, HO	
K10	12	13	12	**12**	100	50	ZC, HO	28°10' 38.0"S 153°33'00.8"E

pH	7.4
Conductivity (uS/cm)	48.4
temp (°C)	21.2
Salinity (%)	3.15
Sampled at 8:40am	
Parameter	**Reading**
DO (mg/L)	7.4
pH	7.9
Conductivity (uS/cm)	53
temp (°C)	23.5
Salinity (%)	3.5
Sampled at 11:00am	

DB	28°21'27"S 153°34'15"E
DC	28°21'26"S 153°34'15"E
Transect	**Start**
KA	28°10'33.6"S 153°32'58.8"E
KB	28°10'33.5"S 153°32'59.1"E
KC	28°10'33.4"S 153°32'59.6"E

U = Upstream site in Cudgera Creek D = Downstream site in Cudgera Creek K = Kerosene Inlet